PERSEVERANCE IN THE FACE OF CHANGE

RESILIENCE ASSESSMENT OF BALINESE IRRIGATED RICE CULTIVATION

BY

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In memory of
my sister-in-law, Christina Lorenzen,
and my grandmother, Rosina Anna Spühler.

DECLARATION

I, *Rachel P Lorenzen*, declare that this thesis, submitted in fulfilment of the requirement for the award of Doctor of Philosophy, in Resource Management in Asia Pacific Program, Crawford School, College of Asia and the Pacific, the Australian National University, is wholly my own work unless otherwise referenced or acknowledged. This thesis has not been submitted for qualification at any other academic institutions.

R. P. L

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Statement on nature and extent of joint research collaboration:

I have collaborated with Stephan Lorenzen in (1) collecting data in the combined 18 months field research in Bali (July 2004 – December 2005) and (2) the preparatory work before analysis of research data (such as coding of data and adding of data into electronic form). Kay Dancey from ANU Cartography created the detailed maps of the research sites with the support of Stephan Lorenzen, using the data Stephan and I have collected in the field combined with aerial imagery analysis of Google maps, conducted jointly by Kay, Stephan and myself. Karina Pelling from ANU Cartography drew the graphic representations of my conceptual model according to my guidelines, and redrew graphic representations of figures from other sources.

I have made note of this collaboration in my thesis where appropriate.

ABSTRACT

The subak in Bali is a type of farmer-managed canal-irrigated rice cultivation system, which has long been recognised for its efficient water use and high rice productivity. Subaks are firmly embedded in local Hindu culture with institutions that guide farmers in sharing water equitably. Water sharing is based on principles of proportionality and transparency and irrigation system maintenance is egalitarian. In the 1960s, rice production was modernised and commercialised with Green Revolution technologies to feed a rapidly growing population. Some of these new technologies initially caused considerable disruption in raising the productivity of rice and irrigation efficiency. Meanwhile, Bali's formerly agriculture-based economy began to diversify with prospering tourism and other industries. Farmers engaging in part-time farming and multiple occupations off-farm have become the norm. Urban and industrial development increasingly competes for agriculture's resources, such as land, labour and water. This increasing pressure raises questions whether subaks are well-equipped to maintain their productivity and efficient resource management in the long run.

This thesis studies these past and contemporary challenges to subaks. It applies an interdisciplinary approach to analyse the data collected in 18 months of field research in Bali. It defines a conceptual model of the subak based on social-ecological systems and resilience theories to examine the impacts of the Green Revolution and ongoing rural diversification. This thesis demonstrates that the subak as social-ecological system, despite temporary and permanent modifications, has remained resilient to the Green Revolution and ongoing rural diversification. The subak has incorporated new agricultural technologies, allowing farmers more flexibility to pursue diversified livelihoods, and the subak cultural and institutional framework has persisted over time. This thesis discusses three scenarios of possible trajectories the subak may follow depending on how current trends unfold. The analysis shows that subaks in peri-urban areas face different challenges to those subaks in the uplands where resource pressure is less intense and off-farm work further away.

Ultimately, the future survival of subaks lies in the hands of Balinese society, the government and farmers. Pathways to subaks' survival include the recent nomination to the UNESCO world heritage list of three specific subak-related sites or the new agrotourism model promoted by the local university. Alternatively, better educated young Balinese, new marketing opportunities for speciality produce, increased viability of payments for ecosystem services combined with the inherent characteristics of Balinese social organisation may open up new pathways for farmers to continue the subak in ways which are so far unimaginable.

ACRONYMS

ADB	Asian Development Bank
BIP	Bali Irrigation Project
BPS	Badan Pusat Statistik
CGIAR	Consultative Group on International Agricultural Research
DPU	Departemen Pekerjaan Umum
EMR	Extended Metropolitan Region
ETH	Eidgenössische Technische Hochschule (*Swiss Federal Institute of Technology*)
FAO	Food and Agriculture Organisation of the United Nations
FFS	Farmer Field School
GDP	Gross Domestic Product
GRDP	Gross Regional Domestic Product
HYV	High-Yielding Variety (also known as MV)
IFA	International Fertilizer Association
IPM	Integrated Pest Management
IRRI	International Rice Research Institute
K	Potassium
MV	Modern Variety (also known as HYV)
N	Nitrogen
N_2	Atmospheric Nitrogen
NH_3	Ammonium
NO_2	Nitrous Oxide
P	Phosphorus
PES	Paid Ecosystem Services
TV	Traditional Variety
UNCTAD	United Nations Conference on Trade and Development
UNESCO	United Nations Educational, Scientific and Cultural Organization
WUA	Water User Association

