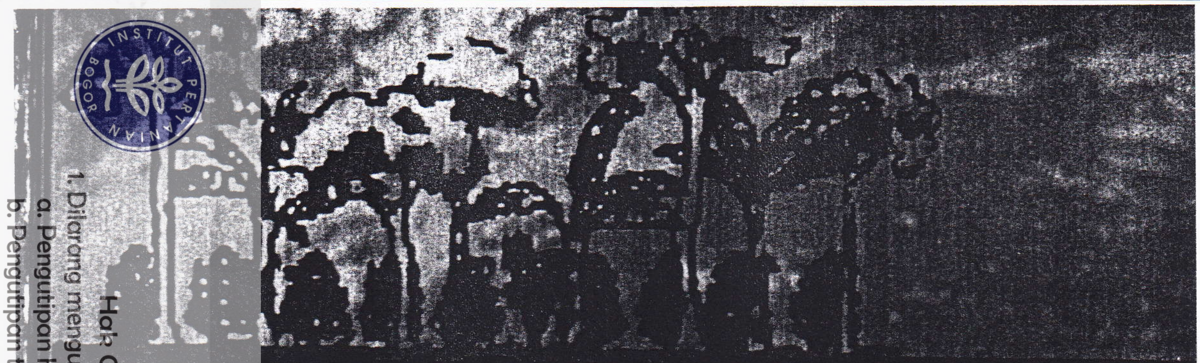

T. TSCHARNTKE
C. LEUSCHNER · M. ZELLER
E. GUHARDJA · A. BIDIN
Editors

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Linking Ecological, Economic and Social Constraints of Land Use and Conservation

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Teja Tscharntke, Christoph Leuschner, Manfred Zeller, Edi Guhardja, Arifuddin Bidin (Eds.)

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With 89 Figures, 1 in colour

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EDITORS:

PROF. DR. TEJA TSCHARNTKE
AGROECOLOGY GROUP
UNIVERSITY OF GÖTTINGEN
WALDWEG 26,
37073 GÖTTINGEN, GERMANY
E-mail: ttschar@gwdg.de

PROF. DR. MANFRED ZELLER
INSTITUTE OF AGRICULTURAL ECONOMICS
AND SOCIAL SCIENCES IN THE TROPICS AND
SUBTROPICS, UNIVERSITY OF HOHENHEIM
(490)
70593 STUTTGART, GERMANY
E-mail:
manfred.zeller@uni-hohenheim.de

PROF. DR. CHRISTOPH LEUSCHNER
DEPARTMENT OF PLANT SCIENCES
UNIVERSITY OF GÖTTINGEN
UNTERE KARSPÜLE 2
37073 GÖTTINGEN,
GERMANY
E-mail: cleusch@gwdg.de

PROF. DR. EDI GUHARDJA
CENTER FOR TROPICAL FOREST MARGIN,
INSTITUT PERTANIAN BOGOR (IPB), JI.
RAYA GUNUNG GEDE, BOGOR 16153,
INDONESIA
E-mail: storma-ipb@indo.net.id

DR. ARIFUDDIN BIDIN
UNIVERSITAS TADULAKO, KAMPUS
BUMI TONDO, PALU 94118,
INDONESIA
E-mail: storma-palu@gwdg.de

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Contents

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List of Contributors

Melani Abdulkadir-Sunito
Department of Communication and Community Development, Faculty of Human Ecology, Bogor Agricultural University, Indonesia

Tatiana Deane de Abreu Sá
Empresa Brasileira de Pesquisa Agropecuária, Embrapa Sede, Parque Estação Biológica - PqEB s/n., Brasília-DF, - Brazil - CEP 70770-901

Diógenes S. Alves
Instituto Nacional de Pesquisas Espaciais (INPE), Av dos Astronautas 1758, CEP 12227-010 São José dos Campos SP, Brazil

M. Amran Amir
Institute of Forest Management, Faculty of Agriculture, Bumi Tondo Campus, Tadulako University, Palu 94118, Indonesia

Iswandi Anas
Laboratory of Soil Biology, Soil Department, Faculty of Agriculture, Institut
Pertanian Bogor (IPB), Darmaga Campus, Bogor 16680, Indonesia

Muhammad Ardiansyah
Institute of Soil Sciences, Bogor Agricultural University (IPB), Bogor, Indonesia

Hadi Susilo Arifin
Department of Landscape Architecture, Faculty of Agriculture, IPB, Bogor, Indonesia

Inge Armbrecht
Departamento de Biología, Universidad de Valle, Apartado Aéreo 25360, Cali, Colombia

Jan Barkmann
Junior Scientist Group "Economic Valuation of Ecosystem Functions and Services" and Environmental and Resource Economics, Department of Agricultural Economics and Rural Development, University of Göttingen, Platz der Göttinger Sieben 7, D-37073 Göttingen, Germany

Pablo C. Benítez
Department of Economics, University of Victoria, PO Box 1700 STN CSC, Victoria BC V8W 2Y2, Canada

Arifuddin Bidin
Universitas Tadulako, Kampus Bumi Tondo, Palu 94118, Indonesia (Sulteng)

Regina Birner
International Food Policy Research Institute (IFPRI), Washington, D.C., USA

Jan Börner
Center for Development Research (ZEF), University of Bonn, Walter-Flex-Str. 3, 53113 Bonn, Germany

Merijn M. Bos
Institute of Agroecology, University of Göttingen, Waldweg 26, D-37073 Göttingen, Germany

Gunnar Brehm
Institut für Spezielle Zoologie und Evolutionsbiologie mit Phyletischem Museum, University of Jena, Erbertstrasse 1, 07745 Jena, Germany

Damayanti Buchori
Department of Pest and Plant Diseases, Faculty of Agriculture IPB, Bogor Agricultural University, Jl. Kamper Kampus, IPB Darmaga, Bogor 16680, Indonesia

Boris Büche
Agroecology, University of Göttingen, Waldweg 26, D-37073 Göttingen, Germany

Manfred Denich
Center for Development Research (ZEF), University of Bonn, Walter-Flex-Str. 3, 53113 Bonn, Germany

Thomas V. Dietsch
Institute of the Environment, Center for Tropical Research, University of California, Los Angeles, La Kretz Hall, Suite 300, Box 951496, Los Angeles, California 90095-1496, USA

Johannes Dietz
Tropical Silviculture, Institute of Silviculture, University of Göttingen, Büsgenweg 1, 37077 Göttingen, Germany and
Plant Ecology, Albrecht-von-Haller-Institute of Plant Sciences, University of Göttingen, Untere Karspüle 2, 37073 Göttingen, Germany

Stefan Erasmi
Institute of Geography, Department of Cartography, GIS and Remote Sensing, University of Göttingen, Goldschmidtstr. 5, 37077 Göttingen, Germany

Raffael Ernst
Department of Animal Ecology and Tropical Biology, Biocenter University of Würzburg, Am Hubland 97074 Würzburg, Germany

Ulrike Falk
Institute of Bioclimatology, University of Göttingen, Büsgenweg 2, Göttingen, Germany

Heiko Faust
Department of Cultural and Social Geography, Institute of Geography, University of Göttingen, Goldschmidtstr. 5, D-37077 Göttingen, Germany

Konrad Fiedler
Department of Population Ecology, University of Vienna, Althanstrasse 14, 1090 Vienna, Austria

Klaus Glenk
Junior Scientist Group "Economic Valuation of Ecosystem Functions and Services" and Environmental and Resource Economics, Department of Agricultural Economics and Rural Development, University of Göttingen, Platz der Göttinger Sieben 7, D-37073 Göttingen, Germany

S. Robbert Gradstein
Institute of Plant Sciences, University of Göttingen, Untere Karspüle 2, 37073 Göttingen, Germany

Gode Gravenhorst
Institute of Bioclimatology, University of Göttingen, Büsgenweg 2, Göttingen, Germany

Stefan Grote
Institute of Bioclimatology, University of Göttingen, Büsgenweg 2, Göttingen, Germany

Edi Guhardja
Kampus IPB Baranang Siang, Ex-Aula Kantor Pusat, Institut Pertanian Bogor, JL Raya Pajajaran, Bogor 16144, Indonesia (Jabar)

Handian Handi
Laboratory for Social Forestry, Faculty of Forestry, Institute Pertanian Bogor, Bogor, Indonesia

