Pt. Govind Ballabh Pant Memorial Lecture : XI

Madhav Gadgil

September 10, 2005
at
Kosi-Katarmal, Almora

G.B. Pant Institute of
Himalayan Environment and Development
Kosi-Katarmal, Almora- 263 643
Uttaranchal (INDIA)

Madhav Gadgil (b. 1942)
was educated at Pune (63, B.Sc. ZBC), Bombay (65, M.Sc. Zoology) and Harvard (69, Ph.D. Biology) Universities.

He was the first biology student at Harvard University to receive a Ph.D degree for a thesis based on mathematical modeling. He won an IBM Fellowship of the Harvard Computing Center for this work; which was subsequently recognized as a Citation Classic.

His scientific interests focus on ecology and evolutionary biology, conservation biology, human ecology, natural resource management and ecological history. He has published around 200 scientific papers and 5 books. Madhav Gadgil was the holder of the Maharashtra State Junior (1957) and Pune University (1961) High Jump records and twice represented the University in All India Athletic Games; these outdoor interests are at the root of his life-long, vigorous pursuit of ecological field work.

Madhav Gadgil's scholarly work has involved extensive interdisciplinary explorations, and his co-authors include Romila Thapar (history), Ramachandra Guha (sociology), K.C. Malhotra (anthropology), Charles Perrings (economics), Manoharan (linguistics), Carl Folke (human ecology), Luca Cavalli-Sforza (human genetics), Vidyanand Nanjundiah (theoretical biology), Anil Gore (biometrics) and K.M. Hegde (farmer), along with many ecologists, including the late Dr. Sálim Ali. He has been largely responsible for introducing careful quantitative investigations in ecology and animal behaviour as well as viewing humans as an integral component of ecosystems to India. He founded the Centre for Ecological Sciences, which has developed strong traditions of working with other researchers, teachers, policy makers as well as NGO workers, farmers and other citizens throughout the country. This has led to innovative experiments of involving High School and College teachers and students in inventorying and monitoring of biodiversity.

In 1976 Madhav Gadgil was asked by the Karnataka Government to look at the management of the state's bamboo resources. His studies resulted in initiation of withdrawal of perverse subsidies to forest based industries in the country. He prepared the project document for and was involved with the establishment of the country's first biosphere reserve in Nilgiris in 1986. He worked on the committee that prepared the blueprint for the establishment of a Ministry of Environment by the Government of India. He was a member of the Science Advisory Council to the Prime Minister of India from 1986-90. He has served as a member of Karnataka State Planning Board for some 8 years. He represented the Government of India on the Scientific Advisory Body to the Convention on Biological Diversity. He worked on the committee that drafted the recently passed Biological Diversity Act, and is currently helping the Ministry of Environment and Forests in working out modalities of inventorying of biodiversity at the level of local bodies such as Panchayats throughout the country. He also served as the Chair of the Science and Technology Advisory Panel of Global Environment Facility from 1998-2002.

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Of bamboos, basket-weavers and paper mills

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Introduction

Permit me to begin by thanking Chairman, Governing Body of the G. B. Pant Institute, Dr. Uppeandra Dhar, Director of the Institute and my other friends and colleagues at the G. B. Pant Institute of Himalayan Environment and Development for this honour of delivering the Pt. Govind Ballabh Pant Memorial Lecture. It is for me an opportunity to pay my respects to that great son of India, Pt. Govind Ballabh Pant, a man of who knew the pulse of the people at the grass-roots. His open, people-oriented approach is particularly relevant today in our attempts to address the difficult challenges of environment and development.

We live in exciting times, with technological developments transforming the world around us as never before. Communication has become easy; information in large measure is becoming readily accessible. Indians are taking good advantage of many of these developments, and have become noteworthy actors in the field of information technology. The in-depth understanding of life processes acquired over last 50 years is now permitting us to design novel life forms, injecting bacterial genes into cotton plants, or getting goats to produce milk containing molecules of spider silk. India, too, is part of this revolution, and biotechnology is beginning to gather momentum in our country.

Nevertheless, in the midst of all these developments, we remain a biomass-based civilization. Many Indians continue to lead lives as ecosystem people, tied closely to the resources of their environment to fulfill many of their requirements. They tend a wide range of plant and livestock varieties, consume wild fruit, bamboo shoots and fish, use fuel-wood to cook their meals and grass to thatch their huts, extensively employ herbal remedies and worship peepal trees and hanuman langurs. With a large proportion of our people in regular touch with the natural world around them, we are also a nation rich in knowledge of utilization of our living resources, ranging from folk medicinal practices and uses of wild foods, vegetable perfumes, cosmetics and dyes, to classical medical systems of Ayurved and Yunani.

But our country’s ecological resource base is under threat, with extensive destruction of natural habitats, widespread degradation of agro-ecosystems and a growing burden of air and water pollution. Simultaneously, India’s knowledge base of uses of biodiversity is also being eroded, with the younger generation becoming increasingly alienated from the natural world. We clearly need to act on several fronts. We ought to conserve the biodiversity resources for their intrinsic value, as a basis of livelihoods of many of our people, as also as raw material for future industrial applications. We should conserve and record the folk and classical knowledge of the uses of biodiversity as well, again for its intrinsic value, to support good management of the biodiversity resources, and also as a basis of future industrial applications.