GLOSSARY

awig-awig	Customary rule book for subaks. Balinese customary villages (*desa adat*) also have such a rule book
Badan Pusat Statistik	Central Bureau of Statistics
banjar	Traditional Balinese hamlet and part of a village
Bimbingan Massal	Mass Guidance. First Indonesian rice intensification program, implemented 1969–1970
Departemen Pekerjaan Umum	Public Works Department
desa adat	Customary village
Dinas Pendapatan	Provincial Tax Office
Intensifikasi Khusus	Lit. transl. 'Special Intensification'. Third Indonesian intensification program to increase rice production, implemented in 1981
Intensifikasi Massal	Lit. transl. 'Mass Intensification'. Second Indonesian intensification program to increase rice production, implemented in 1972
kebun	Dry-land agriculture, also known in Bali as *tegalan*
kecamatan	Indonesian administrative sub-district including several villages
krama subak	Subak council consisting of all subak members
lomba subak	Government-organised subak competition
mencari air	Lit. transl. 'looking for water', water monitoring activity undertaken by farmers and subak heads alike
munduk	Sub-units of subaks, also known as *tempek* in other regions of Bali

ngapit	Sharecropping arrangement in which the sharecropper pays the landowner a third of his yield and also pays for all the expenditures related to the cultivation such as means of production and hired extra-household labour
padi ampat bulan'	Traditional short-duration variety grown in Bali before the Green Revolution (*ampat bulan* lit. transl. 'four months')
padi injin	Traditional black rice variety used for ceremonial purposes
padi ketan	Traditional glutinous rice variety used for ceremonial purposes
padi taun or padi tahon	Traditional long-duration variety grown in Bali before the Green Revolution (*taun* lit. transl. year, indicates the duration of the cultivation season of one Balinese year which is 210 days)
padi tiga bulan, aka tjitje	Traditional short-duration variety grown in Bali before the Green Revolution (*tiga bulan* lit. transl. 'three month')
palawija	A non-rice crop grown in rotation with two rice crops
Panca Tirta Buwana	Lit. transl. 'Five Water Worlds', name of the subak federation of the wider research context
Pasedahan yeh	Administrative unit consisting of several subaks in a particular geographic area for the main purpose of land tax collection
pekaseh	Subak head
pemaksan	Temple congregation
pemangku	Balinese village or subak priest of commoner cast
pengliman	Head of subak sub-unit (munduk/tempek)
pengoot	Subak water levy, paid as substitute for labour

perumahan	Non-traditional housing estate
pura masceti	Temple dedicated to the protection of the rice crop near the ocean against pests, diseases and other evils
pura ulun danu Bratan	Temple located at the caldera lake Bratan. It is dedicated to the Goddess of the lake who provides water and fertility to the rice fields.
Sad Buwana Tirta	Lit. transl. 'Six Water Worlds', name of the subak federation in the main research site
sedahan agung	Lit. transl. 'grand' sedahan, head of the provincial tax office and head of all sedahans in Bali
sedahan yeh	Public servant who heads a pasedahan yeh
sekaha	Lit. transl. 'to be as one'. Balinese social working groups, formed ad-hoc, informally or formally, to attend to various tasks pertaining to religious or secular matters
subak	Bali's farmer-managed canal-irrigated rice cultivation systems
subak-agung	Lit. transl. 'grand' subak, association of subaks along one river or water catchment
subak-gede	Lit. transl. 'big' subak, federation of several subaks which share a dam
Supra-Intensifikasi Khusus	Lit. transl. 'Super-Special Intensification'. Fourth Indonesian intensification program to increase rice production, implemented in 1986

tebasan	Marketing system introduced into rice production with Green Revolution, in which rice is sold shortly before the harvest to a trader while the crop is still standing in the field.
tegalan	Dry-land agriculture, also known as *kebun*
tenah or tektek	A subak member's defined rights and duties for a share of water from the irrigation system
tirta	Holy water