Marieke Harteveld
Plant Ecology, Albrecht-von-Haller-Institute of Plant Sciences, University of Göttingen, Untere Karspüle 2, 37073 Göttingen, Germany

Bettina Hedden-Dunkhorst
Federal Agency of Nature Conservation (BfN), Konstantinstr. 110, 53179 Bonn, Germany

Dietrich Hertel
Plant Ecology, Albrecht-von-Haller-Institute of Plant Sciences, University of Göttingen, Untere Karspüle 2, 37073 Göttingen, Germany

Nadine Hilt
Chair of Animal Ecology I, University of Bayreuth, 95440 Bayreuth, Germany

Patrick Höhn
Agroecology, University of Göttingen, Waldweg 26, D-37073 Göttingen, Germany

Dirk Hölscher
Tropical Silviculture, Institute of Silviculture, University of Göttingen, Büsgenweg 1, 37077 Göttingen, Germany

Andreas Ibrom
Institute of Bioclimatology, University of Göttingen, Büsgenweg 2, Göttingen, Germany and
Risø National Laboratory, Frederiksborgvej 399, DK-4000 Roskilde, Denmark

Tania June
Southeast Asian Ministers of Education Organization Regional Centre for Tropical Biology (SEAMEO BIOTROP), BTIC Building, Jl. Raya Tajur Km.6, Bogor, Indonesia
and
Faculty of Mathematics and Natural Resources, Bogor Agricultural University/SEAMEO BIOTROP, Bogor, Indonesia

Martin Kappas
Institute of Geography, Department of Cartography, GIS and Remote Sensing, University of Göttingen, Goldschmidtstr. 5, 37077 Göttingen, Germany

Katja Kehlenbeck
Department of Crop Sciences: Tropical Crops, University of Göttingen, Grisebachstr. 6, D-37077 Göttingen, Germany

Alwin Keil
Institute of Agricultural Economics and Social Sciences in the Tropics and Subtropics, University of Hohenheim (490), D-70593 Stuttgart, Germany

Michael Kessler
Institute of Plant Sciences, University of Göttingen, Untere Karspüle 2, 37073 Göttingen, Germany

Alexandra-Maria Klein
Agroecology, University of Göttingen, Waldweg 26, D-37073 Göttingen, Germany

Heiner Kreilein
Institute of Bioclimatology, University of Göttingen, Büsgenweg 2, Göttingen, Germany

Werner Kreisel
Department of Cultural and Social Geography, Institute of Geography, University of Göttingen, Goldschmidtstr. 5, D-37077 Göttingen, Germany

William F. Laurance
Smithsonian Tropical Research Institute, Apartado 2072, Balboa, Republic of Panamá and Biological Dynamics of Forest Fragments Project, National Institute for Amazonian Research (INPA), C.P. 478, Manaus, AM 69011-970, Brazil

Christoph Leuschner
Plant Ecology, Albrecht-von-Haller-Institute of Plant Sciences, University of Göttingen, Untere Karspüle 2, 37073 Göttingen, Germany

K. Eduard Linsenmair
Department of Animal Ecology and Tropical Biology, Biocenter University of Würzburg, Am Hubland 97074 Würzburg, Germany

Brigitte L. Maass
Department of Crop Sciences: Tropical Crops, University of Göttingen, Grisebachstr. 6, D-37077 Göttingen, Germany

Adam Malik
Institute of Forest Management, Faculty of Agriculture, Bumi Tondo Campus, Tadulako University, Palu 94118, Indonesia

Sulaiman Mamar
Department of Anthropology, Universitas Tadulako, Kampus Bumi Tondo, Palu 94118, Indonesia

Rainer Marggraf
Environmental and Resource Economics, Department of Agricultural Economics and Rural Development, University of Göttingen, Platz der Göttinger Sieben 7, D-37073 Göttingen, Germany

Arisbe Mendoza-Escalante
Center for Development Research (ZEF), University of Bonn, Walter-Flex-Str. 3, 53113 Bonn, Germany

Johannes Merklein
Institute of Bioclimatology, University of Göttingen, Büsgenweg 2, Göttingen, Germany

Sonja Migge-Kleian
Ecology Group, Institute of Zoology, University of Göttingen, Berliner Strasse 28, 37073 Göttingen, Germany

Roland Olschewski
Institute of Forest Economics, University of Göttingen, Büsgenweg 5, D-37077 Göttingen, Germany

Alexander Oltchev
Institute of Bioclimatology, University of Göttingen, Büsgenweg 2, Göttingen, Germany and A.N.Severtsov Institute of Ecology and Evolution of the Russiona Acadamy of Sciences (RAS), 33 Leninskiy Prosp., Moscow 119071, Russia

Elise Pendall
Department of Botany, 1000 E. University Ave., University of Wyoming, Laramie, WY 82071, USA

Ivette Perfecto
School of Natural Resources and Environment, Dana Building, University of Michigan, 440 Church St. Ann Arbor, MI 48109, USA

Stacy M. Philpott
Smithsonian Migratory Bird Center, National Zoological Park, 3001 Connecticut Avenue NW, Washington, DC 20008, USA

Ramadhanil Pitopang
Department of Forest Managament and Herbarium Celebense, Tadulako University, Palu, Indonesia

Catherine Potvin
Department of Biology, McGill University, 1205 Docteur Penfield, Montreal, Quebec H3A 1B1, Canada

Golam Rakkibu
Institute of Bioclimatology, University of Göttingen, Büsgenweg 2, Göttingen, Germany

Abdul Rauf
Tadulaku University (UNTAD), Kampus Bumi Tadulako Tondo, Palu - 94118, Indonesia

Mark-Oliver Rödel
Department of Animal Ecology and Tropical Biology, Biocenter University of Würzburg, Am Hubland 97074 Würzburg, Germany

Thomas Ross
Institute of Bioclimatology, University of Göttingen, Büsgenweg 2, Göttingen, Germany

Shahabuddin Saleh
Faculty of Agriculture, University of Tadulako, Kampus Bumi Tadulako Tondo, Palu-Indonesia

Klas Sander
Forest Economist, Environment Department, The World Bank, 1818 H Street NW, Washington DC, USA

Matthias Schaefer
Ecology Group, Institute of Zoology, University of Göttingen, Berliner Strasse 28, 37073 Göttingen, Germany

Björn Schippers
Department of Cultural and Social Geography, Institute of Geography, University of Göttingen, Goldschmidtstr. 5, D-37077 Göttingen, Germany

Wenke Schulz
Ecology Group, Institute of Zoology, University of Göttingen, Berliner Strasse 28, 37073 Göttingen, Germany

Christian H. Schulze
Department of Population Ecology, University of Vienna, Althanstrasse 14, 1090 Vienna, Austria

Stefan Schwarze
Institute of Rural Development, University of Göttingen, Waldweg 26, D-37073 Göttingen, Germany

Luitgard Schwendenmann
Tropical Silviculture, Institute of Silviculture, University of Göttingen, Büsgenweg 1, 37077 Göttingen, Germany

M.T. Felix Sitorus
Department of Communication and Community Development, Faculty of Human Ecology, Bogor Agricultural University, Indonesia

Lorena Soto-Pinto
El Colegio de la Frontera Sur, Unidad San Cristóbal, Carretera Panamericana y Periférico Sur, Apartado Postal 63. C.P. 29290, San Cristóbal de las Casas, Chiapas, México

Ingolf Steffan-Dewenter
Agroecology, University of Göttingen, Waldweg 26, D-37073 Göttingen, Germany

Andrea Steingrebe
Ecology Group, Institute of Zoology, University of Göttingen, Berliner Strasse 28, 37073 Göttingen, Germany

Leti Sundawati
Laboratory for Social Forestry, Faculty of Forestry, Institute Pertanian Bogor, Bogor, Indonesia

Endriatmo Sutarto
Department of Agricultural Socio-Economic Sciences, Institut Pertanian Bogor, Jl. Raya Pajajaran, Bogor 16143, Indonesia

Raquel Thomas
Iwokrama International Centre for Rain Forest Conservation and Development, 77 High Street, Kingston, Georgetown, Guyana

Teja Tscharntke
Agroecology, University of Göttingen, Waldweg 26, D-37073 Göttingen, Germany