What's more, we need to handle far better the available scientific, managerial, and oral information to support good management of our natural resources. Nothing brings this home as well as the recent tiger crisis in Sariska. Authorities of our Tiger Reserves have been attempting all these years to come up with exact tiger numbers based on the so-called "total pugmark count". There are several possible sources of errors in such a census of tigers:

- ❖ Pugmarks of some tigers would never be encountered.
- ❖ Different pugmarks of the same tiger may vary so much that they may be assigned to different individuals.
- ❖ Some pugmarks of distinct tiger may be so similar as to be assigned to the same individual.
- ❖ Levels of these errors may differ from locality to locality and season to season, depending on the terrain, tiger densities, and many other factors.

These errors imply that it would inevitably be difficult to arrive at exact numbers of tigers based on total pugmark counts. It is therefore imperative that one estimates the extent of all these sources of errors. Based on these estimates, one should then come up with not just one specific number, but also a range with a statement of the likelihood that the actual numbers will fall within that range. If this is not accepted, and only a single number is provided as if that is a precise estimate, there is a danger that any lower number arrived at in a subsequent year would be taken to imply that there has been a definite decline in the number of tigers. To illustrate, there may be an error margin of + or – 7 tigers with 99% probability in some tiger reserve. The estimate arrived at through total pugmark count in the first year may be 32 and in the second year 29. In reality, the actual total number may have increased, rather than declined from year one to year two. But, if these uncertainties have not been acknowledged, and so far they have not been in the official records, a wrong impression is bound to be created.

If, further, there were a tendency to judge the performance of park managers on the basis of the supposedly exact number of tigers in the area under their charge, then the managers would be inclined to manipulate the data and project a picture of continually increasing numbers of tigers. Such a tendency could be checked if there was in place a system of public scrutiny of the veracity of the numbers being declared. However, no such system has been in operation, so that tendencies to manipulate data have gone on unchecked. This has, in all probability, been occurring in many Tiger Reserves. We now have concrete evidence that it did happen in Sariska, where the publicly declared numbers have been decidedly inflated. A most unfortunate consequence of the broadcasting of such manipulated data has been a failure to recognize the signs of decline in tiger numbers, till a public outcry forced the authorities to acknowledge in 2005 that there were no tigers whatsoever left in Sariska (Tiger Task Force 2005).

Year	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Tiger population (official census)	24	26	26	26	27	26	17
Tiger sightings by staff	17	6	5	3	0	1	0

Adaptive management

These challenges cannot be addressed under the present dispensation, pursuing a pattern of resource management that depends on a centralized bureaucratic and technocratic apparatus treating people, at best, as ignorant subjects, or at worst, as enemies of nature. The standard wholesale solutions currently applied over large tracts of land and waters with such a **"control and command"** approach have proved to be short sighted and to suffer from many serious weaknesses. Thus, our intensive, chemical-based agriculture is suffering from an escalation of pest and disease outbreaks, with many of the causative organisms having acquired resistance. The efforts at eradication of malaria have run into rough weather, with both the malarial parasite and the mosquito vectors having evolved resistance. Our forest resources have been over-exploited, landing women who have the responsibility of collecting the fuel-wood, as well as basket and mat weavers into deep trouble. Many of our marine fish stocks too have declined impoverishing country boat fishermen and depriving large numbers of people of a cheap source of protein.

In fact, the emerging scientific understanding of complex systems tells us that a rigid approach to management of living resources cannot work. The history of the wetland of Keoladev Ghana at Bharatpur in Rajasthan, home to numerous species of resident and migratory water birds illustrates this well. The eminent ornithologist, Dr Salim Ali and his co-workers have spent decades studying this ecosystem. As a result of this work, Dr Salim Ali was convinced that the ecosystem would benefit as a water bird habitat by the exclusion of buffalo grazing. Government accepted this recommendation, and, with the constitution of a National Park in 1982, all grazing was banned. The result was a complete surprise. In the absence of buffaloes, a grass, *Paspalum* grew unchecked and choked the wetland, rendering it a far poorer habitat for the water birds (Vijayan 1987).

Scientists therefore advocate that ecosystem management must be flexible and at all times ready to make adjustments on the basis of continual monitoring of on-going changes. In contrast, the Government authorities made a rigid decision to permanently ban all grazing and minor forest produce collection from Keoladev Ghana, and having once committed themselves have felt obliged to continue the ban, even though it has become clear that buffalo grazing, in fact, helps enhance habitat quality for the water birds. The emerging scientific philosophy therefore is to shift to a regime embodying systematic experimentation with more fine tuned prescriptions. Under such a regime, stoppage of grazing would have been tried out in one portion of the wetland, the effects monitored and the ban on grazing either extended or withdrawn depending on the consequences observed. This would be a flexible, knowledge based approach, a system of **"adaptive management"** appropriate to the new information age, and in complete harmony with our strengthening democratic institutions (Walters 1986).