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CHAPTER 1

INTRODUCTION

STARTING POINT

The beginning of this research may be dated to the time when I undertook field research in East Java as a compulsory part of my agricultural Master's studies at the Swiss Federal Institute of Technology (ETH) in Zurich, Switzerland between 1997 and 1998. I was working with an environmental education centre in East Java and was introduced to irrigated rice cultivation. The farmers in an upland village near the centre struggled with the aftermath of the Green Revolution. Massive pest infestations season after season, irregular water supply to the fields and consequently relatively low yields were a common pattern in this area (Lorenzen 1999: 4). During my stay in Java I had the opportunity to visit a farmers' organisation while attending a workshop in Bali. This visit left a great impression on me, particularly, the way irrigation and rice cultivation was organised. An ingeniously devised and well-maintained irrigation system seemed to deliver sufficient water to every single field, combined with a scheduled planting cycle that resulted in few pest problems and significantly higher yields compared to East Java. In addition, rice production, as it appeared, was perfectly embedded in Balinese culture and Hindu religion. It was then that I knew that one day I would want to learn more about the Balinese farmers' organisation, called *subak*.

For my Master's thesis I examined livelihood strategies of farming communities and ways for sustainable development in a region in the Northern Peruvian Andes.[1] With new market opportunities on the horizon, these communities were shifting their focus from subsistence-based cropping to dairy cattle farming for cash income. Yet with this shift, the pressure on their already scant resource base due to heavy deforestation in the past was further increased. A dynamic systems model of farmers' livelihoods showed that to achieve sustainable development for the region, farmers needed to adapt their land use to reduce erosion, and build on their capacity to preserve their traditional agricultural knowledge and market the milk produced.

While this systemic approach was interesting, I nevertheless felt that an important piece in the analysis was missing: the preparedness of the community for the unexpected. Sustainable development implies continuity, a constant advancement towards sustainability without interruption or disturbance (Berkes et al. 2003a: 2). Nature and life in general, however, is different, characterised by continuous yet dynamic change from sudden catastrophic disasters to slow transformations. These interferences affect communities and their agricultural environment in different ways: some may emerge quite unscathed and adapt to the new circumstances, while others stumble and disappear, having to move on to other livelihoods.

The two experiences in Bali and Peru, the seemingly 'perfect' farming organisation subak and the inconsistencies of the sustainable development concept, informed my initial ideas for this PhD project. When I learnt about Stephen Lansing's detailed research on the subak and how the Green Revolution greatly impacted on this organisation I was even more intrigued to find out how the subak had managed to survive this disturbance and how this farming system appears to thrive in the present day. For the subak must have reorganised

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[1] Sustainable development is defined as a harmonious process of change to meet current and future human needs integrating concerns of economic viability, social equity and ecological integrity (Hediger 1997: 102). Sustainable development in agricultural systems attempts to maintain long-term production amid ecological constraints and socio-economic pressures (Altieri 1995).

and adapted following the impact of the Green Revolution to continue to exist. I discovered an appropriate approach to the study of the subak when I attended a workshop held at the Australian National University in 2004 where Brian Walker presented on the ideas and theories of social-ecological systems and resilience. These theories are based on a sustainable development approach yet integrate aspects of unexpected change, novelty and instability (Holling 2003: xvi). Social-ecological systems theory also acknowledges the integration of humans-in-nature that social and ecological systems are linked (Berkes et al. 2003a: 2–3). This integrative approach fits with what constitutes the subak, for the subak includes both: the organisation of farmers including the rules and regulations as well as the rice fields that are cultivated by these farmers; and the irrigation infrastructure that irrigates the rice fields.

MY THESIS

With this thesis, I aim at answering two questions. My main question focuses around my interest in what the future will bring for the subak. A second question deals with whether the resilience approach is a useful concept to investigate such an institution. This second question will be discussed in the concluding remarks. The thesis is informed by one and half years of extensive field research in Bali where I studied subaks, participated in rice cultivation and village life, and interviewed key persons from government agencies and academic institutions, and farmers in the field.

