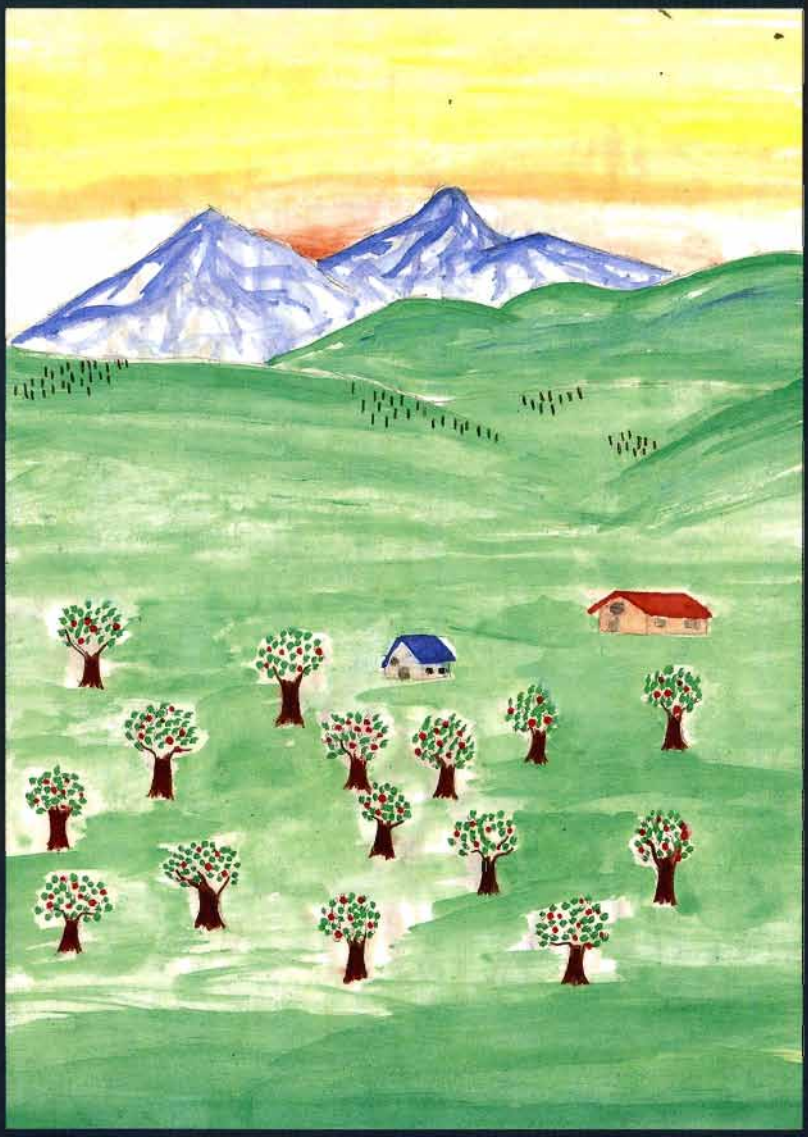
WARNING SIGNALS

From the Apple Valleys of the Hindu Kush-Himalayas

Productivity Concerns and Pollination Problems



Uma Partap
Tej Partap

Abridged Edition

ICIMOD

about ICIMOD

The International Centre for Integrated Mountain Development (ICIMOD)is an international organisation devoted to development of the Hindu Kush-Himalayan region covering all or parts of eight sovereign states, Afghanistan  , Bangladesh  , Bhutan  , China  , India  , Myanmar  , Nepal  , and Pakistan  . The Centre is located in Kathmandu, Nepal. The primary objective of the Centre is to promote the development of an economically and environmentally sound mountain ecosystem and to improve the living standards of mountain populations. The Mountain Farming Systems' Division at ICIMOD was established to promote improvement of farm productivity on small mountain farms without degrading the resource base.

Warning Signals from the Apple Valleys of the Hindu Kush-Himalayas

Productivity Concerns and Pollination Problems

(Abridged Edition)

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Foreword

The great majority of people in the Hindu Kush-Himalayan (HKH) region depend upon agriculture as their main source of livelihood; most are mountain farmers with small farms covering less than two hectares of cultivated land. Thus the well-being of mountain people is to a great extent determined by the state of mountain agriculture; and the potential for economic improvement by the ability to grow crops for sale rather than consumption.

Mountain agriculture in the HKH is slowly transforming from traditional farming of cereal crops to farming of high value cash crops. Cultivation of cash crops like temperate and sub-tropical fruits and vegetables is increasing in several pocket areas. The growing of cash crops on small plots of land has provided a certain measure of relief and income security to marginal and small mountain farmers and has helped alleviate poverty in some mountain areas. In recent years, however, this agricultural transformation has posed new challenges in terms of improving crop productivity and quality. The challenges include crop failure and reduced productivity resulting from inadequate pollination.

As a part of its focus on improving the livelihoods of mountain people, ICIMOD is implementing a project on 'Indigenous Honeybees of the Himalayas: A Community-based Approach to Conserving Biodiversity and Enhancing Farm Productivity' supported by the Austrian Government through Austroprojekt. The main aim of this project is to promote sustainable management of *Apis cerana* and other indigenous honeybees by mountain communities as a way of increasing farm productivity whilst contributing to biodiversity conservation. Research on pollination issues in mountain crops is an important component of this beekeeping project. The main objective of the pollination programme is to address the problem of declining agricultural productivity resulting from pollination failure. The programme aims to raise awareness of the need to manage pollination, and in particular the value of using honeybees for pollination purposes.

The regional case studies of pollination problems and farmers' management approaches described in this book are among the results of this work. Apples were selected as an example because they are the main cash crop in several areas of the region, and because pollination failure was identified as an emerging problem in previous work. The studies were carried out in India, China, Bhutan,

Nepal, and Pakistan, thus providing a detailed view of the commonalities and differences across the region. The advantages of using bees for pollination, and the appropriate approach and steps needed to introduce pollination management through bees in the different areas, is summarised in detail.

The publication is intended to raise awareness among agricultural planners, policy makers, and researchers about the pollination problems faced by mountain farmers, as well as suggesting strategies for change. It highlights the role of government institutions in apple pollination management and the need to strengthen their capacities and their programmes to help apple farmers. I hope that this book will prove useful in raising awareness of the need to incorporate crop pollination management as an essential component of agricultural extension programmes and packages of practices. I also hope that it will help promote increased use of bees and beekeeping for pollination of mountain crops.

Binayak Bhadra
Director of Programmes, ICIMOD

Acknowledgements

This book is the result of the efforts of a large number of people, all of whom we would like to thank.

The collaborating partners that helped us in these surveys – people and institutions in Bhutan, China, India, Nepal and Pakistan – deserve special appreciation. In particular, we wish to express our thanks to the members of the field survey teams.

We are particularly grateful to the mountain farmers, agricultural scientists, extension workers, local leaders, and others who supported us so well by taking time out of their busy schedules to provide us with valuable information related to their experiences with apple cultivation. We owe them our special thanks, particularly the farmers, for their cooperation and help.

Many others provided crucial support during the field studies. We are particularly thankful to Mr. Om Parkash, an apple farmer and lawyer in Kullu, Himachal Pradesh; Dr. Khyal C. Thakur from the International Potato Centre; Dr. Neelima R. Kumar and Professor Dhani R. Gautam from the Dr. YS Parmar University of Horticulture and Forestry; Professor Liaq R. Verma, Department of Biosciences Himachal Pradesh University, Shimla, and Former Vice-Chancellor of the Dr. YS Palmer University, who made the logistical arrangements for the survey in Shimla; Ch. Zulfiqar Ali Khan, Chief of Khush-Hali Associates, Pakistan; and Dr. Muhammad Islam of the Arid Zone Research Institute in Quetta, Pakistan. Professor Liaq Verma also critically reviewed the manuscript and we owe him special thanks for his suggestions, which improved the quality of the publication.

The draft of this book was prepared and discussed with colleagues in ICIMOD and outside. We would like to express our gratitude to many members of staff, in particular Dr. Farooq Ahmad, Mr. Min B. Gurung, Dr. Surendra R. Joshi, Mr. Anirudha N. Shukla, Mr. Satananda Upadhaya, and Ms Shova Bhandari, of the Beekeeping Project; Dr. Tang Ya and Dr. Nyima Tashi of the Mountain Farming Systems Division; Ms Greta Rana, Dr. A. Beatrice Murray, Mr. Sushil Joshi, and Mr. Asha K. Thaku of the Information, Communications and Dissemination Division; Ms. Phuntshok Tsering of the Mountain Enterprises and Infrastructure Division; and Dr. J. Gabriel Campbell and Dr. Binayak Bhadra of the Directorate for their extensive support, encouragement, and help.

We are especially grateful to the Federal Chancellery of Austria who provided the financial support, through Austroprojekt, which enabled us to carry out these studies.

Finally, we thank our daughters, Bhoomika and Uttara, who supported us with their patience and understanding while we spent time that we would otherwise have spent with them. We also very much appreciate the efforts of our elder daughter Bhoomika in preparing the artwork for the cover page.

Uma Partap and Tej Partap
March 2001

Executive Summary

One of the most rapidly increasing and widespread cash crops in the HKH region is apple, not least because apple trees grow best in cool areas and can grow successfully on marginal sloping land that is otherwise unsuitable for growing food crops. At present, apples are grown on some 370,000 ha of mostly marginal land in over 140 hill and mountainous districts in India, Pakistan, Bhutan, China, and Nepal. Apples have emerged as the main cash crop in several areas of the region, accounting for as much as 60-80% of total household income for some apple farmers. Apple growing provides a major source of income not only for growers but also for many other people – including labourers working in apple orchards; those involved in picking, grading, packing, carrying, loading, and transporting apples; farmers in nearby plains areas who plant poplar wood for apple boxes; carpenters who make apple boxes; people working in factories that make cardboard boxes; truck owners and their staff; and fruit trade commission agents, wholesalers, and retailers. It is estimated that the annual production of apples in the HKH region is over 2.2 million tonnes, which helps bring in an income of over US $450 million per year to farmers and others involved in apple farming and marketing.