People's knowledge

The practice of adaptive management calls for detailed, locality specific understanding of the ecological systems. Much of the pertinent information on the status and dynamics of the local ecosystems, as well as uses of their components, resides with people who still depend on it for their day-to-day sustenance. In fact, the Keoladev Ghana story offers an excellent example of the relevance of people's ecological knowledge. Siberian crane is one of the flagship species for which this wetland is being managed. Yet numbers of these migrant birds have dwindled in years following the constitution of the National Park in 1982. In an attempt to understand what people know of this ecosystem, we undertook the preparation of a **"People's Biodiversity Register"** at a village called Aghapur adjoining Keoladev Ghana during 1996-97 (Gadgil et al 2000). The residents of Aghapur suggest that the National Park regulations which prevent people from digging for roots of *Khas* grass have resulted in compacting of soil, making it harder for the Siberian Cranes to get at underground tubers and corms which are an important ingredient of their diet. Whether this is the primary cause for a decline in the visits by Siberian Cranes must, of course, be assessed carefully; nevertheless, this certainly is a plausible hypothesis that needs to be considered in developing a management plan for this wetland.

There is therefore a broad consensus, embodied, for instance, in the Ecosystem Approach adopted by the Convention on Biological Diversity that we need to manage natural resources in a decentralized fashion, respecting the diversity of life, of ecosystems, of people and their traditions. I myself learnt this lesson while working on the management of the bamboo resources of the Western Ghats. I was initially attracted to the study of bamboos because of their fascinating life cycle. I hope to communicate some of this excitement and talk of the evolutionary forces moulding the bamboos. But, I also want to take advantage of this opportunity to share with you what I have learnt of resource and information management, and some of the lessons this has for the future.

Bamboos

The giant grasses that we call bamboos reach their finest development in the monsoon forests of Asia (McClure 1966). Bamboos are light demanders that reach the forest canopy in a single spurt of growth lasting over a few months of the monsoon. They achieve this feat of coupling a high rate of growth with the height of a tree by producing hollow culms strengthened periodically by horizontal septa at the nodes. The culm walls are rich in cellulose and derive their high tensile strength, comparable to that of steel, from the presence of very long cellulose fibers aligned in a longitudinal fashion (Shekhar & Rawat 1956, Anon 1972). All of this renders bamboos excellent structural materials that can be worked easily even with the most primitive tools. Furthermore, bamboo shoots and seeds are an excellent source of nutrition.

As a result, bamboos have played a significant role in human life, even conferring names on many of us in India. Venu is bamboo, and Venugopal, one of Krishna's names, means a cattle-herder fond of the bamboo flute. A primitive hunting-gathering tribe of the Konkan Western Ghats is known as Teer-Kamthavallas, (Teer: arrows, Kamtha: bow) since it depended on bows and arrows made up of bamboos for its subsistence. The bamboo shoots are an important item in the diet of many tribal communities of the Western Ghats, many of whom construct their huts largely out of bamboo with their own efforts. The herders, too, depend a great deal on bamboos not only for their shelter and other tools, but also as a fodder for their animals. Thus, the buffalo and cattle keeping caste of Gavli Dhangars of Western Ghats of Maharashtra and Karnataka depend largely on bamboos for green fodder for their livestock in the summer months, lopping the bamboo culms to bring down the foliage-bearing culm tips (Gadgil & Malhotra 1982). The farming communities extensively use bamboo for farm implements such as seed drills. The farmers of the hill tracts of Dakshina Kannada district of Karnataka tap perennial streams in the higher reaches of the hills and use them to irrigate their terraced gardens. Bamboo and betel nut pipes supported by bamboo pillars are used to convey the water wherever the terrain is uneven. The bamboo pillars themselves are erected in large bamboo baskets full of boulders. Most notably, bamboos are the mainstay of livelihood of a number of specialist basket and mat weaver communities such as *kaikadis* of Maharashtra and *medars* of Karnataka. It was these *medars* who were responsible for getting me involved in a study of bamboo resources thirty years ago, when they gheraoed the Finance Minister of Karnataka, complaining that exhaustion of bamboo by paper mills was destroying their livelihoods (Gadgil and Prasad 1978, Prasad and Gadgil 1981).

Growth pattern

Bamboos are grasses masquerading as trees, with stems buried underground and branches sticking out in the air. As befits grasses, their stems are green and fix carbon. Hence, bamboos have a pattern of growth radically different from that of other trees with which they compete. In a normal forest tree the growth is predominantly in height of the stem, so that the proportion of photosynthetic tissue to the structural tissue steadily declines with an increase in size, leading to a decline in the relative growth rate of the tree (Prodan 1968, Evans 1972). The growth curve of a tree therefore conforms to the sigmoidal pattern, being slow at first, gathering pace at middle sizes, and slowing down again.

But, once a bamboo clump has passed through the seedling and bush stage, it begins to produce culms of the full adult height that reach the top of the canopy in a single, concentrated burst of growth lasting a few months. Beyond this stage, the growth of a bamboo plant is essentially by radial enlargement of the underground rhizome and addition of more and more culms, all of the same form. The proportion of photosynthetic tissue to the total biomass thus changes very little once a bamboo clump has been established. Consequently, the relative growth rate of an individual bamboo clump does not decline with size, but remains constant. The bamboo clump as a whole therefore exhibits an exponential pattern of growth.