The subak is a farmer-managed rice production system which deals with matters related to the irrigation and cultivation of rice in Bali, Indonesia. The subak, firmly embedded into local Hindu culture, is a longstanding institution which is famous for its efficient use of natural resource management and its high productivity. Historical and archaeological evidence indicates that both the organisation subak and wet rice cultivation were established at least several centuries ago, sustaining the local people and allowing for interregional trade ever since (Christie 1992; Scarborough et al. 2000; Schoenfelder 2000; 2003; Christie 2004; 2007).[2] Scholars from different disciplines have praised the Balinese subak as one of the most effective hydraulic organisations in the world (Lansing 1991; Spiertz 1991: 190; Ostrom 1992: 10).[3]

Figure 1.1: Rice terraces in Bali – an engineered landscape fine-tuned over centuries

The Green Revolution which began in the 1960s had a considerable impact on the subak. The introduction of modern agricultural technologies to the cultivation of rice changed the way rice was cultivated, causing temporary disruption to the subak's primary function of producing rice in the first few years. Amazingly though, subaks are still in place today. Rice harvests continue to be amongst the highest in Indonesia and the beautifully arranged rice terraces are one of many attractions for an ever-increasing stream of tourists to the island.

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[2] From the first millennium onwards rice became a major staple, not only grown for subsistence but also for domestic trade and export (Christie 2004: 63).

[3] Ostrom (1992: 10) accredits their success mainly to a well-maintained irrigation system, a strong organisational structure and locally adapted rules, while Spiertz (1991: 190–1) emphasises their efficiency in regulating access to irrigation water, and more importantly their sustainable management of natural resources.

Concurrent to the Green Revolution a larger process of rural diversification began, which shifted the focus of the economy gradually away from agriculture to other emerging industries, in particular tourism. As a result of this process, the harvested rice area has started to decrease as a prospering economy and a growing population are competing for the subak's resource base such as land, water and labour. Attractive off-farm employment and a better education draw particularly the younger generations away from farming. Those remaining in agriculture are an aging farming community increasingly faced with insufficient water supply, more work to maintain the irrigation infrastructure at an operational level, as well as attractive prices to sell their land, especially along roads.

My overall argument is that the recent past and current status quo demonstrate that the subak can survive major disruptions and adapt to changes without altering its main purpose and functioning the management of irrigation and cultivation of rice in a highly productive and efficient way. There is, however, a potential future threat of the subak disappearing given the prospect of continued and mounting pressure on the subak's resources. Are there limits to the subak system with respect to the availability of land, water and labour as well as other features? Questions arise about the value and place of the subak, its role in Balinese culture and society, and whether there is a need to preserve the subak.

To discuss my proposition, I divide my thesis roughly into four parts. In the first part, I define a model of the subak and similar rice production systems. There are multiple facets to the subak and other farmer-managed rice production systems which require attention in the analysis, such as the type of environment and infrastructure used for irrigation and cultivation as well as the ways in which rice is irrigated and cultivated. Several scholars have highlighted these multiple aspects and emphasised the need for a comprehensive approach yet most studies on irrigation systems focus on single (discipline) issues (Geertz

1972: 27; Coward 1980: 15–6; Svendsen and Small 1990: 387–8; Uphoff 1996).[4] Using social-ecological systems and resilience theories to define my model allows for a comprehensive analysis, for these theories emphasise an integrative and interdisciplinary approach.

In the second part, I use my developed model to investigate the subak in relation to change (Figure 1.2). What are the impacts of the Green Revolution on the subak? How did the subak manage with the disruptions caused and how did the subak adapt to the changes? What are the impacts of the ongoing diversification of the rural economy on the subak? How does the subak adapt to the changes that occur? Are there any longer-term implications of these changes?