Although apple growing is often thought of as a major success story, over the last decade farmers in the HKH region have experienced a steady decline in apple productivity, both in yield and in quality of fruit. Farmers estimate that apple productivity has declined by about 50%, and feel that the trend continues. Studies have indicated that there are several factors affecting apple productivity. These include poor structure and nutritional status of the soil (most orchards are planted on marginal land); poor quality of planting material such as rootstock which is susceptible to various diseases and pests; poor planting practices such as inappropriate spacing and the practice of deep planting, thus burying the scion union and promoting scion rooting; poor tree training and pruning, affecting light penetration; the physiological condition of trees; and insufficient pollination and fertilisation due to lack of pollinating insects and inclement weather conditions. Most of these factors have remained constant in past years; what seems to have changed is the level of adequate pollination.

ICIMOD coordinated a series of studies in selected apple-growing valleys of the HKH region to assess the problem of declining productivity, the pollination situation, factors responsible for inad-

equate pollination, and farmers' management approaches; and to suggest ways of tackling the pollination problem. Semi-structured interviews and a survey questionnaire were used to collect information on various parameters related to apple pollination, productivity, and management practices. Apple valleys were selected and field study teams were formed in each of five HKH countries: Bhutan, China, India, Nepal, and Pakistan.

This publication presents the findings of the region-wide survey. It is divided into three parts. **Part I** contains an introduction to apple pollination issues and a brief account of the scale, definitions, and concepts related to the pollination problem. It briefly describes ICIMOD's programme and its focus on creating awareness about 'managed pollination' and using honeybees for pollination to improve crop productivity. The second chapter provides a synthesis of the results and implications of the regional case studies and an overview of the HKH regional problems. The prospects for using honeybees to manage pollination, and the constraints and limitations in promoting beekeeping for pollination are discussed, together with other options like managing non-*Apis* pollinators for pollination, and hand pollination.

Part II presents the detailed findings of the studies. The first chapter (Chapter 3) describes the approach and methodology used for the field studies. Chapters 4 to 8 describe the detailed results of the field studies carried out in each country: Himachal Pradesh (India), Maoxian County (China), Balochistan Province (Pakistan), Thimphu and Paro Valleys (Bhutan), and Jumla District (Nepal). Information is provided on the scale of apple farming, livelihood dependence on apples, the scale of the pollination problem, farmers' management approaches, and the use of honeybees for pollination, as well as pollination issues and implications in each country. Both the scale of the problem and farmers' management strategies were found to vary widely in the five countries.

In **Himachal Pradesh, India**, pollination problems were mainly related to the change to large-scale planting of a single variety, Royal Delicious, starting in the eighties. There were insufficient pollinizer trees to ensure pollination, and at the same time natural insect populations had declined greatly, partly as a result of pesticide use (including on crops grown beneath apple trees), and partly as a result of loss of habitat. The pollination problem had already been recognised and close to a half of the farmers surveyed were practising some form of pollination management. Efforts were underway to increase the proportion of pollinizers using pollinizer bouquets, grafting, and tree replacement, and to promote the use of bees for pollination by promoting systems for both renting and buying colonies. The present demand for honeybees could not be met with the present resources, however.

In **Maoxian Valley, China**, scarcity of land had also led to planting of monocultures of mostly Royal Delicious. Farmers had turned to hand pollination rather than increase the proportion of pollinizers. Commercial beekeepers were unwilling to hire out bees as farmers used high levels of insecticides, and sprayed during blossoming. In the long-term, hand pollination is unlikely to be a viable solution, however. Integrated pest management, grafting of pollinizer varieties, and beekeeping for pollination are likely to provide a more practical long-term solution.

In **Balochistan, Pakistan,** the pollination problem was less marked, although the productivity reported by farmers was markedly lower than that reported in the official statistics and farmers had observed a decline. There was very little awareness of pollination, but there were more pollinizers: orchards were planted with a mixture of varieties, particularly Red Delicious and Golden Delicious. A high proportion of the land is left wild, and farmers still benefited from extensive populations of natural insect pollinators, but the problem of insufficient insect pollinators was increasing. Migratory beekeepers brought hives into Balochistan, but did not place them near orchards. Future efforts are likely to focus on the use of these migratory bees to support apple pollination.

The pollination problems were also less marked in **Thimphu and Paro Valleys in Bhutan** than in some of the other areas. Most farmers had a good understanding of pollination issues, pollinizer varieties were planted, although generally fewer than the optimum, and the country still has much natural forest and low levels of pesticide use, so that there are reasonable populations of wild insect pollinators. Productivity could still be improved, however, and the available natural insect pollinators will be insufficient if larger areas of forest are replaced with orchards. Some farmers were already interested in keeping bees for pollination, but there were none available for renting.

The farmers in **Jumla Valley in Nepal** had only a limited knowledge of pollination. Although productivity was fairly low, this was not of great concern as the marketing possibilities from this remote area were also limited. Recent provision of marketing support had increased interest in productivity issues. As there was less commercial focus, orchards contained a mixture of trees and most probably had a reasonable number of pollinizers. Many farmers kept *Apis cerana* bees in traditional log hives for honey production, although they were not usually placed directly in the orchards, and the low levels of pesticide use mean that there are extensive populations of natural insect pollinators. Even so, there was a clear scope to improve pollination through appropriate management and placement of bees.

Part III contains the Annexes, with a bibliography, and the questionnaire used in the field surveys.

The abridged edition contains only Part 1 and Annex I.

Abbreviations and Acronyms

AKRSP	Agha Khan Rural Support Programme (Pakistan)
BKDO	Beekeeping Development Office
HMG	His Majesty's Government
HH	households
ICIMOD	International Centre for Integrated Mountain Development
INGO	international non-government organisation
IUSSI	International Union for Studies on Social Insects
masl	metres above sea level
MoA	Ministry of Agriculture
NA	not available/not applicable
NARC	National Agricultural Research Centre
NGO	non-government organisation
NWFP	North West Frontier Province
PARC	Pakistan Agricultural Research Council
PPD	Policy and Planning Division
RGB	Royal Government of Bhutan
REID	Research Extension and Irrigation Division
SD	standard deviation
4S	Surya Social Service Society
TSO	tree spray oils
UNDP	United Nations Development Programme
USA	United States of America
USAID	United States Agency for International Development
YSP	Dr. Y.S. Parmar University

Note

For convenience, all values in local currency have been converted to US$ at the rate prevailing at the time of the surveys. The exchange rates used were

1 US$ = IRs 46.05
1 US$ = Nu 46.05
1 US$ = Yuan 8.40
1 US$ = PRs 59.50
1 US$ = NRs 73.60

Glossary

Anther: Part of the stamen that produces pollen grains

Bee Colony: A social community of several thousand bees usually containing a queen and with or without drones

Cross-pollinated: Plants fertilised by pollen from other plants or varieties of the same species (also called 'self-sterile')

Fertilisation: Union of the male nucleus of a pollen grain with the female nucleus of the egg of an ovule

Forage: Food, i.e. for bees pollen and nectar

Foraging: Collection of pollen and nectar by bees

Hermaphrodite: Bisexual, i.e. a flower having both male (stamen) and female (pistil) parts

Insecticide: A substance that prevents, destroys, repels, or mitigates insects

Nectar: sweet, sugary liquid secreted by a special gland (the nectary) of a plant

Nectary: A nectar-secreting gland often associated with the petals of flowers (many plants have extra-floral nectaries)

Ovary: The part of a pistil that bears ovules

Ovule: Forerunner of the seed, present inside the ovary

Pest: Any organism that harms a crop

Pesticide: A poisonous chemical used to control or destroy pests or to prevent them from multiplying

Pistil: Female part of a flower, contains the stigma

Pollen: Granular mass (powdery substance) present in the anther of a flower

Pollinizer: A source plant for compatible pollen for a favoured (commercial) variety

Pollination: The transfer of pollen grains from an anther to a stigma of the same flower (self-pollination) or of a different flower (cross-polllination)

Pollinator: An agent that moves pollen from the anthers to the stigmas of flowers, thus enabling pollination

Self-compatible (self-fertile): A variety that can be fertilised and produce seed with pollen from flowers of the same plant or another plant of the same variety, mostly self-pollinated

Self-Pollinated: A plant in which a flower can be fertilised by its own pollen

Self-incompatible (self-sterile): A variety that requires compatible pollen from a different variety of the same species for fertilisation

Species: An interbreeding population which is reproductively isolated from other similar but morphologically distinguishable populations

Stamen: Male part of a flower, contains the anther

Stigma: The part of the pistil that receives pollen

Variety: Individuals of a species that differ in terms of size, form, colour, and/or other attributes; variety is the next classification below the species' level

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(abridged edition)

The complete edition also includes the following:

PART 2: DETAILS OF THE COUNTRY STUDIES

3 Study Methodology

4 Apple Farming and Pollination Issues in Himachal Pradesh, India

5 Apple Farming and Pollination Issues in Maoxian Valley, China

6 Apple Farming and Pollination Issues in Balochistan, Pakistan

7 Apple Farming and Pollination Issues in Thimphu and Paro Valleys, Bhutan

8 Apple Farming and Pollination Issues in Jumla Valley, Nepal

PART 3: ANNEXES

Annex 2: Questionnaire Used in the Field Surveys (English Version)

The complete edition is available from ICIMOD, ISBN 92 9115 605 1.

Part 1

Apple Pollination Issues in the HKH Region

Chapter 1

Concerns about Productivity in Mountain Farming

There are signs that across the Hindu Kush-Himalayas the overall productivity of many mountain crops – the amount of crop produced per unit of planted area – is going down. Possibly the worst affected crops are the cash crops like fruit, particularly apples, and off-season vegetables that are the hope of the region in terms of providing farmers with cash income and underpinning development efforts. This reduction in productivity is taking place despite extensive efforts at extension and information to support improvements in a range of management practices, and strong support for the introduction of successful commercial varieties. This book is concerned with raising awareness about and stimulating interest in one of the major factors involved, failure of pollination, and suggesting strategies for dealing with the problem.