This simple fact had not been realized before I initiated my studies on bamboos in 1975. It turned out that all available data bore out this postulation of exponential growth. For example, Kadambi (1949) monitored the total number of bamboo culms in three different plots over a period of 7 to 9 years beginning in 1935. A reanalysis of his data shows that the total number of culms in the population as a whole increased exponentially at the rate of about 4 percent per year over this entire period. Our own observations of individual *D. strictus* and *B. arundinacea* clumps over 3 years showed that under protected conditions the number of culms per clump increases exponentially at the rate of 10 percent per year. The individual bamboo clump goes on growing exponentially till it begins seed production. The historical records of clumps with over 200 culms suggest that an exponential growth rate of up to 10 percent a year could very well have been maintained from the establishment of the clump at the age of 8—10 years until the age of seeding of 45-50 years (Rawlinson 1931).

Big bang flowering

Bamboos are, all said and done, grasses. Most grass species sprout with the rain and seed and die en-mass as the monsoon draws to a close. Many bamboo species too enact this drama, but as befits trees, they stretch it out over decades. In fact, 70 out of 72 of the Indian bamboo species possess a long period of vegetative growth followed by a single burst of reproduction, ending in death. Only about eight of these 70 monocarpic species exhibit synchronized or mast seeding of all clumps over an area of several hundred square kilometers. Of the two commonest species of the Western Ghats, *Bambusa arundinacea*, which forms dense stands along water courses in areas of less variable rainfall, belongs to this minority of mast seeders; *Dendrocalamus strictus*, which occurs in scattered numbers in areas of more variable rainfall, exhibits sporadic seeding behavior. Observations on the synchronized seeding of *B. arundinacea* show it to be spread over 5-6 years, with flower and seed production by any individual clump being completed over the dry season from December to April (Gadgil and Prasad 1984).

Our observations at Sampaji in coastal Karnataka revealed that a *B. arundinacea* clump produces an astronomical number of flowers. At each node of a culm there was an average of 133 spikes, and each spike had an average of 156 flowers. Since a single culm had an average of 65 flower-bearing nodes, each culm bore some 1.3 million flowers. Some of the bigger clumps had as many as 52 culms in this population; *B. arundinacea* clumps with as many as 200 culms have been recorded. Thus, even in this population, a single individual produced as many as 68 million flowers. About three quarters of the seeds had no endosperm, so that each bamboo culm produced about 3 lakh fully developed seeds. With seed weighing 0.012 g, this comes to a seed production of 3.6 kg per culm, or around one quintal for an average clump with 23 culms.

Like most other grasses, bamboos produce seeds that are highly palatable to a number of animals, including partridges, junglefowl, rodents, deer, wild pigs and possibly the Indian elephant, as well as people (Troup 1921, Soderstrom and Calderon 1974, Janzen 1976). Since a single clump may produce as many as 100 kg over a few months, and there may easily be as many as 100 clumps per hectare, the seed production may amount to 1 kg per every square meter—a veritable bonanza. Moreover, this seed production takes place in a deciduous forest, where under climax conditions relatively few fleshy fruits or palatable seeds are produced. Hence, predation on these seeds must have been an important evolutionary force moulding bamboo life history. This spectacle of nature has attracted people's attention since time immemorial. In fact, many villagers of Western Ghats date various events such as their own births in relation to the last mast seeding of bamboos. There is abundant historical evidence of these events in written documents as well, including the district gazetteers (Campbell 1883, Gadgil and Prasad 1984).

Predator swamping

Three intriguing questions arise in connection with the life histories of the Indian bamboo species: (1) Why do almost all species, some 70 out of 72, seed just once and die? (2) Why do most species wait so long, from 12 to 60 years or more, before they seed? (3) Why do some, about 7 or 8 of these 70 monocarpic species, seed synchronously over large areas? Janzen (1976) attempts to answer all these questions in terms of predator swamping. He adduces considerable evidence of extensive predation, by both sedentary and nomadic predators, on bamboo seeds. He suggests that a bamboo plant will minimize the risk of mortality suffered by each of its seeds by producing these seeds in enormous quantities and in synchrony with other members of the population, so that many seeds will escape after fully satiating the predator population. Since large seed crops may be produced by vegetatively growing for a long time and then throwing all the reserves into one ultimate effort of breeding, this would simultaneously favour monocarpy as well as a long pre-reproductive period, along with the synchrony of seeding by a whole population. As a corollary he regards the sporadic seeding by species like *D. strictus* as a secondarily derived condition due to human predation concentrating on peaks of seeding and humans mixing up different mast seeding cohorts.

While Janzen's central hypothesis of the role of predator swamping is attractive, there are difficulties in accepting his entire argument. First, the vast majority of the species are sporadic rather than synchronous seeders, indicating that monocarpy with a long pre-reproductive period does not always go together with mast seeding. Second, there is simply no evidence for the kind of human interference Janzen postulates. We therefore propose that a long pre-reproductive life and monocarpy are common adaptations evolved by most bamboo species in seasonal tropics, while synchrony of seeding by an entire population is a further independent adaptation evolved by a few of these species because of some special features of their ecological setting. The forces moulding these parameters are best elucidated in terms of the so-called reproductive effort model of the evolution of life histories (Gadgil and Bossert 1970, Schaffer and Gadgil 1975, Schaffer and Rosenzweig 1977, Charlesworth 1980). This model considers a plant as possessing a limited amount of resources, such that any allocation of resources leading to higher seed output at a given age incurs costs in lower survivorship and vegetative growth (for reproduction at future ages). Natural selection is expected to mould allocation of resources for reproduction so as to maximize the expected contribution of any genotype to the total genetic pool of the population.