André Twele
Institute of Geography, Department of Cartography, GIS and Remote Sensing, University of Göttingen, Goldschmidtstr. 5, 37077 Göttingen, Germany

Adhitya Wardhono
Institute of Rural Development, University of Göttingen, Waldweg 26, D-37073 Göttingen, Germany

Robert Weber
Department of Cultural and Social Geography, Institute of Geography, University of Göttingen, Goldschmidtstr. 5, D-37077 Göttingen, Germany

Plant diversity in homegardens in a socio-economic and agro-ecological context

Katja Kehlenbeck[1*], Hadi Susilo Arifin[2], and Brigitte L. Maass[1]

[1] Department of Crop Sciences: Tropical Crops, Georg-August-University, Grisebachstr. 6, D-37077 Göttingen, Germany
[2] Department of Landscape Architecture, Faculty of Agriculture, IPB, Bogor, Indonesia

*corresponding author: Katja Kehlenbeck, phone +49-(0)511-393750, Email: katja_kehlenbeck@yahoo.de

Summary

Homegardens are generally regarded as a very complex, species-rich agroforestry system managed in a sustainable manner over decades or even centuries. In many densely populated tropical regions, homegardens appear to be the last forest-like islands surrounded by increasingly extended, uniform staple crop fields. With their multi-layered vegetation structure, homegardens serve as an important habitat for wild flora and fauna in these areas. They fulfil not only important ecological, but also many social and cultural functions. However, the major purposes of homegardens are subsistence production and income generation, particularly in rural areas. At forest margins, high production levels in homegardens might help to reduce deforestation. Furthermore, homegardens should be considered as a model for sustainable agroforestry systems, integrating both economic and ecological advantages. Plant diversity, as a basis for homegarden productivity and sustainability, is influenced by a combination of agro-ecological as well as socio-economic factors. The complex interactions of all these factors are not yet fully understood. This paper presents an overview of the existing knowledge and identifies gaps regarding the factors determining plant species diversity and composition in homegardens. We further illustrate this with two case studies from Indonesia (Central Sulawesi and West Java), in which temporal and spatial variations were investigated. In conclusion, plant diversity was mainly influenced by elevation as well as commercialisation, urbanisation, and fragmentation. It was fairly dynamic over time, particularly, when commercialisation was possible. To preserve the sustainability of homegardens and their suitability for *in situ*

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conservation of plant genetic resources, any promotion to intensify production in homegardens should consider the overall ecological functioning of the system in a landscape context.

Keywords: agro-biodiversity, agro-ecosystem, agroforestry, commercialisation, function, homegarden, ***in situ*** conservation, plant diversity, plant genetic resources, species composition, sustainability, urbanisation, vegetation structure, vegetation dynamics

1 Introduction

Homegardens are one of the most complex and diverse agricultural systems worldwide. As their appearance is highly variable, there are several definitions of this system. Homegardens are mostly defined as a piece of land surrounding a homestead that is cultivated with a diverse mixture of perennial and annual plant species arranged in a multi-layered vertical structure, often in combination with raising livestock (Christanty 1990, Kumar and Nair 2004, Soemarwoto 1987). Homegarden systems have existed for millennia (Kumar and Nair 2004, Soemarwoto and Conway 1992) in many tropical regions, where they played an important role towards the development of early agriculture and domestication of crops and fruit trees (Miller and Nair 2005). Individual homegardens have been continuously cultivated for many decades and even centuries, for example, in Sri Lanka (Hochegger 1998). For this reason, homegardens are generally regarded as sustainable production systems (Christanty 1990, Kumar and Nair 2004, Landauer and Brazil 1990, Soemarwoto and Conway 1992, Torquebiau 1992). However, quantitative support for this statement is rare, as most of the published homegarden studies are rather descriptive. In addition, no long-term quantitative study of the same homegarden has been reported. This might be due to the difficulties in measuring sustainability *per se*, resulting in an indirect assessment by using more or less widely accepted sustainability indicators (Kumar and Nair 2004). Torquebiau (1992) and Huxley (1999) suggested several sustainability indicators related to the resource base (e.g., soil, climate, biodiversity), the system's functioning (e.g., management, outputs), and the impact of homegardens on other systems (e.g., forests, wildlife). Kumar and Nair (2004) present extensive data of several recent homegarden studies that mainly describe soil-related and socio-economic aspects of sustainability. Biodiversity, particularly plant species diversity, is the aspect probably most frequently assessed in homegarden research. Numerous publications described plant species and their uses in homegardens worldwide, e.g., in Indonesia (Abdoellah et al. 2002, Arifin et al. 1998, Kehlenbeck and Maass 2004, Soemarwoto 1987), Vietnam (Trinh et al. 2003), India (Peyre et al. 2005), Sri Lanka (Hochegger 1998), Ethiopia (Tesfaye Abebe 2005), Ghana (Bennett-Lartey et al. 2002), Tanzania (Hemp 2005), Mexico (Vogl et al. 2002), Brazil (Albuquerque et al. 2005), Peru (Coomes and Ban 2004), and

Cuba (Castiñeiras et al. 2002, Wezel and Bender 2003). Because of their large crop species and varietal diversity, homegardens are also regarded as an ideal production system for *in situ* conservation of plant genetic resources (Trinh et al. 2003, Watson and Eyzaguirre 2002), crucial for the long-term sustainability of agro-ecosystems. In addition, homegardens can contribute substantially to the conservation of forest tree species, particularly where natural forests have largely been replaced by agricultural fields (Hemp 2005).

In Indonesia and many other tropical regions, the conversion of primary forest to frequently unsustainable agricultural lands has increased dramatically. Forest margins are particularly concerned due to easy access, even in protected areas such as national parks. Sustainable and productive agricultural systems urgently need to be promoted in such agricultural frontier areas to reduce the pressure on further forest conversion. Agroforestry systems like homegardens and forest gardens could serve as a model for such systems because they offer an alternative measure for sustainable use of natural resources. However, neither the functioning nor the potential of homegardens have been sufficiently studied. Research is needed, particularly, concerning nutrient and water balances, carbon sequestration, the value of non-conventional products and services, system productivity, and sustainability, including temporal changes (Kumar and Nair 2004). Especially, changes of plant diversity and its driving factors need to be emphasised. This paper presents firstly an overview of the existing knowledge on roles and functioning of homegardens. Factors determining plant species diversity and composition in homegardens are discussed in more detail. Secondly, we illustrate the complex influence of certain agro-ecological and socio-economic factors on plant diversity with two case studies from Indonesia (Central Sulawesi and West Java), in which temporal and spatial variations were investigated.

2 State of the art in homegarden research

2.1 The multiple roles of tropical homegardens

The basic function of homegardens, especially in rural areas, is subsistence production (Figure 1) (Kumar and Nair 2004, Soemarwoto and Conway 1992). Because of the high plant species diversity existing in homegardens, a wide spectrum of multiple-use products can be generated with relatively low labour, cash or other external inputs (Christanty 1990, Hochegger 1998, Soemarwoto and Conway 1992). Homegardens generally serve as a complement to staple crop fields by producing mainly fruits, vegetables, spices, and many non-food products (Figure 1) (Albuquerque et al. 2005, Karyono 1990, Kehlenbeck and Maass 2004, Kumar and Nair 2004, Michon and Mary 1994, Peyre et al. 2005). However, in densely populated or heavily degraded areas without sufficient staple crop fields, homegardens may also provide large portions of staple food (Soemarwoto and Conway 1992, Tesfaye Abebe 2005). Homegarden products, including those from animals reared in the gardens, have a rather high nutritional value in terms of protein, minerals, and vitamins (Soemarwoto and Conway 1992). As these diverse products are available year-round, homegardens also contribute to food security in times or seasons of scarcity (Christanty 1990, Karyono 1990). Therefore, the importance of homegardens for countering malnutrition and food insecurity has attracted increasing attention (Kumar and Nair 2004). This, for example, has resulted in several manuals for the promotion of growing vegetables in tropical homegardens, as compiled by Helen Keller International (2004).