'Managed' Pollination and Why We Need It

There are several factors that affect the productivity of mountain crops. They include soil fertility; poor quality of planting material; agronomic inputs including irrigation, fertiliser, and/or manuring; and use of pesticides – but pollination plays possibly the single most significant role. Pollination is an essential prerequisite for fertilisation and fruit and seed set. If there is no pollination, no fruits or seeds will be formed, and there will be nothing to harvest.

Pollination: the transfer of pollen from the male part of a flower, the anther, to the female part, the stigma, either of the same flower, another flower on the same plant, or another flower on another plant of the same species. If flowers are not pollinated, they cannot produce seed.

Self-fertile or self-compatible crops are fertilised by pollen from anthers of the same plant or another plant of the same variety. They are mostly self-pollinated, with pollen carried by wind or plant movement

Self-sterile or self-incompatible crops require compatible pollen from a different variety of the same crop.

Crops can be divided into two categories: self-fertile (self-compatible) and self-sterile (self-incompatible). Self-fertile crops include such plants as wheat, rice, and maize. They are largely self-pollinated and farmers rarely have any pollination problems with them. In contrast, many commercial varieties of fruit and vegetables are partially or fully self-incompatible. Successful pollination requires the presence of another appropriate compatible plant (i.e. a pollinizer), conditions that ensure synchronised or overlapping flowering in the two plants (the stigmas of the commercial variety

Good pollination – a cluster of well-developed apples

flowers must be receptive at the same time as the anthers ripen in the pollinizer flowers), and a pollinising agent like a bee. To obtain good yields, farmers must ensure that these conditions are met – this is crop pollination management.

Although mountain farmers try their best to enhance crop productivity by improving agronomic inputs, for example use of better quality planting material, better irrigation, and improved fertiliser and pesticide application, they rarely consider managing pollination – and neither do the government organisations advising them. This is probably the major reason why many crop yields are declining despite improvements in all agronomic inputs.

In 1997, ICIMOD (the International Centre for Integrated Mountain Development) published a discussion paper on 'Managed Crop Pollination: The Missing Dimension of Mountain Agricultural Productivity' (Partap and Partap 1997). In this paper we looked at the question of why farmers and agricultural institutions do not pay attention to the role of pollination in ensuring agricultural productivity. What do farmers and institutions know about it? Are mountain farmers and agricultural research and extension institutions aware of it? Do they understand the severity of the problem? Our research indicated that few farmers or institutions in the Hindu Kush-Himalayan (HKH) region were aware of the severity of the problem, and most did not have the mandate or expertise to address it. The paper highlighted the lack of information on the value of managing pollination.

Clearly more concrete information was needed to document the severity of and variation in pollination problems across the HKH region and to identify clearly the factors responsible for inadequate pollination. We chose apples as a representative, widely grown, and economically important, self-incompatible crop and carried out an extensive survey of apple-growing areas in India, China, Pakistan, Bhutan, and Nepal. The results are likely to be indicative for the many other crops like temperate and sub-tropical fruits, vegetables, and seed vegetables that require a management strategy to ensure pollination. Apple farmers, agricultural scientists, extension workers, and local leaders were interviewed to collect information on pollination-related productivity issues in a series of case studies. This book summarises the outcome of these studies.

The Importance of Apples for Farmers with Marginal Land

Agriculture is the basis of the livelihood of over 80% of the rural population in the countries of the HKH region. However, more than 90% of the farmers in the hill and mountain areas are marginal or small land-holding families, cultivating less than one hectare of land each (Banskota 1992; Partap 1995; Koirala and Thapa 1997; Partap 1999). Most agricultural land in the mountain

areas is not only marginal in terms of potential productivity, its quality also appears to be deteriorating as indicated by declining soil fertility and crop productivity. Many mountain families face food shortages of varying degrees, and these are contributing to the chain reaction process of poverty–resource degradation–scarcity–poverty (Jodha and Shrestha 1993). It is necessary to explore all possible ways of increasing the sustainable productivity and carrying capacity of the farming systems in the mountains (Partap 1998, 1999). Development efforts tend to focus on exploring farming approaches to increase the productivity and carrying capacity of farms (Partap and Partap 1997; Partap 1999).

Cabbages planted between apple trees

One option for enhancing the farm income of mountain farmers is to exploit the comparative advantage or 'niche' for the cultivation of cash crops such as fruits, off-season vegetables, and vegetable seed. Mountain farmers can never have a comparative advantage in producing grain. Crops such as apples, almonds, pears, peaches, plums, cherries, and off-season vegetables bring farmers several times the income they could expect from staple food crops, and farmers' interest in them is increasing (Partap 1995, 1999; Partap and Partap 1997). These high-value crops can be grown in the mountains at a time when they cannot be produced in the lowlands and can command a relatively high price in the market. The diversification of mountain agriculture from the farming of traditional grain crops to the farming of cash crops on small plots of land has provided relief to some marginal and small farmers (Partap 1999). Farmers can earn money to buy food and other necessities for themselves and ensure a better education for their children. In Himachal Pradesh, for example, a farmer can earn up to US $4500 per hectare annually with a net return of US $2000-2200 from fruit farming (Sikka and Saraswat 1992). In other words, a marginal farm household with between 0.5 and 1 ha of land could earn up to US $1600 per annum, and a small farm household (1-2 ha) up to US $4000. These incomes are much higher than those that could be obtained through any of the other farming activities possible on such land.

Apples have emerged as the leading cash crop in several areas of the HKH region, assuming great importance in helping many farmers move out of the poverty trap. They are found in areas as far apart as the Indian Himalayas, northern Pakistan, the mountain areas of China, and northern Bhutan. They can account for 60-80% of the total household income of those who grow them and studies indicate that in the areas where apples are grown there is now food security and reasonable economic well-being (Sharma 1996). The area of land devoted to apple orchards in the five countries studied ranged from 230,000 ha in India to 2000 ha in Bhutan, with a total annual production ranging from 1,320,000 tonnes in India to 13,000 tonnes in Bhutan (Table 1.1). The beauty of apples is that the trees can be (and are in many areas) planted successfully on cold marginal slope

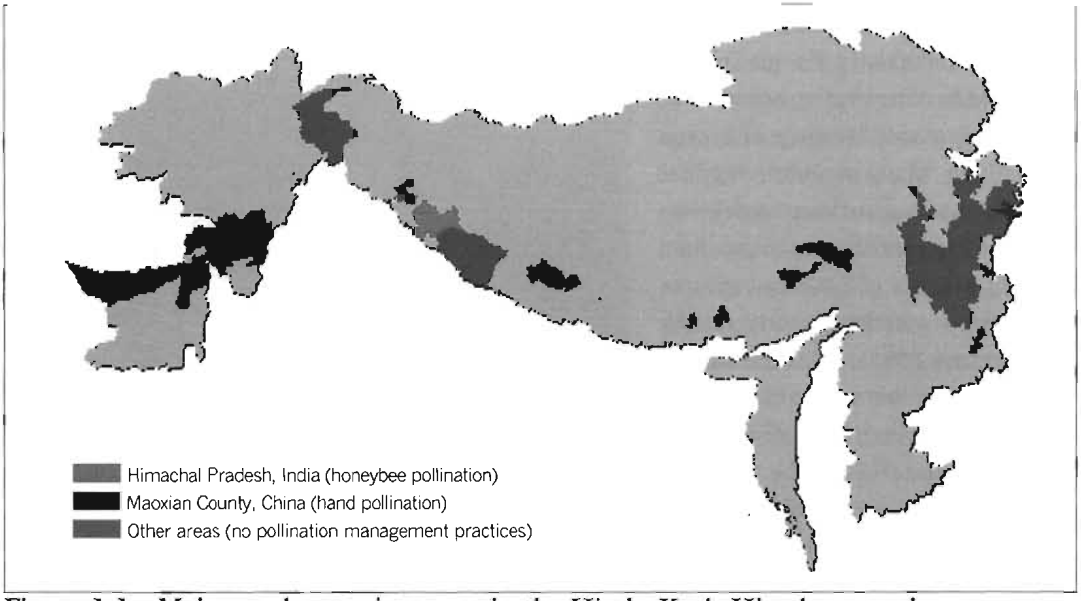


Figure 1.1: Major apple growing areas in the Hindu Kush-Himalayan region

Table 1.1: **Area and productivity of apple farming in the Hindu Kush-Himalayan region**

Country	Area ('000 ha)	Production ('000 tonnes)	Productivity (tonnes per ha)
Indian Himalayas[1]	228	1321	5.8
Nepal[2]	5	30	6.0
Bhutan[3]	2	13	6.5
Chinese Himalayas[4]	83	208	2.5
Pakistan[5]	49	638	12.9
Total	**367**	**2210**	**6.2**

Sources: [1]National Horticulture Board, New Delhi, India (1998), Department of Horticulture, Himachal Pradesh (1998), Verma (2000); [2]MInistry of Agriculture (1999); [3]Ministry of Agriculture, Royal Government of Bhutan (1999); [4]Government of China (1997), Government of Tibet Autonomous Region (1997); [5]Ministry of Food, Agriculture and Livestock, Government of Pakistan (1998-1999), Khan (1998).

land that is unsuitable for growing crops such as rice and wheat. Apples were grown in more than 140 hill and mountain districts in the countries studied.

Apples bring income not only to farmers but also to many other people linked to the farming, post-harvesting, and trade chain. Labourers working in apple orchards; those involved in picking, grading, packing, carrying, loading, and transporting apples; farmers supplying wood and carpenters making apple boxes; factories making cardboard boxes; truck owners, contractors, wholesalers, and retailers, all earn a good income from apples – as do those working in factories involved in post harvesting processes like making juice, jam, wine, or cider. The estimated total annual production in the HKH of 2.2 million tonnes of apples helped to bring in a gross income of over US $450 million per year to those involved in apple farming and marketing. In Himachal Pradesh alone, the estimated direct annual income from apples in 1999 was US $150-170 million, and the indirect income to the province was far higher, about US $1.5 billion per year (Toderia 2000).