The significance of the exponential growth pattern of bamboo clumps is evident in the context of this model. This growth pattern implies a substantial cost in terms of future reproduction, if reproduction at an early age cuts into growth. Hence at early ages, and smaller sizes, the current fecundity, will be rather low compared to the residual reproductive value, so that a zero reproductive effort will be optimal. As Hamilton (1966) has shown, this balance will gradually shift in favor of higher reproductive effort as the organism ages even if the growth were to continue exponentially. In addition, as the bamboo clump grows, a larger proportion of the culms will be crowded in the center and will be unable to photosynthesize effectively, thereby further reducing the cost incurred by cutting into growth.

Thus, while the exponential growth pattern will favor a long pre-reproductive period, the reproduction once commenced need not be total, leading to monocarpy. Monocarpy will be favored when every additional reproductive effort brings greater returns in terms of effective reproduction, and every additional reproductive effort is attended upon by lower cost in terms of future survival and reproduction. As Schaffer and Rosenzweig (1977) point out, predator swamping implies the first of these conditions, since every additional seed produced stands a better chance of escaping predation. Predator swamping thus favors monocarpy, but will not guarantee it unless the second condition is also fulfilled. We suggest another mechanism which will guarantee monocarpy: the role of death of parent in affecting the survival of seedlings. Bamboos are light-demanding plants that grow in a forest with a closed canopy under climax conditions. The opening of the canopy therefore would make a tremendous difference to the chance of survival of the seedling. A suicidal bout of breeding followed by the death of the parent creates such a gap in the canopy and therefore may strongly favour monocarpy.

Our suggestion is that (a) the exponential form of growth of a bamboo plant, (b) the critical role of death of the parent in ensuring the survival of seedlings, and (c) progressive reduction in risk of seed predation with increasing seed output all would favor the evolution of a monocarpic life cycle with a long pre-reproductive period, a common feature of almost all bamboo species in seasonal tropics and subtropics. Given this, the evolution of synchronous mast seeding will depend on two other factors: the extent to which predators on seeds of one individual will prey on seeds of another individual, and year-to-year variation in the probability of success of seeds and seedlings due to fluctuations in parameters such as rainfall. If individuals of a species are so scattered that predators on seeds of one individual or its progeny are unlikely to prey on the seeds of another individual, there will be no special advantage for members of a population to seed in synchrony. In fact, it may be advantageous for a plant to program its offspring to reproduce in different years if there is wide year-to-year fluctuation in germination or seedling survival success, so that at least some of its grand-offspring are born in a favorable year (cf. Murphy 1968). *D. strictus,* known for its often sporadic seeding, occurs at low densities under climax conditions and is characteristic of regions of more fluctuating rainfall regimes. Furthermore, *D. strictus* appears to occur in several different ecotypes, each of which may have a different length of life cycle. The asynchronous seeding of *D. strictus* therefore is more plausibly explained as fitted to its particular ecological niche, rather than as a recent, secondarily derived condition.

Bambusa arundinacea, on the contrary, occurs in dense stands lining the watercourses under climax conditions and inhabits more constant environmental regimes. In such a dense stand, there would be definite advantage to the whole population seeding in synchrony in swamping predators. Furthermore, the death of the whole population and the great forest fires that follow enhance the chances of survival of the seedlings. The last proposition need not invoke group but only kin selection if the individuals in a stand are closely related, as appears possible. The mast seeding of *B. arundinacea* may then be a further adaptation over and above monocarpy following a long pre-reproductive period.

Industrial Uses

The long cellulose fibers of bamboo render it an ideal raw material for production of paper. This was realized us early as 1910 (Pearson 1912), and the first paper mill in India based on bamboo was established at Naihati in West Bengal in 1919. The first paper mill based on bamboo of the Western Ghats tracts was established at Bhadravathi in Karnataka in 1937; and others have followed. These mills were expected to use bamboo resources on a sustained yield basis in accordance with the prevalent tenets of conservation forestry. When the Mysore Paper Mill (MPM) was established at Bhadravati in 1937, a survey of the bamboo resources of the division was carried out, and the yield annually obtainable on a sustained basis was estimated at over 100,000 tonnes. At that time, the capacity of the factory was low, and only a fraction of this yield was expected to be utilized. Initially MPM did not face any resource shortage. The yield estimates, however, did not take account of the periodic gregarious flowering of bamboos. This of course is thoroughly unscientific since this phenomenon is well known and documented. Much of the bamboo stock of Bhadravati division flowered and died in 1954-55, a time which coincided with an increase in the capacity of the mill to higher bamboo requirements of around 55,000 tonnes a year. Following the flowering in 1954-55, MPM started exploiting bamboo resources of other divisions rich in bamboo, namely Karwar, Mercara, Mysore, Chamarajnagar and Kollegal. Bamboo regeneration is expected to take 10-15 years to establish itself, and MPM should have been in a position to switch back to Bhadravati division by 1965-70. The regeneration, however, failed almost totally, and MPM continued to exploit bamboo from all these other areas and also in new areas like Mangalore and Coondapur divisions. The sustained yield calculations have obviously been wide of the mark.