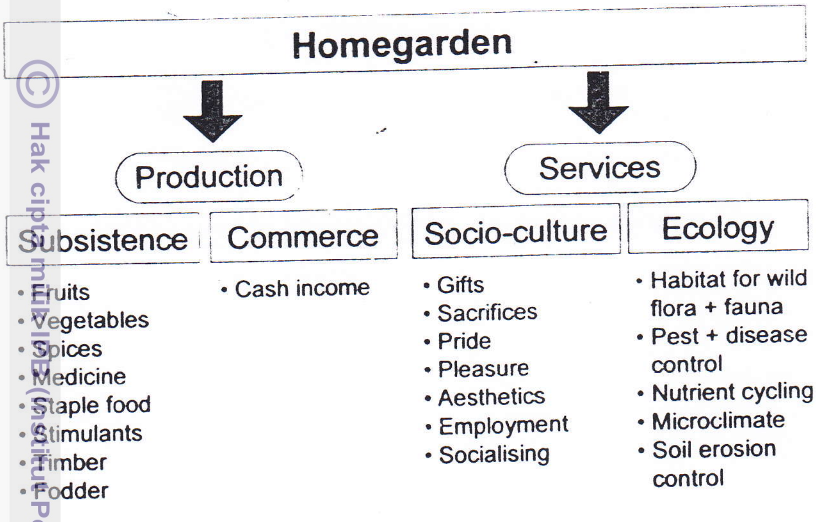

Fig. 1. Main functions of homegardens and selected products/outputs.

The second important function of homegardens is the generation of cash income, particularly in regions with good market access (Figure 1) (Christanty et al. 1986, Michon and Mary 1994, Tesfaye Abebe 2005, Trinh et al. 2003). Most of the income is said to be derived from perennials such as fruit trees, cacao, and coffee, but in peri-urban areas or tourist centres, also vegetables and ornamentals are frequently grown as cash crops (Abdoellah et al. 2002, Soemarwoto and Conway 1992). The portion of income from a homegarden may vary from only 1–7% (Arifin et al. 2005) to more than 50% of the household's total income (Trinh et al. 2003), depending on market access, among other factors.

In addition to the production, homegardens have important social and cultural functions (Abdoellah et al. 2002, Christanty 1990, Soemarwoto and Conway 1992). They are mostly 'open' for everyone, thus, providing a place for children to play and for the neighbourhood to meet and chat. The exchange of homegarden products and planting material is common in many traditional societies. Homegardens also serve as status symbol and the aesthetic purpose partly outweigh the productive function, especially in urban areas and better-off households (Arifin et al. 1998, Karyono 1990). Some plant species in homegardens are believed to have a magical value (Abdoellah et al. 2002), others are necessary for religious ceremonies, e.g., Hindu Balinese families need their homegardens as source and place for making sacrifices (Arifin et al. 2002, Kehlenbeck unpublished).

Homegardens also fulfil ecological functions (Figure 1), particularly in landscapes where large, monotonous, and monofunctional agricultural fields dominate (Christanty 1990). The multi-layered vegetation structure of homegardens is said to resemble natural forests and offers a habitat for a diverse community of wild plants and animals (Albuquerque et al. 2005, Hemp 2005, Karyono 1990, Michon and Mary 1994). This structure appears to contribute substantially to the sustainability of homegarden systems.

2.2 Biodiversity as a sustainability indicator

The multi-layered vegetation structure in homegardens, created by the wide spectrum of cultivated and wild plants, appears to be responsible for many other benefits/advantages of this system. The contribution of (agro-) biodiversity to (agro-)ecosystem functioning and sustainable production is more and more recognised both for man-made and natural systems (Atta-Krah et al. 2004, Clergue et al. 2005, Main 1999, Schwartz et al. 2000). On the one hand, intra-specific diversity is not only a key source for breeding, but also important for sustainability because it enables individual species to adapt to a changing environment and, therefore, ensures their long-term survival (Atta-Krah et al. 2004, Main 1999). Inter-specific diversity, on the other hand, leads to important synergistic ecological processes and enables ecosystem functioning. This refers to efficient, complementary resource utilisation, efficient nutrient recycling, and a low risk of soil erosion (Clergue et al. 2005, Main 1999, Kumar and Nair 2004, Soemarwoto and Conway 1992, Torquebiau 1992, Wiersum 2004).

In addition to ecological aspects of sustainability, biodiversity also contributes to socio-economic sustainability of agro-ecosystems. Productivity of a species-rich agro-ecosystem is generally rather high and stable because the multi-species system forms a buffer against biotic (pests and diseases) and abiotic (storms and droughts) stress (Atta-Krah et al. 2004, Clergue et al. 2005, Wiersum 2004). Recent studies demonstrated the importance and monetary value of plant diversity for pollination services and pest control in agroforestry systems (Bos et al., this volume, Olschewski et al., this volume). A diverse, multi-species production system reduces the risk of total crop failure and provides year-round available products of high nutritional value. Thus, plant diversity contributes to sustainability in the aspect of household food security (Atta-Krah et al. 2004, Huxley 1999, Kumar and Nair 2004, Main 1999).

Wiersum (2004) stressed a further potential of multi-species agroforestry systems towards sustainability: a diverse range of useful plant species in a system enables its effective adjustment to changing socio-economic conditions and demands of future generations. Nevertheless, the suitability of biodiversity as an indicator to assess sustainability might be critically examined because there is no threshold value for an ideal number of species in a sustainable system (Main 1999). Biodiversity also seems to be highly variable over time, while homegarden research has so far neglected to quantify such changes.

2.3 Factors influencing plant diversity in homegardens

Garden diversity varies depending on a combination of external and intrinsic factors that are related to garden features, agro-ecology, and sócio-economy (Christanty et al. 1986, Hodel et al. 1999). However, plant diversity is not only influenced by clearly idenfifiable single factors but rather by a complex interaction between several of them. This interaction is not yet understood, and additional intrinsic factors, like individual preferences and practices of the gardener, may even play an overriding role for the composition and level of plant diversity (Abdoellah et al. 2002, Castiñeiras et al. 2002, Hodel et al. 1999). In addition, these factors may vary in their relative importance over time and, thus, affect plant diversity (Figure 2). A better understanding of these interrelationships and the processes leading to them would help to assess the sustainability of the system as well as its suitability for *in situ* conservation of plant genetic resources. How selected factors influence plant diversity in homegardens is presented below in more detail.

Agro-ecological factors

Agro-ecological factors such as elevation, climate, or soil fertility might limit plant diversity in homegardens (Figure 3). Many homegarden studies have highlighted the effect of elevation on plant diversity, which, in terms of species richness, generally decreases with increasing elevation (0–1000 m) due to decreasing mean temperature (Hodel et al. 1999, Karyono 1990). Tesfaye Abebe (2005) also reported lower diversity indices in higher elevations (1500–2000 m). Less fruit tree species, but more vegetables and medicinal plant species were cultivated in homegardens of higher elevations (Castiñeiras et al. 2002, Shrestha et al. 2002, Soemarwoto and Conway 1992). However, research results of Quiroz et al. (2002) in Venezuela suggested that the highest diversity is found in homegardens of intermediate elevation (600–1300 m), where gardeners have the opportunity to cultivate both tropical and subtropical useful plants.

Not only temperature, but also precipitation influences plant diversity. Homegardens in West Java harboured higher plant diversity in the wet than in the dry season (Soemarwoto and Conway 1992). Plant diversity of Ghanaian homegardens was higher in the humid forest ecozones than in the hot and

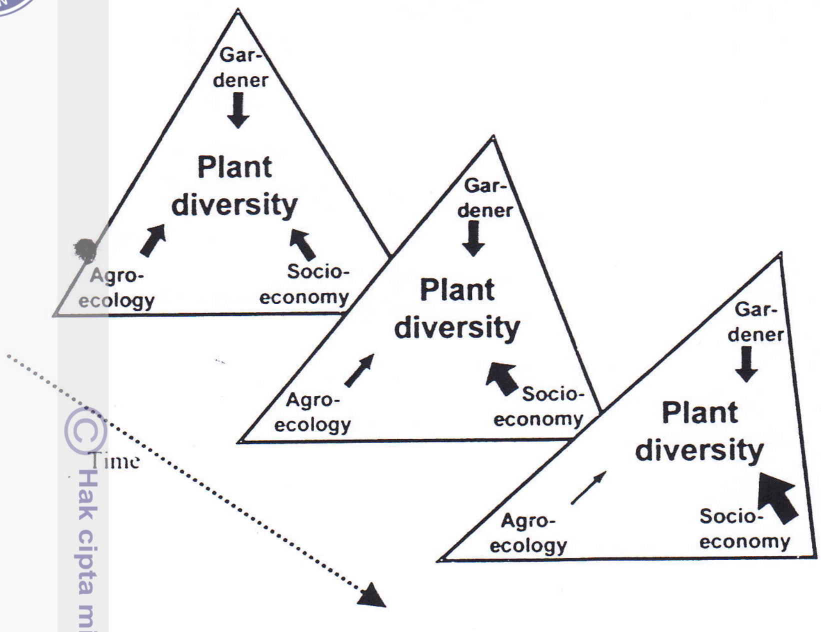

Fig. 2. Schematic illustration of the relative importance of different factors on plant diversity in homegardens and their temporal changes. Here, the importance of socio-economic factors (e.g., commercialisation) increases over time, while that of agro-ecological characteristics (e.g., infertile soil) decreases, for example due to the use of industrial fertiliser.