The Emerging Scenario of Declining Apple Productivity

The officially reported average yield of apples in the HKH region varies from 2.5 to 12.9 tonnes per ha (Table 1.1). Our studies suggest that the real values may be even lower, particularly in Pakistan where the productivity at the sites we studied ranged from only 2.3 to 2.9 tonnes per hectare. Even the official figures are very low compared to the average yield of 25-30 tonnes per ha in Europe and other horticulturally advanced countries (Nadda and Tiwari 1998). Over the last seven to eight years, apple productivity has declined in the HKH region in terms of both yield and quality of fruit. In Himachal Pradesh, for example, apple productivity went down from 10.8 tonnes per ha in 1982 to about 4.3 tonnes per ha in 1998 (Department of Horticulture Himachal Pradesh 1998) and is declining further. Similarly, in Maoxian County apple productivity went down from 12.3 tonnes per ha in 1983 to 6.2 tonnes per ha in 1990 (Local Government Report, Maoxian County, 1998).

Several factors have been identified that affect apple productivity in the region. The social, physiographic, and physiological factors are mostly well understood and have been studied in some detail. They include the poor structure and nutritional status of soil (most orchards are planted on marginal land); poor quality of planting material such as rootstock that is susceptible to various diseases and pests; poor planting practices such as inappropriate spacing and the practice of deep planting, thus burying the scion union and promoting scion rooting; poor tree training and pruning, limiting light penetration; and the physiological condition of trees (Schilde and Bourgo 1998; High Value Agriculture Ltd 1998). The importance of pollination for maintaining apple productivity and quality is generally less well recognised, however, and the problems of inadequate pollination and poor fertilisation due to lack of pollinating insects and inclement weather conditions have received little attention in the region in comparison with other factors (Partap and Partap 1997). Although many farmers make all possible efforts to manage other factors, they almost always ignore pollination management.

The Apple Productivity Study

The studies described here were carried out under the aegis of the ICIMOD project 'Indigenous Honeybees of the Himalayas: A Community-based Approach to Conserving Biodiversity and Enhancing Farm Productivity', which is supported by the Austrian Government. One component of this project is crop pollination research; others include the state of pollinator diversity, and the importance of managing honeybees. The pollination programme is intended to address the problem of declining agricultural productivity of crops in the HKH region by raising awareness about the need

Apple flower – waiting for a pollinator

for managing pollination and the use of different species of honeybees. The survey was needed to confirm the previous indication that pollination problems were indeed a major factor in declining productivity, and to assess the extent and distribution of pollination problems in different crops – before making suggestions and implementing trials to improve the situation. Field surveys were performed in apple-growing areas in five countries – Bhutan, China, India, Nepal, and Pakistan. The surveys focused on the extent of apple productivity and pollination problems, the factors causing inadequate pollination, and farmers' management practices. The main objectives were

- to highlight the scale of the pollination problem;
- to document farmers' strategies for managing the problem;
- to analyse the role of bees and beekeeping as pioneer options for managing crop pollination;
- to analyse apple productivity, pollination issues, and options;
- to look at the level of institutional support in addressing the pollination issue; and
- to make recommendations.

A total of 530 apple growers were surveyed, and a number of key informants, including local government officials, scientists, progressive farmers, and beekeepers, were interviewed. The major findings are summarised in Chapter 2, which gives a regional overview of pollination-related productivity issues in the HKH. Both the scale of the problem and the farmers' management strategies were different in different countries. The review of the capabilities and programmes of government institutions in managing apple pollination indicates a clear need to strengthen their capacities so that they can serve apple growers better. Details of the study methodology and country results can be found in Part 2.

Chapter 2

Inadequate Pollination: The Major Cause of Declining Apple Productivity in the Region

The field surveys in selected apple growing areas of Bhutan, China, India, Nepal, and Pakistan clearly identified inadequate pollination as the major cause of declining apple productivity. Inadequate pollination not only reduces apple yield by causing poor fruit set, it also increases premature fruit drop and leads to poor fruit quality. Such fruit has poor market potential and fetches a low price, affecting the overall income of farmers.

Several factors contributed to the poor pollination. They included scarcity of pollinizer varieties in the orchards, insufficient populations of natural insect pollinators in the local environment, and changes in weather conditions during flowering. In India and China farmers were aware of the problem and the impact on apple productivity, but not in Bhutan, Nepal, and Pakistan. Farmers in the areas studied in India and China have already adopted different practices for managing pollination including the use of honeybees and hand pollination, but in Bhutan, Nepal, and Pakistan research and extension systems have yet to offer pollination management packages to farmers.

Factors Responsible for Inadequate Pollination in Apples

Pollinizer scarcity in the orchards

Many of the commercial varieties of apples planted by the farmers in the HKH region are self-incompatible and require cross-pollination with pollen from a compatible pollinizer variety. In order to ensure adequate pollination, it is necessary to plant sufficient pollinizer trees in such a position that each tree of the main variety has a pollinizer tree near it, so that pollen is available to its flowers. The optimum number and placement of pollinizers depends on several factors including the pollinizer variety, the main variety planted, and the number of pollinators. The standard requirement is for 20% of trees to be pollinizers, the normal minimum requirement is 11% if trees are planted in a strict geometrical arrangment (every third tree in every third row is a pollinizer) and closely spaced; some experts

A **pollinizer** (also spelt polliniser, pollenizer, and polleniser) is a source plant for compatible pollen that normally blooms at the same time as the target plant. For good yields, apples require a different variety of tree (for example Golden Delicious for Royal Delicious) as a pollinizer.

A **pollinator** is the agent that moves pollen from the anthers to the stigmas of flowers, thus enabling pollination. The most common pollinators are bees, but they can also be birds, butterflies, bats – and even humans.

Inadequate pollination may be the cause of ...

A.W. Jasra

... low fruit bearing

A.W. Jasra

... and premature fruit drop

recommend a proportion of 30-50% to achieve optimal pollination if the second variety has a market value (Mayer et al. 1985; Verma et al. 1997; Smith and Bradt undated; Deslauriers undated). It is equally important to select a pollinizer variety that blooms profusely and has a flowering period that overlaps with that of the commercial varieties.

Overall more than half of the farmers in the study areas had less than the minimum requirement of 20% pollinizer varieties in their orchards, most had only between 7 and 12%. The survey found the following situation.

In India, only 2% of farmers in the Shimla Hills, and Kullu Valley and none in Kinnaur met the standard requirement of 30% pollinizer trees in their orchards. About one quarter of farmers in Himachal Pradesh had between 20 and 25% pollinizer trees. It seems that in an attempt to have more trees producing commercial varieties of apple, and as a result of lack of knowledge about the importance of pollinizer–pollination systems, farmers have ignored the need to plant appropriate ratios of pollinizer apple varieties. In earlier times farmers grew

Pollination in apples

Apple flowers are hermaphrodite or bisexual, they have both male and female parts on the same flower, but most commercial varieties of apple can only be fertilised by pollen from flowers of a different, compatible, variety. In other words they are partially or completely self-incompatible. Pollination and fertilisation are a prerequisite for fruit set. To produce fruit, apples must be cross-pollinated and require pollinators to transfer pollen from the flowers of one tree to the flowers of another

Each apple flower has 5 sepals, 5 petals, 15–20 stamens with anthers producing pollen, and a pistil with a 5-chambered inferior ovary with 2 ovules in each chamber (or locule), 5 styles united at the base, and 5 stigmas. The same number of ovules must be fertilised in each chamber to produce a fruit of perfect shape and good quality. Generally, one ovule is fertilised in each chamber, rarely two. If the ovules in any one chamber are not fertilised, the fruit will be irregular in shape and size, reducing its market value.

a mixture of many varieties like Commercial, Golden, Jonathan, Red Gold, Red, and Royal Delicious. These provided pollen compatible with other varieties and there was generally good fruit set. In the early 1980s farmers started planting Royal Delicious on a large scale because of its high commercial value, and they slowly uprooted the other apple varieties – which could have been excellent pollinizers for Royal Delicious. During the past decade, the total apple-growing area has increased considerably, and all new orchards were planted only with Royal Delicious, although it is completely self-sterile and cross-pollination is essential. At the start of this trend there were still sufficient trees of the pollinizer varieties in the old orchards to ensure pollination, but over the last seven to eight years the problem has become serious.

The main reasons why farmers ignored the planting of pollinizers in China were market demand for a particular variety and scarcity of land. Apples from pollinizer varieties have a very low market value, and farmers do not want to sacrifice their land for a variety that does not bring them income. The farmers in China preferred to pollinate their apple flowers by hand, thus cutting down on the number of pollinizer trees needed.

A.W. Jasra

Inadequate pollination not only reduces yields but also causes low fruit quality

In Bhutan, farmers knew more about the need for pollinizers, and most farmers had planted pollinizer varieties – but the proportion was less than the recommended value (only 7-10%).

The farmers in Pakistan and Nepal knew little about managed pollination and planted few pollinizer trees. The majority of farmers in Nepal did not know which varieties were pollinizers or what the pollinizer proportion was in their orchards.

Whatever the reasons, the lack of appropriate proportions of pollinizer varieties in farmers' orchards is today one of the key factors in inadequate pollination of apples.

Declining populations of natural insect pollinators

Decline in the diversity and abundance of natural insect pollinators is the second most important factor affecting apple pollination, and thus productivity. A pollinator is the agent that transfers pollen between flowers. The known pollinators of apple trees include different types of insects like honeybees, bumblebees, solitary bees, and flies like dipterans and syphids (McGregor 1976; Free 1993; Verma and Chauhan 1985; Bangyu et al. 1997; Batra 1997a,b).