West Coast Paper Mills (WCPM) at Dandeli in North Kanara was the second paper mill to be established in Karnataka, more than 20 years later, in 1958. The mill was accorded a certain concessional area in the Uttara Kannada and adjacent regions. The sustained yield for this concessional area was estimated at 1,50,000 tonnes a year, and the mill was started with a requirement of about one-half the expected yield. Again, no account had been taken of the possibility of gregarious flowering which began in 1959 just as the mill swung into production. WCPM, however, did make serious efforts to promote regeneration, and bamboo regeneration in its concessional areas has been much more successful than in Bhadravati division. The annual yield, however, still averaged only about 40,000 tonnes in contrast with the expectation of 1,50,000 tonnes. WCPM was, therefore, forced to bring in bamboo not only from the neighbouring states of Kerala, Tamil Nadu, Maharashtra and Andhra Pradesh, but from as far away as Meghalaya. Again, the sustained yield calculations had obviously gone awry.

Declining stocks

There thus appears to have been a consistent overestimate of the yield obtainable from the bamboo stocks of Karnataka ever since industrial consumption began in 1937. I was asked by a Working Group of the Karnataka State Council for Science and Technology, set up in response to the complaints by the state's basket-weavers, to look into this problem and assess afresh the current position. Narendra Prasad and I carried out such an exercise on the basis of the data available from the State Forest Resources Survey, the West Coast Paper Mills and on the basis of extensive field work. The Forest Resources Survey figures were clearly overestimates, and our field studies suggested that this was by a large margin, a factor of ten times. In fact, there were some very gross errors. Thus, the area assigned to the township of West Coast Paper Mill still showed high levels of bamboo stocks in a survey following its disforestation, simply because it had copied figures, number by number, from an earlier Working Plan. The estimate we arrived at for Karnataka as a whole after correcting for these overestimates was that only ~1,33,000 tonnes of sustained yield of bamboos was available on an annual basis.

This yield was to be contrasted with the then regular annual supply of 80,000 tonnes to WCPM, 55,000 tonnes to MPM and 10,000 tonnes to rights and privilege holders, a total of 1,45,000 tonnes. This was an underestimate as a great deal of harvest by the rural population for household use went unrecorded. The total yearly harvest was then more likely to be in region of 1,60,000 tonnes, in any case, well above the annual sustainable yield.

The result, of course, has been a year-by-year decline in the bamboo stocks of the State. Unfortunately there was little reliable quantitative data to make a definite estimate of this decline. However, in a number of places that we visited in our survey, we received reports that areas almost entirely lacking in bamboo were extremely rich in bamboo stock at an earlier time. This decline was particularly evident in the case of *Bambusa arundinacea* which has a much more gregarious flowering habit.

Manipulating bamboo clumps

Our studies brought out many other weaknesses as well in the so-called scientific management of the bamboo resources. Such scientific management calls for:

- Reliable estimation of the stocks
- Sound understanding of dynamics of stocks including mortality / regeneration, and
- Knowledge of growth pattern of individual plants.

As mentioned above, the stock estimates were faulty, and no account was taken of the well-known phenomenon of the gregarious flowering and mass death of *B. arundinacea* in drawing up the management plans. The third element, the growth curve of an individual tree is required to determine the size at which to harvest it so as make the most of its growth potential. Analogously, the regime prescribing the number of culms to be extracted from bamboo clumps of different sizes has to be based on a model of the growth of the bamboo clump. Karnataka Forest Department had attempted to do this on the basis of Kadambi's (1949) investigation. This was flawed because Kadambi had failed to appreciate the exponential nature of the growth of a bamboo clump. Consequently, his model did not allow for the continually increasing growth potential of every bamboo clump and therefore prescribed excessive harvests from smaller sized clumps.

Apart from prescribing the number of culms to be extracted from clumps of different sizes, the sylvicultural practices followed at the West Coast Paper Mills involved the operation of cleaning of the thorny covering that develops naturally at the base of a bamboo clump, especially in the case of *Bambusa arundinacea.* This "*clump cleaning"* operation was meant to decongest the clump and promote better growth of the new shoots. Our studies showed this practice to be actually counter-productive, for the removal of the thorny covering rendered the young shoots readily accessible to grazing by a whole range of animals, including porcupines, wild pigs, and monkeys as well as domestic livestock.

This brings me back to the theme of people's knowledge. Our studies were triggered by the claims of basket weavers that it was the practices and pressures of the paper industry that was the cause of the decline of Karnataka's bamboo resources. On the contrary, the industry as well as Forest Department claimed that over-harvests by villagers and excessive grazing by their livestock caused the decline. Right from the beginning therefore we tried to understand the practices followed by, and investigate the relative impacts of the rural as well as the industrial sector. We discovered that the villagers never cut the bamboo culms right at the base. Rather, they left the thorny covering of the clump intact and cut the bamboos at a height of about a meter and a half. In fact, our conversations revealed that the villagers were fully aware of the problems caused by *clump cleaning* and made sure that their own practices did not expose the new shoots to grazing.