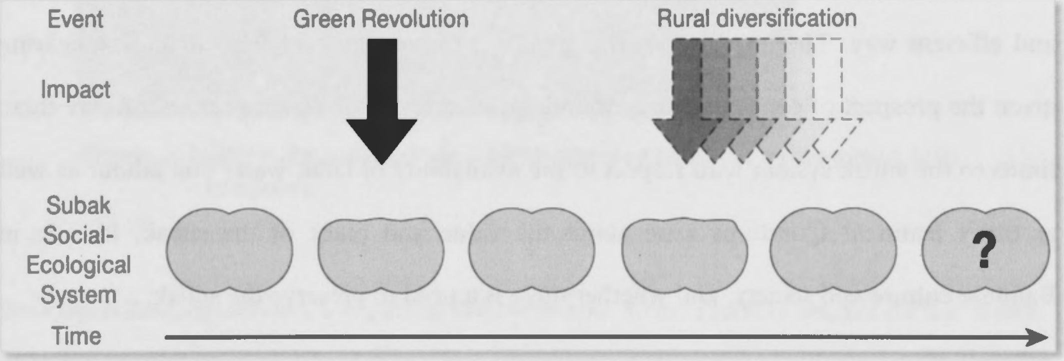

Figure 1.2: Applying the concept of resilience to the development of the subak

In the third part, I focus on the future of the subak. Given present-day pressures on the resource base, what potential trajectories may arise? What other types of farming systems could exist in Bali that are different to the subak? I discuss these questions using three different scenarios of where to the subak may potentially develop in future.

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[4] Bos et al. (2005), for example, drafted guidelines for the assessment of irrigation system performance which serve as basis for performance quality, improvements projects, or comparison of similar systems' performance. Ostrom (1992) concentrates on institutional settings required for successful outcomes of self-governed irrigation systems. 'Canals and Communities' (Mabry 1996) discusses social organisation of historically evolved, locally managed irrigation systems.

The last part of the thesis deals with the applicability of the resilience and social-ecological systems approach to the study of the subak and similar rice production systems. Two workbooks have been developed for scientists and practitioners to assess the resilience of social-ecological systems. Yet real-world applications using field research data are still rare, for social-ecological systems and resilience theories are in their infancy. I conclude with possible next steps to encourage discussion and further studies about the future of the subak.

SOUTHEAST ASIAN IRRIGATED RICE PRODUCTION SYSTEMS

Irrigated rice cultivation developed in the intermontane basins of continental Southeast Asia and volcanic foothills of insular Southeast Asia where water is available in abundance (Tanaka 1991: 568; Barker and Molle 2004b: 1–2) (Figure 1.3). The rugged topography necessitated the development of specially adapted techniques to capture and deliver the water to the plants as well as to keep the water in the fields. Mountain slopes were transformed into terraces following the mountain contours, while controlled stream diversion irrigation systems evolved that used gravity to divert water for the flooding and irrigation of the terraces (Kaida 1991: 578). The building as well as the maintenance of this engineered landscape required the combined effort of groups of farmers fine-tuning the system over centuries (Lansing 2006a: 62; Lansing et al. 2006: 331).

Many of these canal-irrigated rice production systems have a long history of several centuries, and in many areas these systems have been highly productive with several harvests of the same crop year after year (Shivakoti 2000: 2; Gany et al. 2004: 40; Christie 2007: 236). The continuous cultivation of rice is sustained with fertility restored and maintained by the supply of nutrient-rich sediments through the irrigation water and nutrient-releasing biochemical processes which originate from submerging the crop in water (Netting 1993: 3, 42; Bouman et al. 2007: 32).

Figure 1.3: Map of continental and insular Southeast Asia

In larger irrigation systems, the kingdoms would support farmers in the construction and maintenance, while in smaller systems it was often small communities of farmers without or with limited support from a governing agency. Yet even with external construction and maintenance, operational responsibilities remained generally in the hands of farmers (Yoder and Pradhan 2005: 473). Particularly in the more populated regions, such as the Philippines, and Java and Bali in Indonesia, Barker and Molle (2004a: 9; 2004b: 2) argue that autonomous local community irrigation systems developed as the dominant form of organisation because there was greater need for community cooperation to gain access and share water.

The construction and maintenance of such systems requires the investment of considerable time and labour, which farming communities are only willing to contribute if they benefit from it. To commit to long-term productive cooperation these irrigator communities developed rights and responsibilities by means of collective-choice processes for the efficient and equitable allocation and distribution of water to all its members (Mabry 1996: 8; Dayton-Johnson 2003: 328–32; Barker and Molle 2004a: 7). These water allocation rules include work commitment regulations for irrigation system maintenance as well as avenues for conflict resolution in case of rule breaking.