In recent years the diversity and populations of these natural insect pollinators have been declining for several reasons – including loss of food and nesting habitats due to clearance of forest and

grassland for agricultural purposes and indiscriminate use of pesticides. Changes in climate might also be affecting insect numbers. In all the study areas, farmers mentioned that in the past there were more insects like wild bees, butterflies, and moths during the apple-flowering season but that now most of them have disappeared. The majority of farmers identified pesticide use as the main cause of loss of natural insect pollinators. But increase in the amount of marginal land taken over for agriculture, and concomitant loss of wild habitat, must also have contributed. The increase in orchard area per se was also thought to play a role, with the natural populations of insects being too small to pollinate the newly-developed large areas of apple crops. This problem is less well understood than some others. The problem can be simply summarised as 'less insects available to pollinate more crops'. The scarcity of natural insect pollinators, and lack of replacement by 'managed' pollinators like hive bees, is another major cause of inadequate pollination in apples in the HKH region.

Changing climatic conditions

The third major reason suggested for pollination failure is climate change. Weather plays an important role in determining the success or failure of pollination as it affects both pollen production and the activities of pollinating insects (Verma et al. 1990). A drop in temperature or rainfall when apples are in flower can have an adverse effect on pollinator activity. Rain falling on the flowers can wash away the pollen grains, and hail can damage the flowers resulting in pollination failure and a decline in fruit set. The farmers in the study areas had observed an increase in bad weather conditions during the apple-flowering period in terms of the occurrence of frost, rain, hailstorms, and low temperatures.

Apple Pollination Management Today in the Survey Areas

Inadequate pollination is a relatively new problem in the HKH region and little research has been done on options to address it. In two of the HKH areas studied, Himachal Pradesh in India and the Maoxian Valley in China, productivity had dropped so severely that farmers and institutions were compelled to search for a solution. It was in these areas that the problem of insufficient pollination was first recognised, and it is here too that farmers and institutions have started investigating and testing pollination management options. The different approaches being tried are described briefly in the following.

Apple pollination management in Himachal Pradesh, India

Thanks to the efforts of government institutions, the majority of apple farmers in Himachal Pradesh are now well aware of the apple pollination problem and the factors responsible for it. They are trying different ways to improve pollination. Management efforts include planting different varieties of pollinizers, increasing the proportion of pollinizer trees, and increasing the number of pollinating insects in the orchards.

Managing the pollinizers

Now that farmers have become aware of the need for pollinizers to ensure yield and quality of apples, they are trying to increase the pollinizer proportion in the orchards, either by replacing some trees of the main variety with pollinizers, or by grafting pollinizers onto the main trees.

Grafting is sometimes necessary because grafts produce flowers more quickly than newly-planted trees. The most common varieties of pollinizer used are Commercial, Golden, Red Gold, and Tydeman's Early Worcester. Crab apple (wild apple) varieties are also being promoted as pollinizers. Crab apple varieties have considerable advantages: the trees are small and take up less space in orchards, they produce a good quantity of flowers, and they have long flowering periods of more than a month and are thus available to provide pollen to any variety, whether early or late blooming (Partap 1998).

It takes newly-planted pollinizer trees a minimum of four to five years to produce flowers, and grafts two to three years. As a short-term solution, farmers are practising 'bouquet pollination' – flowering pollinizer branches are cut and hung on the trees of the main variety, with the base placed in plastic bags filled with water to keep them fresh

Managing pollinators (hiring honeybees for pollination)

Many farmers in the valleys covered by the surveys are using honeybees (both *Apis cerana* and *Apis mellifera*) to increase the number of pollinating insects in their orchards. Some farmers keep their own honeybee colonies while others rent them from the Department of Horticulture, the University of Horticulture and Forestry, or private beekeepers. The present fee (2001) for renting honeybee colonies is IRs 300 (US $7.50) per colony for two weeks.

Increasing the pollinizer proportion ...

... crab apples placed between commercial trees

... grafting pollinizers onto trees of the main variety

... hanging pollinizer bouquets on trees of the main variety at the time of flowering

Preparing pollinizer bouquets ...

... putting pollinizer branches in plastic bags

... filling the bags

An additional IRs 500 (US $12.50) is charged as a refundable security deposit giving a total of IRs 800 (US $20). *Apis mellifera* is the main bee species provided. The colonies are kept in movable-frame hives. At present, Himachal Pradesh is the only place in the whole of the HKH region where a well-organised system has been established for hiring and renting honeybee colonies. A number of pollination entrepreneurs (beekeepers who rent honeybee colonies for crop pollination) have now started up in the state to complement the official services.

One problem that has arisen is that there are not enough colonies available for all the farmers who want to rent them. The State Government is now making efforts to encourage farmers to keep their own honeybee colonies for pollination. For this, the government has created a special section, 'The Beekeeping Development Office' (BKDO), under the Department of Horticulture. This office supports the sale of *Apis mellifera* colonies at a subsidised rate of IRs 300 (US $7.50) per colony – the market price is greater than IRs 2000 (US $50).

In addition to increasing the number of insect pollinators by renting or buying colonies of honeybees, some farmers are trying to save the populations of existing pollinators by making judicious use of carefully selected less toxic pesticides and spraying outside the apple flowering period.

Pollination entrepreneurs ...

... honeybees being transported to apple orchards

... colonies of honeybees being used for pollination

Apple pollination management in Maoxian Valley, China

A different approach is being followed in Maoxian County in China. Here, hand pollination of apples has become common practice. Since orchards are small, families try to pollinate their orchards themselves by training all members of the family (men, women, and children) making it a community effort (Partap and Partap 2000). Farmers also share days or hire labourers for the pollination of their apple orchards. These 'human pollinators' have been termed 'human bees' (Partap and Partap 2000). People do the work that could otherwise be done by honeybees. The advantage is that by far fewer pollinizer trees need to be planted, thus utilising the scarce land resources to a maximum for producing commercial varieties of fruit.

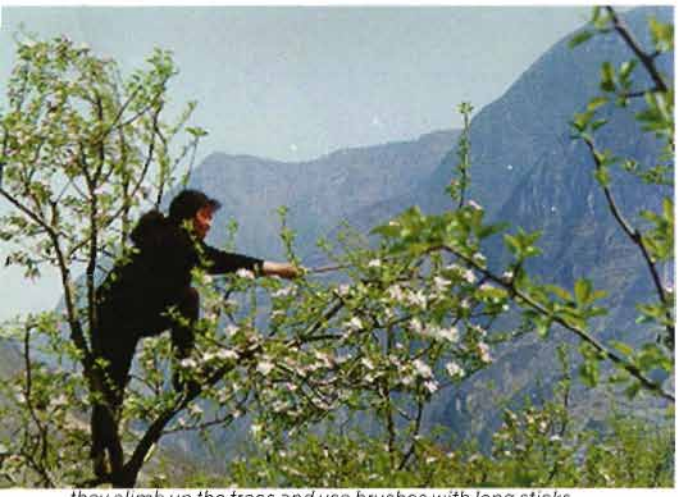
In hand pollination the anthers are picked from the flowers of the pollinizer varieties when the flowers are at the balloon stage (partially open) and then dried to release pollen grains, usually by spreading them out in the sun for a day or two, but sometimes in a cardboard box with an electric bulb, or even using an electric blanket. The pollen grains are stored in a cool, dry place and remain viable for three to four days. Pollen is mixed with a little white flour or skimmed milk powder and applied to the flowers of the main variety within two days of the flowers opening. Farmers normally apply pollen with the help of a hand-made brush, the filter side of a cigarette, or a pencil rubber. The farmers pollinate three out

Pollen is collected from the flowers of the pollinizer variety at the 'balloon stage'

Farmers in Maoxian County usually dry pollen by spreading it out in the sun ...

... some use electric blankets

Farmers apply dried pollen to the stigmas of flowers using hand-made brushes, cigarette, pencil rubbers, even camel hair brushes...



... they climb up the trees and use brushes with long sticks to pollinate distant flowers

of the five flowers in each apple inflorescence. Hand pollination is carried out three times in a season so as to cover some of the late flowers. The process is repeated in hundreds of apple orchards every year.

Apple pollination management in Pakistan, Bhutan, and Nepal

In Pakistan, Bhutan, and Nepal farmers are not yet aware of the importance of pollination or of the pollination crisis in their orchards, thus there are no clear management strategies.

In the Balochistan Province of Pakistan, apple productivity has been fluctuating and declined sharply in 1997-1998. Farmers are facing apple pollination problems both as a result of a lack of appropriate proportions of pollinizer trees and a lack of natural insect pollinators, but most apple growers are not aware of the source of their problems.

In Bhutan the apple orchard area is increasing but the yield per hectare is either static or declining. In the past there were adequate populations of natural insect pollinators, including wild honeybees (*Apis laboriosa*). The latter have survived because over 60% of land is forested and religious taboos mean there is no honey-hunting. However, the area of apple orchards has increased considerably during the past decade, with apple trees replacing forests on sloping land because Bhutan's agricultural policy prohibits fruit farming on flat irrigated cropland. This loss of natural forest is affecting the populations of natural insect pollinators and thus natural apple pollination. The process of decline of natural insect pollinator populations has just started and is expected to become more serious in the future. Already, despite religious taboos and the paucity of bee colonies, some farmers have started to keep bees for apple pollination.

In Nepal, farmers grow apples in a number of remote areas like Jumla, Mustang, and Solukhumbu. In Jumla, despite very poor yields, farmers were completely unaware that they had a pollination problem. They first realised that pollination was acting as a limiting factor in 1999 when ICIMOD

started its survey on apple pollination issues in collaboration with a local non-governmental organisation (NGO), the Surya Social Service Society (4S). In 2000, 4S organised an awareness-cum-training course on pollination problems and management for selected apple farmers of Jumla in collaboration with the Department of Agriculture of His Majesty's Government of Nepal (HMGN) and ICIMOD. Since April 2000, some leading farmers in Kholikot and Mahatgaon have started keeping honeybee colonies in their orchards.