Science as an inclusive enterprise

Clearly then the so-called scientific management of bamboo resources was riddled with problems. This is not an isolated example; in fact, the entire management of forest, wildlife and biodiversity resources of the country is grounded in a faulty paradigm. It is true that this management follows certain systematic procedures; but science is not a matter just of systematic procedures. Rather it is a system of continual open scrutiny of the procedures being employed towards any given set of objectives, such as estimation of bamboo stocks and yields that can be sustained, or an assessment of tiger numbers, and of the level of reliability of the results these procedures produce. As a matter of fact, skepticism is at the very heart of scientific inquiry. Therefore, the main ingredients of the scientific enterprise are:

- Open access to all facts and inferences,
- Rejection of all authority other than that of empirical facts, and
- Welcoming all interested parties to question all assertions as to facts as well as logic.

All these three ingredients have been missing in the so-called scientific management of forest, wildlife and biodiversity resources of the country. In this enterprise there is no tradition of transparency, of sharing of the results, the methodology employed to arrive at them and the logic followed in the deductions. A truly scientific enterprise would treat documents such as “Working Plans” as scientific documents to be made available for peer review by all interested parties, not as official documents to be kept away from the public gaze. The yields expected to be realized, and the stocks expected to be left behind after the harvests would be treated as hypotheses to be tested. If the yields do not materialize, or the stocks are not sustained, then a scientific enterprise would acknowledge that there are obvious errors of fact or logic, and attempt to look for and correct them. It would also try to bring on board all interested parties, not just the official machinery in the effort to understand the mistakes and correct them. None of this happens today, and it is imperative that we devise ways of injecting the democratic, inclusive culture of science in the management of India’s living resources.

In this endevour, we need to bring on board not only scientists to work with the foresters and wild life managers. For there is abundance evidence that given the nature of complex ecological systems, scientists too have a limited understanding of their functioning. At the same time, lay people may have observations of much value, as in case of the negative impact of cleaning of the thorny covering of a bamboo clump mentioned above. The experience of a group of Bangalore-based ecologists investigating the fate of wild amla (*Phyllanthus emblica)* populations on the nearby BRT Hills provides another example worthy of note. Their hypothesis was that the regeneration of amla is governed by the amount of fruit collected for commercial use, and that the low levels of regeneration in recent years were related to excessive harvests of the fruit. So they laid out statistically well-designed experiments to test the influence of different levels of harvests of fruit. The local Solliga tribals told them that these experiments would yield no results of interest, because, according to their understanding of the ecosystem based on many years of first-hand observations, the levels of regeneration were primarily influenced by forest fires. Amla seeds require fire to germinate well, and the Solligas felt that the low levels of regeneration were related to the suppression of forest fires in recent years. The scientists did not initially give credence to this view and continued with their experiments. Only later did they come to the conclusion that the Solligas had indeed been right. So it is highly appropriate for us to put in place a more inclusive system of obtaining inputs from all people.

The recently enacted Biological Diversity Act provides excellent opportunities to bring together people's knowledge with scientific knowledge. This ambitious act aims to promote conservation, sustainable use and equitable sharing of benefits of India's biodiversity resources, including habitats, cultivars, domesticated stocks and breeds of animals and microorganisms. With this in view it provides for the establishment of a National Biodiversity Authority (NBA), State Biodiversity Boards (SBB) and Biodiversity Management Committees (BMC) at the level of Panchayats, Municipalities and City Corporations. The Act stipulates that "Every local body shall constitute a BMC within its area for the purpose of promoting conservation, sustainable use and documentation of biological diversity including preservation of habitats, conservation of land races, folk varieties and cultivars, domesticated stocks and breeds of animals and micro-organisms and chronicling of knowledge relating to biological diversity". The NBA is authorized to scrutinize all Intellectual Property Rights related applications and ensure that they properly acknowledge the contributions of providers of indigenous knowledge. NBA is expected to consult all local BMCs in this respect and to ensure appropriate arrangements for equitable sharing of benefits.

While there are many significant initiatives such as Joint Forest Management and Watershed Development towards decentralization of ecosystem management, none of the institutions set up for the purpose have a statutory backing. The BMCs have the required legislative support and should therefore be in a position to strike roots more effectively. Most significantly, BMCs would serve to take science right down to the grass-roots, since, the rules lay down that "The main function of the BMC is to prepare People's Biodiversity Register in consultation with local people. The Register shall contain comprehensive information on availability and knowledge of local biological resources, their medicinal or any other use or any other traditional knowledge associated with them."

New institutions

Unfortunately, there are serious difficulties in injecting the democratic, inclusive culture of science in the study and management of India's living resources. As of today, almost every forest and wildlife researcher runs into serious difficulties with the officials in charge of the resources. The bureaucracy in turn has complaints about individual researchers and their motivations for research. The fact is that all forest and wildlife research, unlike most other research areas, is extremely dependent on the cooperation of the administration, as all forest areas are controlled and access is only through the bureaucracy in charge. Therefore, without any pre-agreed rules of the game, the relationship is highly dependent on the individuals concerned. It is worth quoting in this context from a submission of Raghunandan Chundawat, a wildlife researcher working on snow leopards and on tigers in Panna Tiger Reserve to the Tiger Task Force (2005): "Unfortunately in last three decades no system has been created that encourages or institutionalizes access to available professional research in protected areas nor that takes advantage of the growing body of professionals with expertise in relevant areas who work outside the government. We need to change the attitude of our management from a guard protecting jewels to a librarian who is managing library of unexplored knowledge and inviting people for learning. These problems occur now and again because we have failed to create a system, which supports and provides protection to independent research in the country."