dry savanna zones (Bennett-Lartey et al. 2002). In contrast, Cuban homegardens harboured higher diversity under semiarid conditions as compared to humid conditions, caused though by irrigation (Wezel and Bender 2003). However, variation in plant diversity might occur also due to small-scale climatic variation, like droughts caused, for example, by El Niño events (Figure 3).

Soil fertility is another agro-ecological factor that generates variation of plant diversity, but its influence has not yet been studied in detail. Hodel et al. (1999) simply assumed an influence of soil factors on diversity without quantifying this. In forest gardens, Kaya et al. (2002) reported lower species diversity on marginal soils compared to more fertile soils. Many cultivated plant species, particularly vegetables and spices, do not give adequate yield under unfavourable soil conditions such as low pH value or P content. Therefore, gardeners might stop cultivating these species while switching to a reduced set of crops that can cope with low soil fertility.

Garden features

Within the major factors influencing plant diversity, garden size is one of those frequently analysed. Among others, Abdoellah et al. (2002), Hodel et al. (1999), and Quiroz et al. (2002) reported a positive relationship between garden size and plant species richness. In small homegardens, particularly tree species richness decreased, resulting in a poor vertical vegetation structure. However, diversity indices such as the Shannon index decreased with increasing garden size, probably due to more uniform planting patterns and dominance of a few species in large gardens (Peyre et al. 2005). Homegarden age is thought to influence plant species richness positively (Coomes and Ban 2004, Quiroz et al. 2002). After setting up a new homegarden, gardeners start planting with a rather small set of crops. Over time, more and more species may be introduced by gardeners or resprout from the former vegetation, while established, reliable species remain (Figure 3). However, Hodel et al. (1999) did not find any relationship between plant diversity and garden age when surveying homegardens of Vietnam.

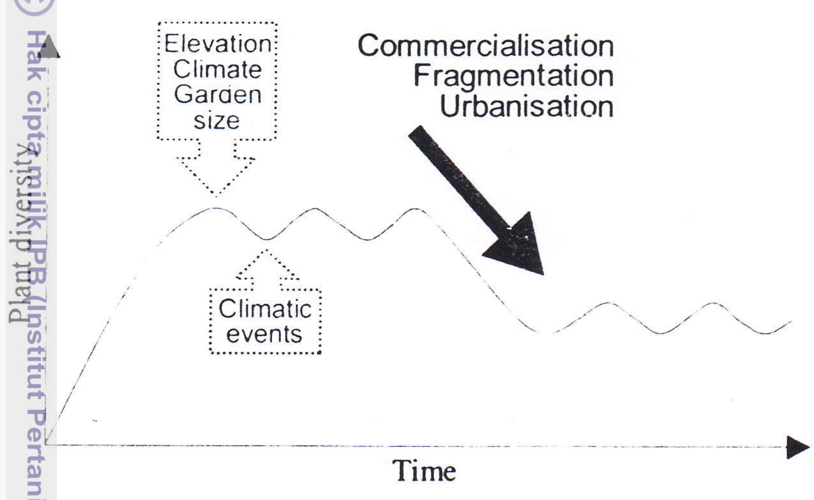

Fig. 3. Schematic development of plant diversity (except ornamentals) in homegardens over time under the influence of changing socio-economic conditions. Agro-ecological factors (e.g., elevation) may limit plant diversity, while short-term/small-scale climatic events might cause a certain fluctuation.

Socio-economic factors

Among socio-economic factors, the negative influence of market proximity and market-oriented production on plant diversity in homegardens has frequently been recorded (Figure 3) (Abdoellah et al. 2002, Christanty 1990, Michon and Mary 1994, Quiroz et al. 2002, Shrestha et al. 2002, Soemarwoto and Conway 1992, Tesfaye Abebe 2005). In remote areas, traditional subsistence homegardens provide the owner families with a wide spectrum of products to meet their daily needs, thus, resulting in a high plant diversity. Good market access, on the other hand, might push gardeners from subsistence to semi-commercial or commercial production. Peyre et al. (2005) and Shrestha et al. (2002) argued that cultivation of cash crops, particularly of annual vegetables, leads to decreasing numbers of perennials such as fruit and timber trees. Therefore, commercial homegardens often lack the upper vegetation strata. The focus of development agencies on improving nutrition and income through the promotion of mostly exotic, annual vegetables, might lead to such negative effects (Shrestha et al. 2002). But also a slightly positive relationship of plant species richness and the amount of cash income generated in the homegarden is reported (Hodel et al. 1999, Quiroz et al. 2002, Trinh et al. 2003). This effect was explained by higher labour investment in the commercial homegardens, from which also subsistence crops could profit. Possibly, a well-balanced mix of subsistence and cash crop production might lead to higher plant diversity.

Besides commercialisation, the scarcity of land generally also reduces the biodiversity in homegardens. Families with insufficient staple crop fields are forced to grow high proportions of staples in their homegardens (Soemarwoto and Conway 1992). As many staple food crops are light-demanding, perennials like fruit or timber trees disappear from such homegardens (Karyono 1990). Urbanisation is also said to reduce plant species diversity (Hodel et al. 1999, Karyono 1990, Michon and Mary 1994). In peri-urban regions with good access to large markets in the city, many traditional homegardens are converted into commercial fruit tree or vegetable gardens, thereby losing most of the less productive subsistence plants. At the highest urbanisation level, homegardens are generally rather small and dominated by ornamentals, giving priority to the aesthetic function instead of subsistence production.

Gardeners' characteristics

Certain characteristics of the gardener and his/her household are known to influence plant diversity in homegardens. A gardener's age can influence plant diversity positively (Quiroz et al. 2002), possibly because, over the years, gardeners try to cultivate new crops while they continue to plant well-tried species. In addition, older gardeners often have more time for homegardening and are supported by their grown-up children. Consequently, higher time allocation to homegardening leads to higher plant diversity (Hodel et al. 1999, Quiroz et al. 2002). Therefore, also large households with large labour force generally maintain a higher species richness in their homegardens as compared to small, labour force-constrained households (Quiroz et al. 2002, Tesfaye Abebe 2005). Farmers as compared to non-farmers might maintain a higher plant diversity in their homegardens due to higher time allocation and experience of the farmers (Arifin et al. 1997).

How formal education or sex of the gardener influence plant diversity in homegardens is still uncertain (Castiñeiras et al. 2002, Hodel et al. 1999, Quiroz et al. 2002). Similarly, the influence of a household's wealth status on plant diversity is debated controversially. Generally, homegardens of well-off households are said to harbour fewer food-producing plant species because such households purchase food and prefer ornamentals (Hodel et al. 1999, Karyono, 1990). In other cases, higher plant diversity found in homegardens of wealthy families was related to larger garden sizes and larger landholdings suitable for staple crop production (Coomes and Ban 2004, Shrestha et al. 2002).

Ethnicity of the gardener may also be a factor explaining variation in plant diversity of homegardens (Hodel et al. 1999, Soemarwoto and Conway 1992). Ethnic and cultural influences are particularly important for plant species composition. Different ethnic groups prefer different plant products and, therefore, cultivate for example more vegetables or more medicinal plants in their homegardens (Christanty et al. 1986, Shrestha et al. 2002, Soemarwoto and Conway 1992, Trinh et al. 2003). Migration can, thus, have a positive effect on plant diversity in homegardens, as long as the plant species brought from the migrants' home regions establish successfully in the new environment. On the other hand, migrants also adopt useful plants from indigenous gardeners. However, plant diversity in migrant homegardens could be rather low due to poverty and discrimination (Hodel et al. 1999), e.g., by assigning land of poor soil quality for settlement to such groups. Besides, shortage of labour for homegarden management and poor access to suitable agricultural land for staple food crops might further decrease plant diversity in migrant homegardens.