Looking Ahead: Solutions to the Pollination Crisis

Pollination of self-incompatible crops like apple requires the presence of pollinizer trees and of pollinators, mostly insects. The problem of planting sufficient pollinizers lies outside the scope of this book, which focuses on pollinators. However, increasingly, departments of horticulture are becoming aware of this problem, which is important for many fruit crops not only apple, and activities to address the problem are underway.

Once sufficient pollinizer trees are present, the most important concern is to ensure that pollen transfer actually takes place. There are different ways of managing this including the use of honeybees (*Apis* spp.), rearing and using pollinators other than honeybees, and hand pollination.

Honeybees for pollination and the significance of honeybee diversity

For apples, one of the most practical approaches to increasing the number of pollinators is to use honeybees. Research has shown that pollination by honeybees increases fruit set, enhances fruit quality, and reduces fruit drop in apple trees (Dulta and Verma 1987). Honeybees are also the most efficient pollinators among insects because they can be managed in sufficient numbers and show flower constancy (Free 1964, 1966; McGregor 1976). The hive-kept species of honeybees (*Apis cerana* and *Apis mellifera*) are of great value because they can be moved to orchards where and when necessary. At present, pollination using honeybees is the most cost-effective method for pollinating apple and other fruit crops.

The HKH region is one of the richest in honeybee species diversity in the world. There are five species of honeybee: three wild species that cannot be kept in hives – the giant honeybee (*Apis dorsata*), the little bee (*Apis florea*), and the rock bee (*Apis laboriosa*) – and two hive species – the Asian bee (*Apis cerana*) and the introduced bee (*Apis mellifera*). All honeybees are good crop pollinators, but because the wild species' cannot be kept in man-made hives they cannot be transported to the sites where bees are needed. The honeybee species' diversity in the HKH region holds much potential for wider use in managing crop pollination in ways suited to the conditions in specific areas. In particular, the native hive honey bee *Apis cerana* offers clear advantages as a pollinator in remote and higher altitude areas.

Advantages of Apis cerana for crop pollination in high altitude areas

Both *Apis cerana* and *Apis mellifera* are excellent pollinators of mountain crops (Verma and Partap 1993; Partap and Verma 1992; 1994; Partap and Partap 1997, 2001). However, *Apis mellifera* performs better when daytime temperatures are relatively high, and temperature fluctuations are low, whereas *Apis cerana* is cold resistant and can perform well even when

daytime temperatures are relatively low, on cloudy days, and at higher altitudes with marked temperature fluctuations. In mountain areas, *Apis cerana* is a better pollinator of vegetable and fruit crops during spring and early winter than *Apis mellifera*. The race of *Apis mellifera* introduced to the HKH region is generally found to be more suitable for beekeeping under the warm agro-climatic conditions of the low hill and plains areas. In higher altitude areas, the native hive bee, *Apis cerana,* offers considerable advantages for beekeeping, whereas introduction of *Apis mellifera* can be problematic (ICIMOD 2002). Some of the advantages and disadvantages are summarised in the boxes.

If beekeepers introduce *Apis mellifera* to higher altitude areas for summer honey production, the exotic bee replaces the hardier native species, and the overall pollination of early crops is adversely affected. It can also lead to cross-infections that weaken the bees of both species. This has been shown in the mountain areas of Pakistan, where *Apis mellifera* has been introduced on a large scale for honey production – and the yield and quality of produce from early blooming mountain crops has been greatly reduced as a result of the lack of pollination (AKRSP, personal communication). At higher altitudes, *Apis mellifera* displaces the native bee without replacing its special pollination capabilities, and doesn't itself perform well.

Notwithstanding, *Apis cerana,* tends not to be popular among beekeepers (particularly commercial beekeepers), because of its lower honey yield. The institutions promoting beekeeping in the HKH region have so far focused exclusively on honey production rather than pollination, and have promoted the introduction of *Apis mellifera*, despite the considerable advantages of *Apis cerana* for pollination at higher elevations. Studies indicate, however, that some high mountain races of *Apis cerana* can match *Apis mellifera* in both behaviour and honey production. Activities are underway to select improved species, which will increase support for *Apis cerana* beekeeping.

When all these points are considered, it seems that *Apis cerana* should be promoted in higher altitude areas, and *Apis mellifera* and/or *Apis cerana* in the more accessible lower regions,

Advantages of beekeeping with *Apis cerana* in mountain areas

- Cold resistant, performs well at lower temperatures
- Available for pollination of early crops
- Flies in poor weather conditions
- Thrives on mixed, diverse crops
- No capital outlay, farmers can collect colonies from the wild and propagate them
- Minimum labour for maintenance, simple log hives can be used
- Relatively disease resistant
- Does not need feeding, fumigating, migration in winter
- Requires no external inputs, remoteness no problem
- Suitable for small-scale and stationary beekeeping

Problems with *Apis mellifera* at higher altitudes

- Poor tolerance of cold and widely fluctuating temperatures
- Requires migration to lower altitudes in winter
- Not available for pollination of early crops
- Requires intensive management practices with standardised equipment and external inputs
- Requires larger foraging grounds with monoculture-based agriculture
- Prone to diseases, parasitic mites, and wasps
- Introduces exotic diseases to which native (hive and wild) species are susceptible
- Less suitable and often unprofitable for small-scale and stationary beekeeping

particularly when bees are primarily kept for pollination. This will ensure better pollination of mountain crops and also help in conserving the indigenous species.

Decline of the native hive bee

Beekeeping with the native honeybee *Apis cerana* is a traditional household activity among several mountain communities. But the promotion of *Apis mellifera* over the past few decades has adversely affected indigenous *Apis cerana* beekeeping and led to the replacement of *Apis cerana* with *Apis mellifera* in many areas of the HKH region (Partap and Partap 1997). Studies carried out by ICIMOD have shown that at present there are only a few areas in the mountain districts of Nepal, India, China, and Pakistan where *Apis cerana* is being kept by beekeepers and farmers (ICIMOD 1998; Bangyu and Tan 1996).

Constraints to using honeybees for pollination in the HKH region

Hive bees can play an important role in pollination – and in areas like N. America, Europe, and Japan they are used extensively to ensure pollination of fruit and vegetable crops (see for example McGregor 1976, 2002; Morse and Calderone 2000). However, although beekeeping is common in the HKH region (stationary beekeeping with *Apis cerana* and migratory beekeeping with *Apis mellifera*), bees are only used specifically for pollination in a few areas. Beekeeping has only been promoted as an enterprise for honey production; neither the policies nor the institutions involved have focused on developing and promoting beekeeping for crop pollination. Considerably more research and development efforts will be needed before honeybees can be effectively promoted for pollination on a large scale in this region. The main constraints to using bees for pollination are lack of awareness among farmers, lack of beekeeping in horticultural development packages, scarcity of honeybee colonies, and lack of knowledge about honeybees' foraging behaviour.

Lack of awareness among farmers is one of the main problems. With a few exceptions, farmers in those areas of the HKH region where there is a pollination problem with apples are not aware of the value of honeybees for apple production. This is both because beekeeping has always been promoted exclusively as an enterprise for honey production, and because apple growing is a new activity and there is no indigenous knowledge on the needs for production.

Beekeeping from the perspective of crop pollination has been overlooked in agricultural development strategies for hill areas of the HKH region. Agricultural institutions offer different packages of practices for specific crops to promote high-value farming of cash crops. These packages suggest to farmers the kind of inputs needed to maintain sustainable yields of specific crops like soil preparation, irrigation, use of fertiliser, and pesticide spray schedules. However, beekeeping as an input to manage crop productivity has not yet been included. Thus farmers have no way of knowing how essential it can be. This weakness in the agricultural extension system needs to be addressed. Though a few farmers are aware of the value of beekeeping for crop pollination, in the HKH region there is no formal system for hiring and renting honeybee colonies of the sort prevalent in horticulturally developed countries of the world (see, for example, Morse and Calderone 2000).

Scarcity of honeybee colonies for pollination is the third major constraint on promoting honeybees for apple pollination. In the apple valleys where honeybees are being used for apple pollination, the number of honeybee colonies is far below that required for pollination of the whole crop in the area. In Himachal Pradesh about 78,000 ha are planted with apple trees. Theoretically some

230,000 colonies would be needed to pollinate the whole apple crop in Himachal (on the basis of 2-3 colonies of *Apis mellifera* or 3-5 colonies *of Apis cerana* needed to pollinate 1 ha of apple orchard). However, there are only about 10,000-12,000 honeybee colonies in all, and not all of them can be used for pollination. Thus, the available honeybees meet only 4-5% of the calculated total demand. It seems that the expansion of horticultural farming in Himachal has not been accompanied by a corresponding increase in the number of honeybee colonies (Nadda and Tiwari 1998). This highlights the fact that, in addition to raising awareness, training farmers, and creating the right policy environment, it is important to focus on ways of increasing the number of honeybee colonies in each area.

Lack of knowledge among farmers about the foraging behaviour of honeybees is another constraint hindering the use of honeybees in crop pollination. Even those farmers in the HKH who do know that they can use honeybees to increase apple pollination and yield don't always know how to use the bees. Few people know about the foraging or pollination behaviour of honeybees. For example, farmers in some villages in Himachal Pradesh, unaware that honeybees do not visit flowers during the night, had stolen colonies of honeybees from neighbouring orchards during the night and returned them early in the morning, in the hope that their apple trees would be pollinated.

Overcoming constraints to promoting honeybees for pollination

Diversification of mountain agriculture towards high-value cash crops requires pollination management since most commercial varieties of these high-value crops are cross-pollinated. Farmers have been looking at the ways in which institutions (government and non-government, private entrepreneurs, researchers) can help. The various suggestions are summarised below.

Raising awareness about the importance of using honeybees for crop pollination is the first step in promoting beekeeping for pollination

Horticultural extension

The first and most important step in promoting the wider use of honeybees for crop pollination is to include beekeeping as part of horticultural development efforts. Horticulture, especially apple farming, is being promoted in several areas of the HKH region. Official institutions offer packages of practices for each type of crop, but the importance of managing pollination to achieve a sustainable yield has been overlooked. Since pollination is essential for the production of fruits and seeds, crop pollination management should be included in horticultural development packages, with beekeeping for crop pollination as a 'double benefit approach'.