In order to overcome these difficulties, the Tiger Task Force (2005) has proposed institutional mechanisms that would streamline the existing, clearly unsatisfactory procedures. The Task Force notes that the researchers often feel that their work is not properly used to make management decisions, while Managers feel that much of the research fails to address significant management issues; evidently because there is no existing mechanism of fruitful communication between the researchers and the managers. The Task Force proposes the establishment of such an institutional mechanism both at the state and the national levels. This could take the form of panels that may be chaired by the I G F (Wildlife) / Chief Wildlife Warden, and include the Secretary of the National Biodiversity Authority / State Biodiversity Board, and experts in ecology, social sciences and bio-statistics. It would be best if these panels serve as "single window" clearing houses for all matters relating to forest, wildlife and biodiversity research so that they streamline current procedures rather than create another layer. It is suggested that the Panels be required to meet every two months and clear all pending decisions.

These Panels may perform the following functions:

- Develop broad guidelines governing all forest, wildlife and biodiversity research by forest and wildlife managers as well as other researchers. Such guidelines would pertain, for instance, to collection of plant specimens, creation of grazing exclosures etc

- Create web-based computerized databases of all relevant research findings, so that both managers and researchers are aware of the state of the art and can direct their energies in the most fruitful channels.

- Suggest areas of research relevant to management decisions, for instance, what are the *bona fide* fuelwood needs of villages that are still inside Tiger Reserves. There should however be no ban on undertaking projects that may seem to have no immediate relevance to management. After all, our understanding of what is relevant is limited. Thus, despite of many years of work, Dr Salim Ali had not understood the vital role of buffaloes in maintaining bird habitats at Bharatpur.

- Arrange dialogues between researchers and managers so that research findings relevant to management are taken on board.

- Examine and decide on according permissions for research, along with any conditions that the researchers must observe. Since the Chief Wildlife Wardens would chair the State Panels, no further clearance from Forest Department should be necessary. In case either the researchers or the local forest officials have any grievances the same Panels should serve as a dispute resolution forum. In case the disputes persist the Central Panel should serve as an arbitrator.

- Ensure that the researchers make their data available to the public within some specified time frame. While it is legitimate for the researchers to claim intellectual property rights over their research, it is important that they agree to release their original data within some specified period such as three years from the date of collection. This would give sufficient time for researchers to publish their work and gain scientific credit, while ensuring that all work done becomes available to the public and for management purposes within a reasonable period.

Managing the information

Clearly, the most serious lacuna in our approach to managing information on India's biodiversity resources has been a lack of openness and willingness to take everybody along. The inclusive, open approach that I am trying to advocate depends crucially on free access to all information, except where very evident security concerns are involved, to all people. Today, this would be best ensured by posting all pertinent information on the web, in English, as well as in all Indian languages. The recent moves towards ensuring freedom of information have fortunately removed all bureaucratic hurdles to such an endeavour. The information to be thus made available should include all research and survey results, pertinent satellite imagery, resource maps, Working Plans and Management Plans, as well as on-going schemes of habitat manipulation interventions, along with the information collected through the People's Biodiversity Registers, and any other pertinent information. A competent technical group involving ecologists, statisticians and computer scientists should help in organizing all the relevant information in a suitably designed web-based Information System. This effort may be conducted in collaboration with the recent initiative of the National Biodiversity Authority to develop a countrywide, networked Biodiversity Information System.

It is only when we successfully institute such a **"share and inform, promote and facilitate"** approach in place of the current **"control and command"** approach, that we would be able to do justice to India's rich heritage of biodiversity resources and associated knowledge.

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Madhav Gadgil has been always interested in sharing his scientific understanding and environmental concerns with the broader public. His first series of popular scientific articles on animal behaviour, written when he was 16 years of age, were published in the Marathi science magazine, Srishtidnyan. He has subsequently written about 40 popular articles in Marathi and over 200 in English. His book, "This Fissured Land: an Ecological History of India" has been widely read, being reprinted every year over the last decade, and has been translated in Malayalam and Marathi. For the last five years he has been writing a fortnightly natural history column for "Hindu". These articles begin with a short poem composed by himself.

Madhav Gadgil has served as a Lecturer on Biology at Harvard University, as a Distinguished Indo-American Lecturer at University of California at Berkeley and as a Visiting Professor of Human Biology at Stanford University. Since 1973 he has been on the faculty of Indian Institute of Science, where he became a Professor in 1981. Madhav Gadgil has been awarded the National Environment Fellowship, and the Pew Scholars Award in Environment and Development. He has been elected to all the Science Academies of India, the Third World Academy of Sciences and the U.S. National Academy of Science. He is an Honorary Member of the British Ecological Society and the Ecological Society of America. He is a recipient of Shantiswarup Bhatnagar and Vikram Sarabhai Awards, Ishwarchandra Vidyasagar Gold Plaque, Volvo Environment Prize and Harvard University's Centennial Medal. He was awarded the Rajyotsava Award by Government of Karnataka and Padmashri by President of India.

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Shanti Swarup Bhatnagar Award for Biological Sciences 1986
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PEW Scholars Award in Conservation and the Environment 1993
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Volvo Environment Prize 2003

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Fellow, Third World Academy of Sciences 1992 -
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Fellow, Indian Academy of Sciences 1979-
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Honorary Member, British Ecological Society, 1994-
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