In conclusion, no individual factor alone determines the plant diversity found in homegardens, but rather a complex combination of agro-ecological, socio-economic, cultural, and political factors causes spatial and temporal variation of plant species. In the following two sections, this is illustrated by recent results of homegarden research in Sulawesi and Java.

3 Case study 1: Plant diversity in rural homegardens of Central Sulawesi, Indonesia

In association with the collaborative research program STORMA, selected homegardens on the island of Sulawesi were studied, focussing on the dynamics in diversity of cultivated plants over time and the specific influences of selected factors on plant diversity. The study was conducted from 2001 to 2004 in the Napu Valley (elevation about 1100 m), Central Sulawesi, described in more detail by Kehlenbeck and Maass (2004, 2006).

Ten households with homegardens were randomly selected from each of five villages differing in their market access and origin of inhabitants (Table 1). The study included interviews with gardeners, measurement of homegarden size, and complete inventories of useful plants (i.e., excluding ornamentals and weeds). In three villages, homegardens were studied over time (Kehlenbeck and Maass 2006), in two villages only in 2004. Besides plant species number and abundance, also density of plant individuals (no. of individuals/100 m^2), Shannon index (H'), and Sørensen's similarity coefficient were determined

(Magurran 1988). For assessing changes of plant species composition over time, a principal component analysis (PCA) was carried out, based on the mean abundance of cultivated plant species per village in the 30 homegardens revisited.

Table 1. Characteristics of five villages studied in the Napu valley, Central Sulawesi, in 2004.

	Wuasa	Rompo	Wanga	Siliwanga	Tamadue-Trans
Year of foundation	1892	1915	1923	1992	1991
Inhabitants (no.)	2,600	400	350	600	700
Ethnicity	90% locals	90% locals	75% locals	95% migrants	99% migrants
Distance to paved road	0 km	5 km	0 km	0 km	5 km
Market access	Good	Poor	Medium	Medium	Poor

Sources: STORMA survey data (subproject A4 'Economic Analysis of Land Use Systems of Rural Households') and Kehlenbeck (unpublished).

In 2004, homegarden sizes ranged from 250 m^2 to 2,400 m^2 (medians per village are given in Table 2), and they were established 2–40 years ago (median = 11 years). In the 50 homegardens, a combined total of 206 plant species were grown, including about 42 wild species (mainly used as fuel wood/timber, medicine, or vegetable) and many underutilised species (mainly used as vegetable). In addition to the 206 useful plant species, 162 ornamental and 58 weed species were identified in the homegardens.

3.1 Variation of plant diversity over time

Principal Component Analysis based on plant species composition resulted in a clear distinction of the three villages along the ordination axes (Figure 4). Despite temporal changes, villages remain clearly separated in the ordination space. Axis 1 explains about 50% of the total variability and is positively correlated with some staple crops, particularly paddy rice (*Oriza sativa*), cassava (*Manihot esculenta*), and sweet potato (*Ipomoea batatas*). Axis 2, explaining about 20% of the total variability, is negatively correlated with certain traditional vegetable species, such as *Clerodendron minahassae*, eggplant (*Solanum macrocarpon*) and yard-long bean (*Vigna unguiculata*), but positively with the cash crop species groundnut (*Arachis hypogaea*), vanilla (*Vanilla planifolia*), and spring onion (*Allium fistulosum*). Thus, axis 2 can be interpreted as reflecting the continuum from traditional subsistence crops towards modern cash crops.

In Wuasa, homegardens were characterised by a rather small portion of staples, but a high portion of cash crops, recently growing strongly (Figure

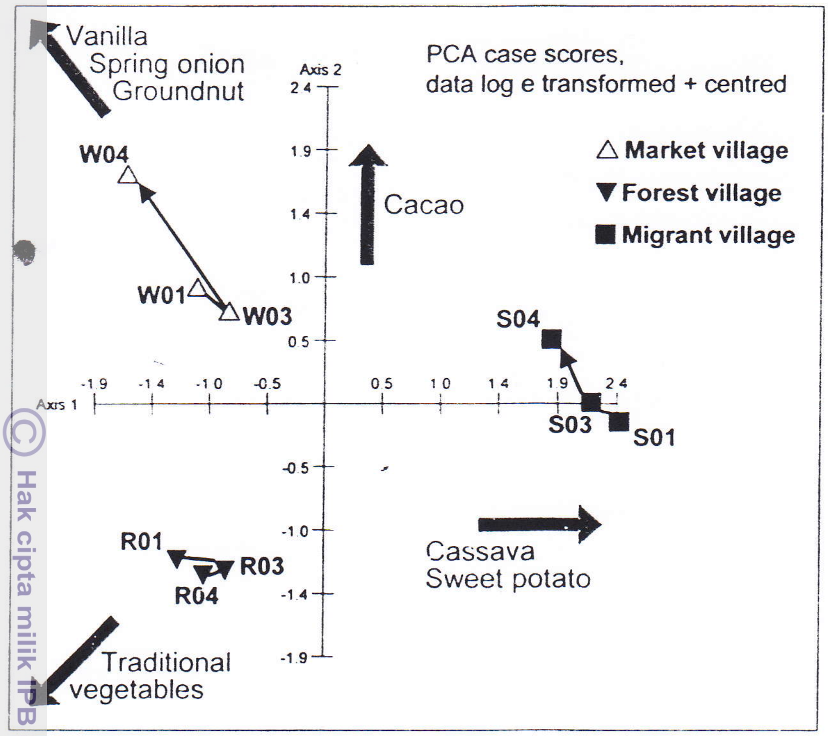

Fig. 4. Changes of plant species composition (except ornamentals) from 2001 to 2004 in 30 homegardens of three villages in the Napu valley, Central Sulawesi. Results of a Principal Component Analysis, based on mean abundance data per village of 196 plant species cultivated in the homegardens surveyed over time; data log e transformed and centred before analysis.

4). This pattern reflects the increasing importance of commercial crops in this particular village with its rather good market access. In Siliwanga, a migrant village with intermediate market access, a similar, but less pronounced trend was found. Its starting position was different from Wuasa, due to a markedly different plant species composition, characterised by the dominance of staple crops in Siliwanga. However, the abundance of these staples had already decreased over the short time span of this investigation. Partly, they were replaced, for example, by the cash crop cacao (*Theobroma cacao*). In the remote village Rompo with rather poor market access, no change towards more cash crops has been detected. Homegardens in this village were still characterised, for example, by traditional vegetables, whereas abundance of cash crops and staples was rather low. Market access, therefore, seems to play a major role towards commercialisation of homegardens. Contrary to findings in the literature, this commercialisation has not yet led to a decrease of the overall relatively high plant species diversity in the homegardens studied (Figure 5).

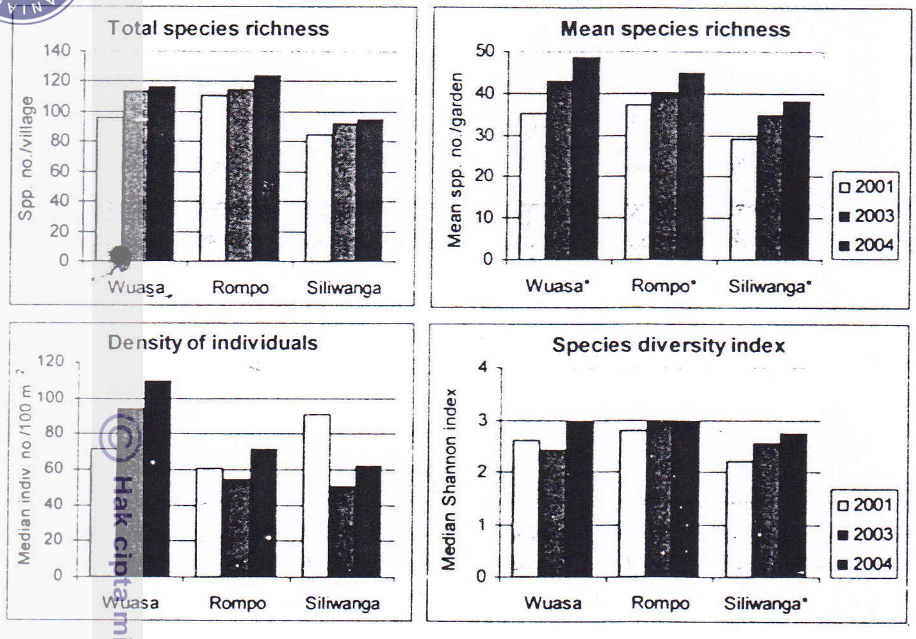

Fig. 5. Diversity parameters of plant species (except ornamentals) of 30 homegardens in three villages of the Napu valley, Central Sulawesi, from 2001 to 2004. (In villages followed by an asterisk, changes of the respective variable over time were significant at $P \leq 0.05$ by Friedman test).