Influencing thinking

The second step is to change the general 'mindset' about honeybees and beekeeping, and to raise awareness about the importance of managed crop pollination. Traditional thinking is that beekeeping is for honey production, its role in crop pollination is rarely considered. Today, most government agencies are only engaged in promoting beekeeping for honey production. The move towards introduction of *Apis mellifera* to increase honey production is an example of this. Countries in Europe, the USA, and Japan have been using honeybees for pollination of crops such as apples, almonds, pears, plums, cucumbers, melons, watermelons, and a number of berries for a long time. In the USA the first colonies of honeybees (*Apis mellifera*) were rented for apple pollination in 1909 in New Jersey (Morse and Calderone 2000). In contrast, in the HKH region, renting of colonies for apple pollination only started in 1996, and is still restricted to a very few areas.

There is a need for a change in thinking about the value of honeybees as crop pollinators at many levels: policy, planning, research, beekeeping, and farming. The initial thrust of the pollination programme will need to raise awareness about the need for managing pollination through honeybees and to generate the knowledge and information needed to facilitate the formulation of strategies that will ensure the wider use of beekeeping for pollination. Honeybees should be seen as crop pollinators first, and as honey producers second. Changes in research and development investment policies may be needed to encourage this.

Training in orchard planning and management

A further important step is to train apple farmers in orchard planning and pollination management. Many farmers in mountain areas have insufficient knowledge about the best layout for orchards. More information is needed on appropriate pollinizer varieties, proportions of pollinizers, placement of pollinizers in relation to the main variety, and pruning and thinning of trees. Farmers also need to know about the importance of bees, and numbers and placement of bee colonies.

Increasing the number of colonies

The next step is to increase the number of honeybee colonies available for pollination. There are about 370,000 ha of apple orchards in the HKH region, theoretically these need about a million bee colonies to ensure optimum pollination. The actual number available is much lower. In our survey, farmers rated this as the major problem. Since beekeeping is not traditional in Bhutan or the Balochistan Province of Pakistan there are few colonies, and in China beekeepers are not willing to provide bee colonies to apple farmers for pollination, partly for fear of the effects of insecticide spraying. The number of colonies should be increased by multiplying the existing colonies through breeding and mass queen rearing. Such efforts will require more trained manpower and a large amount of scientific, management, and extension inputs.

Another part of increasing the number of honeybee colonies for pollination is to encourage private entrepreneurs to keep large numbers of honeybee colonies that they rent to farmers for pollination. In addition to the rental fee, these 'beekeeping for pollination entrepreneurs' can earn income through the sale of honey and beeswax. Such a system benefits both farmers and beekeepers. Pollination entrepreneurs have already become established in a few apple valleys in the region.

An apiary of Apis mellifera *in Kullu Valley, Himachal Pradesh, which rents honeybee colonies to farmers for apple pollination*

Promoting beekeeping

The final step is to encourage individual farmers, village communities, and commercial pollination entrepreneurs to rear and keep bees for pollination. Individual apple farmers could be encouraged to keep their own honeybee colonies for pollination if training is available and there is a supply of colonies. Honeybee entrepreneurship schemes need to be encouraged. Himachal Pradesh has recently started such a programme, as mentioned above. The government agency arranges sales of *Apis mellifera* colonies to apple farmers at a subsidised price and the State Department of Horticulture, and the University of Horticulture and Forestry provide training, and some honeybee colonies free of charge, to apple farmers.

Beekeeping for apple pollination can also be promoted at community and village level. The requirement of honeybee colonies for apple pollination is 2-3 colonies of *Apis mellifera* or 3-5 colonies of *Apis cerana* per hectare. Since landholdings are often small, individual farmers may need only 1-2 colonies of honeybees. In high elevation and inaccessible areas, and on a small-scale, only *Apis cerana* should be promoted, both because this bee is suitable for stationary beekeeping and for the other reasons summarised above. In accessible areas if *Apis mellifera* is kept, then the colonies need to be migrated to low hill or plains' areas during the winter season, and brought back at the time of apple flowering because there is no bee forage available in the winter and the *Apis mellifera* colonies are susceptible to cold. If farmers feed the bees with sugar during the winter months, the colonies are not strong enough early in the season when they are needed for apple pollination. It is not economic to migrate small numbers of bees; a truckload is needed. Thus farmers in these areas should be encouraged to migrate their colonies collectively. Community and village-level management of beekeeping can be a very useful way of ensuring both apple pollination and a good honey harvest.

Providing for increased bee numbers

Given the large number of honeybee colonies that will be required in areas with large acreages of crops; it is possible that the number of bees may exceed the present carrying capacity of an area. It may well be necessary to either increase the number of honeybee forage plants through new plantations and/or to promote migratory beekeeping as an enterprise. The latter would also help strengthen upland-lowland linkages.

Investment in crop pollination

Apples are only one example of a number of cash crops grown by the HKH farmers which require managed pollination for increased production and quality. Vegetable seed production is another

Institutional efforts to promote beekeeping for apple crop pollination in Himachal Pradesh

The Role of the Himachal Horticulture and Forestry University

- Strong scientific expertise available on honeybees, beekeeping, and pollination
- Field stations in apple-farming areas monitor problems related to horticulture and focus on problem-solving research
- On-farm research into and demonstration of the positive effects of beekeeping for apple pollination
- Special awareness programmes launched in apple-farming areas
- The Agriculture Science Centres, (the university extension centres) give beekeeping training on-demand to farmers and interested new entrepreneurs
- The university provides bee colonies for pollination; the Beekeeping and Horticulture Research Stations keep both *Apis cerana* and *Apis mellifera* for this
- Training and demonstrations on how to use bees for pollination

The Role of the Government of Himachal Pradesh Department of Horticulture

- Establishment of a Beekeeping Development Office for Pollination (BKDO), which maintains and rents honeybee colonies to farmers; *Apis mellifera* colonies sold at a subsidised rate (IRs 300 [US $7.5] per colony, against a market price of about IRs 2000 [US $50])
- Annual assessments of the demand for honeybee colonies by apple farmers, and arrangements for supply facilitated with private beekeepers
- Attractive financial support for starting a beekeeping enterprise for pollination
- Provision of honeybee colonies at a subsidised rate to promote their use for pollination

The Role of the Himachal Apple Growers' Association

- Platform for farmers to discuss emerging problems and to act as a strong pressure group to seek government intervention
- Raised the apple-pollination problem faced by farmers with the university and government and sought rapid solutions
- Raised awareness about the scale of the problem in the state and encouraged farmers to become beekeeping entrepreneurs for pollination; coordinated honeybee demand–supply aspects

crucial sector where pollination management is essential. It is necessary to evolve strategies to promote investment in research and development that will enhance the use of honeybees for pollination. This means developing area-based approaches, making full use of the existing diversity of honeybee species in the HKH region.

Strengthening research and extension systems

Beekeeping for crop pollination is a new activity in the HKH region. There are few institutions in the region with explicit mandates or expertise. Most institutions promote beekeeping as a cottage industry to increase family income through the sale of honey. Promoting the value of honeybees as reliable pollinators of apples and other fruit and vegetable seed crops will require special efforts to strengthen research and extension systems. In Pakistan, for example beekeeping with *Apis mellifera* for honey has been heavily promoted by the government, but crop pollination is not included on the agenda of the honeybee research and development agencies. The approach being taken in Himachal Pradesh is summarised in the box as an example.

Other options for pollination

Non-honey bees

Species of bumblebees and solitary bees like *Amegilla, Andrena, Anthophora, Ceratina, Halictus, Megachile, Nomia, Osmia, Pithis*, and *Xylocopa* are important pollinators of apple flowers in the

HKH region (Batra 1997b), but the natural populations of these bees are declining. In principle, many of these pollinators could be reared on a large scale and managed for the pollination of apple trees and other crops. In many developed countries various natural insect pollinators, including some species of bumblebees and solitary bees, are being reared and managed commercially for pollination of crops, particularly those that are less, or not effectively, pollinated by honeybees. Bumblebees, for example, are used for the pollination of potatoes and tomatoes, alkali bees and leaf cutter bees for the pollination of alfalfa, and various species of bumblebees and solitary bees for pollination of apple, almond, and other fruit trees, and cotton, mustards, lucerne, and berseem (Crane 1990). The solitary bee *Osmia cornifrons* Rad. is being managed on a large scale in Japan where it is used to pollinate one third of all apple crops (Batra 1995, Sekita 2001).

Some species of bumblebees and solitary bees are excellent pollinators of apple trees, and can be managed for their pollination. Batra (1997a) reported that the halictine bee (a solitary bee, *Lasioglossum (Evylaeus) matianensis*) is the predominant pollinator of apple trees at altitudes higher than 2600 m and that it can be managed simply by providing nesting sites.

According to Batra (1997b), there are two approaches to enhancing the pollination of fruit crops using solitary bees. The first is to manage the habitat around orchards to provide nesting sites for the native pollinators in the area. Making sunny plots by removing shady vegetation from any existing nest aggregations can increase the population of most species. This type of habitat management may take up too much space, however, and thus be too costly, and in many areas of the HKH, farmers (especially fruit growers) have already cleared the habitat required for these pollinators. Keeping native habitat may also interfere with orchard operations or provide a refuge for crop pests. The second approach is to keep populations of solitary bees in bee shelters and place them near the orchard. Shelters can be made from inexpensive materials. They take up little space and do not interfere with most operations or harbour crop pests. With these solitary bees, the adults are only active while the crops are in flower. After the flowers have been pollinated, the adult bees die and the dormant brood can be put into storage until the next pollination season, when the next generation of adult bees will emerge to help carry out crop pollination (Batra 1997b).