There are various studies of such indigenously devised systems. Siy (1982), for example, studied the *zanjeras* in the Philippines, emphasising their innovativeness, effectiveness and appropriateness. Cohen and Pearson (1998: 88) note that Northern Thailand's traditional communal irrigation systems' autonomy and unity provide an efficient basis for intensive wet season rice production. Neef et al. (2006) observe, in their comparative study of Thai community irrigation systems in Thailand and Vietnam, the strong social cohesion amongst members which provides the basis for stable and equitable irrigation water management. Shivakoti (2000) alludes to the fact that although the socially and culturally embodied norms on which traditional farmer-managed irrigation systems operate vary, they are all based on the same principles of a proportionate ratio of labour and tool contributions to land holding size. Vermillion (1986; 2000) concludes in his study of transmigratory Balinese irrigation systems in North Sulawesi that even though recently established, these irrigator societies have developed effective water allocation without formal or hierarchical control. Coward (1979: 34; 1980: 25) marvels at the 'remarkable congruence' of human organisation, natural environment and physical structures.

Overall, the literature on indigenously devised irrigated rice production systems suggests that although there is great variation in different locations, these systems are highly effective in meeting user demands for irrigation water and ensuring an intact infrastructure. They are well adapted to the local circumstances, both in terms of natural environment and community social structures. They are also incredibly effective, being based on locally devised and culturally embedded rules that portray strong social cohesion among the community members. Often, these systems integrate a ritual component which further reinforces communal solidarity (Shivakoti 2000: 5).

Twentieth Century Challenges

The twentieth century has brought considerable change to many of these communal irrigation systems with the introduction of new technologies to increase rice production for a growing population and increased state intervention for a stronger control and support in meeting these higher demands for rice.[5] Rice production was transformed from a previously mainly subsistence crop into a market commodity in the twentieth century.

In the first half of the twentieth century, production increases were mainly accomplished through improvements of existing irrigation infrastructure and expansion of cultivation areas. In the post-war period the focus shifted to increased land and labour productivity with the introduction of high-yielding varieties, chemical fertilisers and commercial forms of harvesting along with further and larger investments into irrigation. Formerly exclusive rice production systems were not only intensified but often expanded to alternate with other cash crops (or be replaced by these), which allowed for a deeper market penetration and diversification.

While rice production all across Southeast Asia significantly increased and average hectare yields improved from 1.5 to 2.5 tonnes in the Green Revolution period (1961 to 1980), investments into irrigation proved not always successful (Figure 1.4, Figure 1.5). Irrigation renovation, improvement and expansion works that were undertaken often disregarded existing local system constellations, undermining local management systems and weakening social cohesion and collective action (Lansing 1991; Horst 1996; Barker and Molle 2004a: 16). According to Ostrom (1992: 5), large-scale irrigation projects failed because of unrealistic plans about actual areas to be irrigated, overestimation of agricultural

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[5] Pre-twentieth century participation in communal irrigation was generally minimal, such as for example in Thailand, where rice was not a main export crop (Cohen and Pearson 1998: 90).

yields and under-investment in recurrent costs. Moreover, the diversification of agriculture to other cash crops as well as intensification of annual cropping intensity put a strain on the capacity of existing irrigation systems and their communities, requiring intervention from outside (Lansing 1991; Cohen and Pearson 1998: 109). Walker (2003), for example, discusses a recent case of emerging water resource conflicts between farming communities due to intensified agricultural production along a river in northern Thailand.

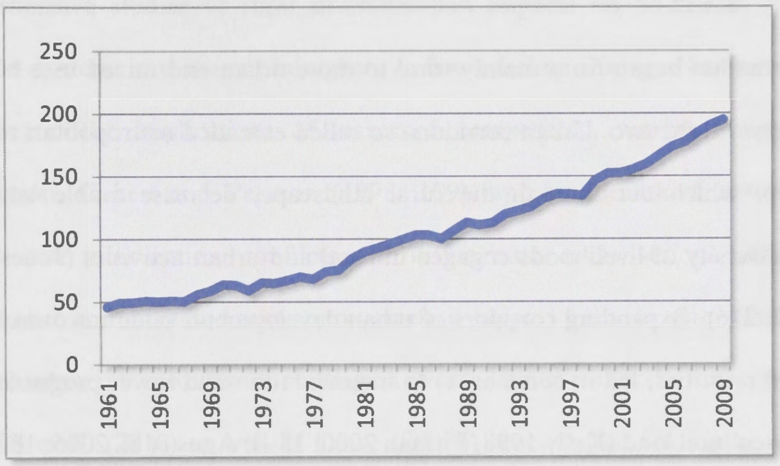

Figure 1.4: Southeast Asian rice production output (million tonnes), 1961–2009
Source: (FAOSTAT 2011)