Plant species richness in the homegardens revisited even increased markedly over time both per village and per garden (Figure 5). In the three villages, a combined total of 152, 171, and 178 useful plant species were identified in 2001, 2003, and 2004, respectively. Mean density of plant individuals increased over time only in the market village. Changes in Shannon diversity index were not clear except in the migrant village Siliwanga, where the index increased significantly. In the latter village, however, plant species richness and Shannon index continued to be markedly lower than in the two local villages.

3.2 Spatial differences of plant diversity

When comparing homegardens in all five research villages, marked differences in their plant diversity became apparent. In homegardens of the two migrant villages, Siliwanga and Tamadue-Trans, diversity parameters were mostly lower than in those of the three local villages that did not differ significantly from each other (Table 2). In addition to diversity parameters, plant species composition was clearly different between the five villages studied in 2004. Sørensen's coefficient showed a higher similarity between the three local

Table 2. Median size, mean plant species (except ornamentals) richness, median density of plant individuals, as well as median Shannon diversity index (ranges in brackets) of 48 homegardens in five villages of the Napu valley, Central Sulawesi, in 2004.

	Median HG size (m^2)	Mean plant species number		Median no. of plant individuals/100 m^2		Median Shannon index H'	
Wuasa (local)	740	48.5a	(23–68)	69.0a	(29–394)	3.0ab	(1.5–3.5)
Rompo (local)	660	44.9ab	(28–65)	74.5a	(39–96)	3.0a	(2.4–3.3)
Wanga (local)	600	38.1ab	(13–56)	37.0ab	(20–117)	3.1ab	(1.5–3.3)
Siliwanga (migrant)	900	35.9ab	(22–44)	42.5ab	(13–110)	2.6ab	(2.3–3.0)
Tamadue (migrant)	2250	33.0b	(22–50)	22.5b	(7–46)	2.3b	(2.1–2.9)

Medians were used, when variables were not normally distributed. Means and medians in a column followed by different letters are significantly different at $P \leq 0.05$ (by Tukey HSD for plant species number; Nemenyi test for density of plant individuals and Shannon index).

villages (0.72–0.76) than between these and the two migrant villages (0.58–0.63) or between the two migrant villages (0.64).

3.3 Identification and discussion of main factors influencing plant diversity in homegardens of Central Sulawesi

The influences of several agro-ecological, garden-based, and socio-economic factors as well as gardeners' characteristics on plant species richness and Shannon diversity index were analysed by multivariate regression analysis, based on data of all 48 homegardens studied in 2004.

Agro-ecological parameters

As elevation and climate were roughly constant throughout the research area, only the influence of the factor 'soil fertility' on plant diversity was investigated in this study. The following soil fertility parameters were tested: sand content, content of C_{total} and plant available P (Bray I), pH value (H_2O), effective cation exchange capacity ($CEC_{eff.}$), and base saturation. Plant species richness was not affected by the tested parameters. C content influenced the Shannon index negatively. This unexpected negative influence of C content (which is comparable to organic matter content) is related to the fact that in the migrant villages with their rather young and large homegardens, the soil had a relatively high C content, but a low P content and pH value. At the same time, plant diversity in many of these homegardens was rather low (Table 2), caused by the dominance of staple food or cash crops in many migrant homegardens (see below).

Garden features

Plant species richness was positively influenced mainly by garden size (Figure 6). Influence of garden age on plant diversity was not detected.

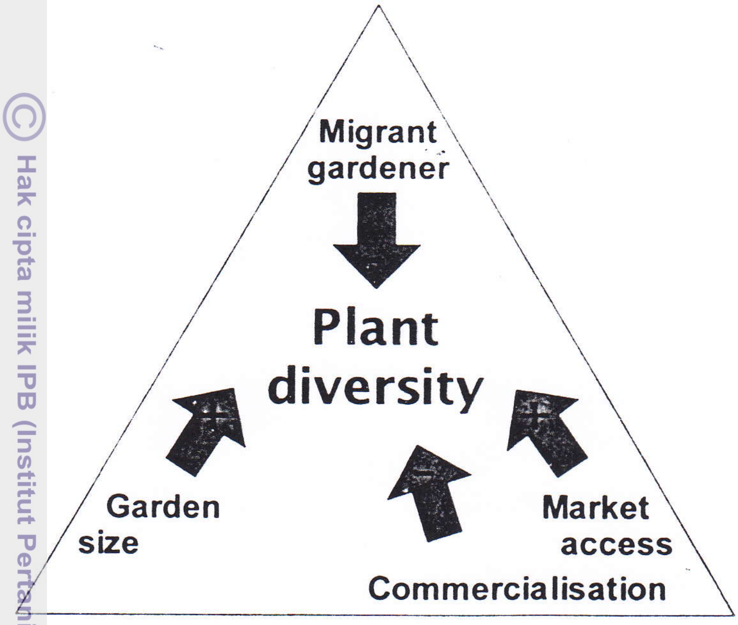

Fig. 6. Schematic diagram how different factors influence diversity of cultivated plants (except ornamentals) in 48 homegardens in five villages of the Napu valley, Central Sulawesi, in 2004.

Socio-economic factors

Generally, a better market access is said to cause a decrease of plant diversity in homegardens. In 2001, this tendency was detected in the study region, where plant species richness and Shannon diversity index were highest in the remote village Rompo (Figure 5). In 2004, however, results showed a positive influence of market access on plant diversity (Figure 6). This could be caused by the activity of a new village development project that promoted medicinal plants in homegardens. In the market village Wuasa, the project was relatively successful, resulting in a conspicuous increase of medicinal plant species richness from 3 (mean in 2001) to about 8 species per garden in 2004. Commercialisation, on the other hand, influenced plant diversity negatively. In homegardens dominated by cash crops like cacao or coffee, plant diversity was markedly lower than in subsistence homegardens.

Gardeners' characteristics

Neither household-related features (e.g., household size or wealth status) nor gardeners' characteristics (e.g., age, sex, level of formal education) played a significant role for plant diversity, apart from the origin of the gardener. In homegardens of migrants, significantly lower plant diversity could be expected than in homegardens of locals (Figure 6). Due to economic constraints after arrival, many migrants in the study area focussed strongly on staple food (in Siliwanga) or cash crop production (in Tamadue) in their homegardens. Plant diversity might increase in the future, when migrant families establish staple crop fields or plantations in the surroundings of their villages. In Siliwanga, such an increase of plant diversity already occurred over time (Figure 5). However, the situation in migrant homegardens of the Napu valley was quite far away from statements in the literature that such homegardens generally harbour higher plant diversity than homegardens of locals.

4 Case study 2: Plant diversity in homegardens of West Java, Indonesia

In West-Java, changes of homegardens' plant diversity were studied along an urban-rural continuum as well as along an elevation gradient. For the investigation of urbanisation effects, the vegetation structure and composition of 115 homegardens in six villages were studied (Arifin et al. 1998). The six villages differed in their urbanisation level. One was a rural village, three were characterised as intermediately urbanised, and two as urban villages, founded in the 1940s, the 1950s, and the 1980/1990s, respectively. In each homegarden, both useful and ornamental plants were inventoried. Overall, homegarden sizes ranged from 30 m^2 to 4000 m^2, with means per village from 70 m^2 to 530 m^2 (Table 3). A combined total of 440 plant species were grown in the 115 homegardens, about half of the species being ornamentals.