There is good potential for the managed use of non-*Apis* pollinators in the Himalayan region. There are thousands of hectares of land under cash crops that need cross-pollination. But owing to lack of expertise and institutional capability, the HKH countries have so far not been able to make real use of these pollinators. Batra (1997b) summarised the characteristics of solitary bees that make them useful as pollinators, these characteristics could be used as criteria for selection of natural insect pollinators to be reared and managed for fruit tree pollination (see box).

In cold and arid areas of the HKH region, for example Balochistan (Pakistan), Mustang (Nepal), and Lahul (Himachal Pradesh), where stationary beekeeping cannot be practised because of the prevailing cold and dry climatic conditions and lack of forage during the greater part of the year, managing non-honeybees for pollination is a good option. These areas have a number of different types of solitary bees. Since only two to three per cent of total land area is cultivated, a lot of space is available for these bees to hibernate. But major research and extension efforts will be needed

Characteristics of solitary bees that make them useful for pollination of fruit crops

Host Preference and Foraging Behaviour

- Solitary bees prefer fruit blossom and the brood can develop well on a diet of nectar and pollen
- An individual bee works rapidly, quickly dispersing a large amount of pollen
- The bees work across rows and among plants of different cultivars maximising cross-pollination
- The pollen is carried loosely in fine body hairs and is easily brushed onto stigmas of other flowers
- The bees have a short flight range and stay close to their nest in the orchard
- The bees forage in the cool, cloudy, windy, or rainy weather that is common in the spring in hill areas
- Both males and females visit and pollinate flowers

Life Cycle, Nesting Habits, and Manageability

- The period of adult activity naturally coincides with the time of fruit flowering
- The bees thrive in the climatic zones where fruit trees are grown
- They nest in inexpensive man-made or altered natural substrates and can find all their material needs in or near the crop
- They live in colonies or nests so that it is easy to manage a large population
- They are gentle, permitting human activities near their nests
- They are relatively free of parasites and predators or can be easily managed to eliminate them
- Each female makes many cells that produce next generation females, thus the population increases rapidly, and pollination is enhanced because females are better pollinators than males
- The bees can be mass reared, so that large numbers can be made available at the flowering time of the crop

Source: Batra (1997b)

before such insects can be reared and managed for pollination of crops in the region. At present, there are no government institutions or private entrepreneurs engaged in rearing and managing these insects for pollination purposes. Popularising the rearing and use of non-*Apis* pollinators in the HKH region will take many years.

Humans as pollinators

Hand pollination, although the most reliable method of ensuring pollination takes place, is expensive, laborious, and time-consuming and is unlikely to be sustainable in the long term, particularly as labour costs increase.

Making use of honeybee diversity: different approaches for different areas

The most promising approach to reversing the decline in productivity of fruit and vegetable crops in the HKH region is to introduce the approach of integrated pollination management. For apple crops, the most practical approach at present is to promote the use of honeybees.

There are various possibilities: beekeeping for pollination using *Apis cerana, Apis mellifera,* or a combination of the two, and promotion of wild honeybees. Which is best, depends on the particular conditions in an area. The most promising approaches in each of the different areas studied are summarised below.

Apis cerana and Apis mellifera beekeeping for pollination

A combined approach using both species might be most appropriate in the apple valleys of Himachal Pradesh, India, and Maoxian County, China, where apples and other temperate fruits have emerged as important cash crops. Traditional beekeeping with *Apis cerana* is common in these areas; farmers generally keep a few colonies around their houses in wall or log-hives. Equally *Apis mellifera* is

Beekeeping is common in Maoxian Valley but local institutions do not promote the use of honeybees for pollination

(A.W. Jasra)

A commercial, migratory Apis mellifera apiary in a Juniper forest of Balochistan. The honeybees are not used for pollination

also widely popular for honey production. Thus *Apis cerana* and *Apis mellifera* could be used to complement each other for pollination.

Apis mellifera beekeeping for pollination

In lower altitude hill areas of Pakistan the best approach is likely to be promoting the use of the *Apis mellifera* bees that are now kept for honey production for the pollination of apple crops. Migratory beekeeping for honey production with *Apis mellifera* has already been widely promoted by the Government of Pakistan, and *Apis mellifera* beekeeping is flourishing well in both hill and plains areas where sub-tropical fruit and vegetable crops are grown. But the bees are not being used for pollination. Hives are most commonly placed along the roadsides, in forest, or on wasteland – but not in the orchards. *Apis mellifera* is suitable for large-scale migratory beekeeping, and the colonies could be moved easily to areas requiring pollination services, for example where pollinator populations may not be sufficient and/or stationary beekeeping is not possible because of the cold winter conditions.

Apis cerana beekeeping for pollination

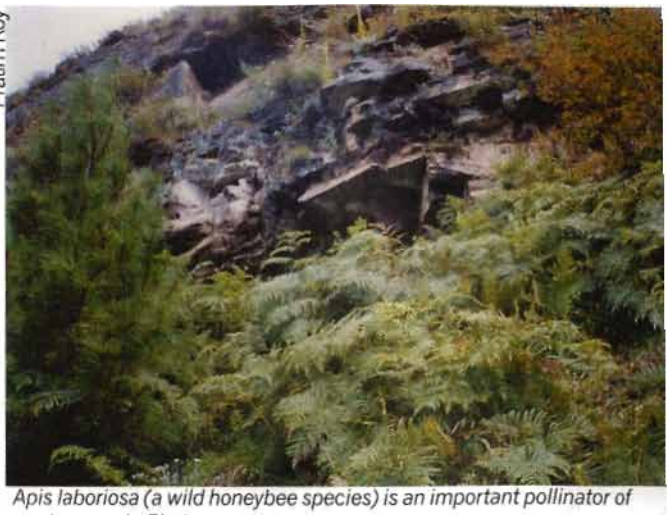
In Nepal the most appropriate approach for apple pollination is likely to be the promotion of *Apis cerana* beekeeping. Traditional beekeeping with *Apis cerana* is common in the mountain areas of Nepal where apples are grown, and these areas already have a gene pool of this bee. *Apis mellifera* can be more difficult to manage at these higher elevations. Introduction of *Apis mellifera* in the traditional isolated *Apis cerana* areas should be discouraged. In lower elevation areas with good access, *Apis mellifera* can be promoted for the pollination of other fruit and vegetable crops.

Wild bees for pollination

In Bhutan the best approach may be to focus on using wild honeybees for pollination. Three wild honeybee species are found in the HKH region: *Apis dorsata* and *Apis florea* in low and middle hill

areas and *Apis laboriosa* in high mountain areas. All are excellent pollinators of crops and wild plant species. They play an important role in improving farm productivity and conserving biodiversity. Their natural populations need to be maintained so that they can provide a needed pollination service for wild plants, as well as for apples and other crops. In Bhutan, support for ensuring populations of wild bees is likely to be more successful than encouraging beekeeping, the potential for which is restricted by religious taboos, as more than 60% of the land area is forested, wild bees are already widespread and play an important role in crop pollination, and religion prohibits honey hunting, which has helped natural populations of wild bees to increase.

Pratim Roy



Apis laboriosa (a wild honeybee species) is an important pollinator of apple crops in Bhutan

Conclusion

The declining productivity of fruit and vegetable crops, in particular apples, in the HKH region can be attributed to a number of factors, but among these pollination plays a major role. The approach outlined above for raising awareness of the problem and introducing integrated pollination management with bees on a large scale, should make it possible to arrest and reverse this decline, and restore faith in cash crops as a way of reducing poverty and supporting development in the region.

Annex 1

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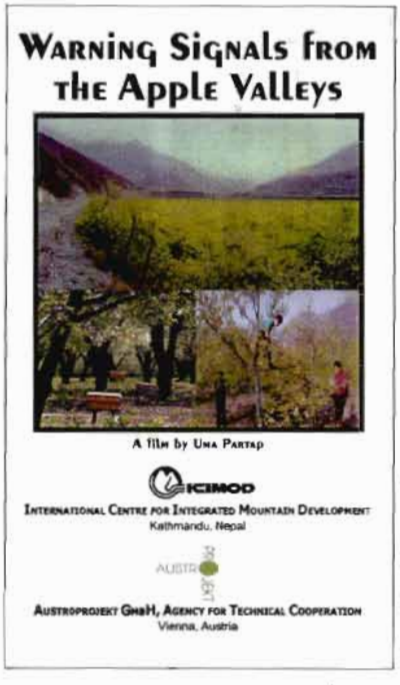
See also ...

Warning Signals from the Apple Valleys



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This video, shot in apple valleys in Himachal Pradesh (India), the Northern Areas and Balochistan Province of Pakistan, and Maoxian county of China, highlights the pollination problems faced by apple farmers (and farmers of other crops) in the Hindu Kush-Himalayan region. The importance of apples in the economy of mountain areas is shown, together with the problem of declining apple productivity due to inadequate pollination. Excellent shots illustrate the major causes: insufficient pollinizers (trees), lack of pollinating insects, and bad weather conditions (climate change). The film shows how some farmers manage apple pollination — large-scale use of pollinizer bouquets to increase the proportion of pollinizers and use of honeybees as pollinating insects in Himachal Pradesh, India; and hand pollination in Maoxian county China.

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Uma Partap is a Research Officer for pollination in the ICIMOD Beekeeping Project. She has a Ph.D. in Biological Sciences from Himachal Pradesh University, Shimla, India and eighteen years of research experience that covers diversified fields including drought eco-physiology and pollination ecology. At ICIMOD, Dr. Partap has been instrumental in establishing the crop pollination programme under the Mountain Farming Systems Division. At present, she is studying pollination issues in mountain crops and focusing on raising awareness among agricultural planners, policy-makers, researchers, and farmers in the Hindu Kush-Himalayan region about the importance of managing crop pollination and the use of bees for this purpose. She has published various books and manuals in English and regional languages (Hindi, Nepali, and Urdu) and about forty research papers on such topics as bee pollination, bee flora, honeybee behaviour and drought eco-physiology, as well as produced a video film highlighting apple pollination issues in the HKH region.

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