For the study of elevational effects on plant diversity, 30 homegardens each were investigated in three villages in the same watershed. The villages were located at different elevations (low: 300 m, intermediate: 950 m, high: 1300 m), and were founded in the 1940s, the 1950s, and the 1960s, respectively. Vegetation composition (both useful and ornamental plants) and structure of homegardens, as well as management patterns were studied in detail.

4.1 Spatial differences of plant diversity

Rural–urban continuum

Plant species number varied largely among the 115 homegardens studied (Table 3). Mean species number per homegarden did not differ markedly between the rural, the intermediate, or the urban homegardens. However, urban gardens harboured a markedly higher number of ornamental plant species per homegarden than rural gardens. In addition, the proportions of both ornamental species and individuals increased with a higher level of urbanisation (rural: 40% of total species and 47% of total individuals were ornamentals; urban: 70% of total species and > 80% of total individuals were ornamentals). Homegarden size decreased continuously from rural to urban sites (Table 3). Vertical vegetation structure decreased in complexity from rural to urban. Consequently, urban homegardens mostly lacked the strata above 5 m, and strata above 2 m were represented by only few individuals.

Table 3. Mean size and mean diversity characteristics of useful and ornamental plant species (range in brackets) of 115 homegardens studied in six villages with different urbanisation levels in Cianjur and Bogor, West Java, in 1995.

Village urbanisation level		HG size (m^2)	Total plant spp. no. per HG	No. of ornamental spp. /HG	No. of total plant individuals per 100 m^2	No. of ornamental individuals per 100 m^2
Rural	(N = 30)	530	36 (6–82)	14	63	29
Intermediate 1	(N = 21)	380	49 (32–79)	25	72	40
Intermediate 2	(N = 10)	190	32 (7–85)	14	107	59
Intermediate 3	(N = 20)	130	20 (2–53)	11	58	34
Urban 1	(N = 10)	70	34 (18–63)	24	280	233
Urban 2	(N = 24)	90	37 (16–78)	26	240	201

Rural homegardens were distinguished from the urban ones by their dominant function in subsistence production, expressed by the rather high number and abundance of useful plants, particularly fruit trees, vegetables, and staple crops. In urban homegardens with their representative, aesthetic function, plant diversity was composed mainly of ornamentals.

Elevation gradient

Plant species richness in homegardens decreased continuously from low to high elevations (Table 4). In the intermediate and high elevations, homegardens were markedly smaller than in the lowlands. Despite their rather small size, homegardens of intermediate elevation harboured much more plant individuals than homegardens in the high- or lowlands. Density of individuals was markedly lower in homegardens of the lowlands than in higher elevations. However, the highest density was found in homegardens of intermediate altitude. Plant species composition was different along the elevation gradient. Homegardens in the lowlands were dominated by perennial fruit trees, and in the highlands by vegetables.

Table 4. Mean size and mean diversity characteristics of useful and ornamental plant species (range in brackets) of 90 homegardens studied in three villages of different elevation in Cianjur watershed, West Java, in 2000.

Village elevation level	HG size (m^2)	Total plant spp. no. per HG	No. of total plant individuals per HG	No. of total plant individuals/ 100 m^2
High (1300 m; N = 30)	190	27 (14–36)	280 (107–670)	150
Intermediate (950 m; N = 30)	220	40 (27–64)	490 (225–771)	220
Low (300 m; N = 30)	560	44 (26–74)	350 (182–867)	60

4.2 Discussion of main factors influencing plant diversity of homegardens in Java

Agro-ecological parameters

Elevation negatively influenced plant species richness in homegardens. However, the lower plant diversity in highland homegardens might also be caused by their relatively smaller size as compared to the lowland ones. This positive relationship between homegarden size and plant species richness is well documented in the literature (Section 2.3). The statement by Quiroz et al. (2002) that the highest plant diversity is found in the homegardens of intermediate elevations (i.e., 600–1300 m) is only partly confirmed by this study. Although density of plant individuals was highest in homegardens of intermediate elevation, species richness was not.

Socio-economic factors

Urbanisation affected the richness and abundance of useful plant species negatively, but those of ornamentals positively. As in the elevation gradient, these results might be confounded with the decrease of homegarden size along the rural-urban continuum. However, the shift in plant species composition from useful plants to more ornamentals due to urbanisation confirms statements by Hodel et al. (1999) and Karyono (1990).

Fragmentation of rural homegardens was also found to change plant diversity in homegardens (Arifin et al. 1997). Where the formerly rather large, rural homegardens were divided into small plots because of the traditional inheritance system, the upper vegetation layers tended to disappear. The proportion of a few cash crops as well as ornamental plants increased in disfavour of many subsistence crops.

5 Common issues for the maintenance of homegardens' plant diversity in Indonesia

Plant diversity in Indonesian homegardens is mainly threatened by commercialisation, fragmentation, and urbanisation. This loss of plant diversity may be accompanied by a disruption of the agro-ecosystem's functioning and, as a consequence, the loss of its sustainability, e.g., due to the interruption of nutrient cycles or the impoverishment of the multi-layered vegetation structure. Maintaining the complex and species-rich, subsistence-oriented character of traditional homegardens should, thus, be promoted. Local knowledge on management and use of the diverse plant community in homegardens should be preserved, enlarged, and spread both within and among regions. If homegarden size falls below a critical minimum of about 100 m^2, plant diversity and structure as well as a garden's production potential suffer strongly (Arifin et al. 1997). Households should, therefore, avoid to divide their homegardens, particularly the back and side yard gardens, where most of the useful plants occurred (Arifin unpublished). However, there is an increasing need for income generation from homegardens. To meet this demand, the efficiency of garden cash crop production could be improved. Many semi-commercial homegardens give only unsatisfactory yields because the gardeners lack specific knowledge of how to manage the cash crop properly. Besides, only cash crops that need few external inputs, but obtain a rather high, stable price and, simultaneously, do not disturb biodiversity, structure, and functioning of homegardens should be promoted, e.g., shade-tolerant, climbing spices such as vanilla (*Vanilla planifolia*) or black pepper (*Piper nigrum*).

6 Conclusions and Outlook

Traditional homegardens may serve as a model for a sustainable agroforestry system. Plant diversity is seen as a major factor towards sustainability and productivity of the system. However, plant diversity in homegardens is very dynamic over time and prone to marked reduction due to a complex interaction of different socio-economic factors, e.g., commercialisation. A holistic research and development approach is needed to meet both the livelihood goal (better nutrition and income of gardeners) and the conservation goal (preserving agro-biodiversity and ecosystem functioning) in homegarden management

(Shrestha et al. 2002). The suitability of homegardens for *in situ* conservation of plant genetic resources should not be taken for granted due to the temporal changes of plant diversity, small population sizes per species, and strong selection pressure by gardeners. Therefore, gardeners should be closely involved in the whole conservation process (Kehlenbeck and Maass 2006). Additionally, not single homegardens, but rather an aggregate of the homegardens of whole villages or regions should be considered as a conservation unit (Trinh et al. 2003).

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TEJA TSCHARNTKE holds a university professorship in agroecology at the University of Goettingen and is editor of the journal Basic and Applied Ecology. His main fields of competence are multitrophic plant-insect interactions, ecosystem services and biodiversity research at local and landscape scales.

CHRISTOPH LEUSCHNER is a university professor of plant ecology at the University of Goettingen. His key expertise is in the ecology of trees and forests in temperate and tropical regions and the vegetation ecology of Central Europe.

MANFRED ZELLER holds the position of professor for rural development policy at the University of Hohenheim. His research focuses on quantitative analysis of rural development policy and its impact on sustainable land use, food security, economic growth and poverty.

EDI GUHARDJA obtained his Ph.D. from the University of Illinois. He holds a university professorship in the Faculty of Mathematics and Natural Sciences at the Pertanian Institute, Bogor. His special fields of competence and interest are biology and plant taxonomy.

ARIFUDDIN BIDIN studied Economics and Development Planning at the University of Trisakti, Jakarta. His major interest is the development of Universities in Indonesia. Recently, he became a senior lecturer at the Faculty of Economy and vice rector of the Tadulako University in Palu (Central Sulawesi), with the added responsibility for international cooperation.

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