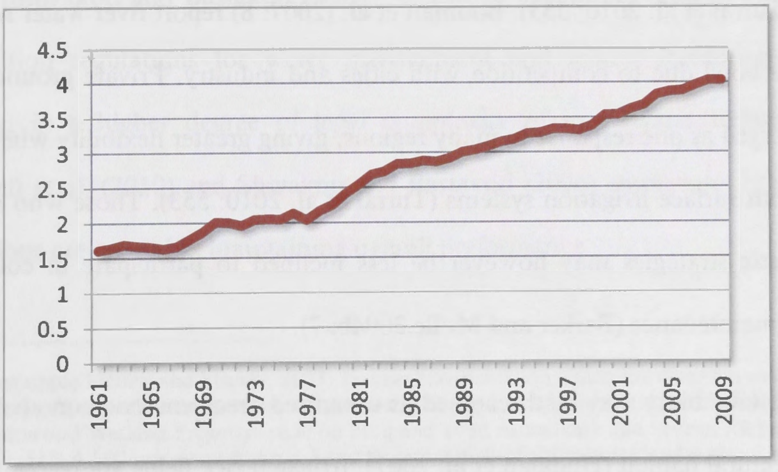

Figure 1.5: Southeast Asian rice yields (tonnes per hectare), 1961–2009
Source: (FAOSTAT 2011)

Concurrent with agricultural commercialisation, a larger process of change began which altered previously almost entirely agrarian societies and economies. This process of deagrarianisation saw the emergence of non-agricultural industries and rapid urbanization, allowing Southeast Asian farming communities to participate in a in a wider, richer and more powerful economy (Harriss 1982: 16–7, 37; Elson 1997: 238). Agriculture as a source of employment and income decreased in importance, with part-time farming becoming the norm (Rigg 1998; Eder 1999; OECD 2001; Rigg 2003; Barker and Molle 2004a; Francks 2005).[6]

A spatial transformation began from mainly rural to more urban and mixed uses blurring the boundaries between the two. Urban corridors, so called extended metropolitan regions, began to develop, which cut through the rural landscape, decrease arable land, yet accommodate a diversity of livelihoods engaged in rural and urban activities (Jones 1997: 240–3; Rigg 2003: 316). Expanding corridors of urban development, often uncontrolled or biased by political priorities, led in some areas to fragmentation and lower productivity of the remaining agricultural land (Kelly 1998; Firman 2000: 13–4; Agus et al. 2006: 182).

Industrialisation and urbanisation increase the number of competing water users. With new water users on the agenda priorities for water allocation tend to shift even to the point of over-allocation (Turral et al. 2010: 553). Bouman et al. (2007: 8) report river water scarcity in Thailand's rice bowl due to competition with cities and industry. Private groundwater pumping has emerged as one response in many regions, giving greater flexibility when used in conjunction with surface irrigation systems (Turral et al. 2010: 553). Those who opt for more individualistic strategies may however be less inclined to participate in collective irrigation system maintenance (Barker and Molle 2004b: 7).

Environmental sustainability may be threatened as urbanised areas encroach on ecological functions of the natural habitat (Hudalah et al. 2007). Irrigated rice fields are recognised as

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[6] Part-time farming is possible because peak demands for agricultural labour are short-term and seasonal. This

a special class of wetlands (Kirk 2004: 1). Extensive studies on impacts on the ecology of wetlands (mainly biodiversity) due to land fragmentation have been so far mainly undertaken in Western countries, such as for example the US or Switzerland.[7] Recent work on multifunctionality and ecosystem services of irrigated rice fields may give, however, some indication of what vital functions may be lost due to increased conversion of rice fields such as, for example, reduced flood and heat mitigation, limited groundwater recharge and increased erosion (Agus et al. 2006; Groenfeldt 2006: 73–5).[8]

Comprehensive studies of rural diversification impacts on Southeast Asian communal irrigation systems are sparse, however. A few scholars discuss Northern Thai irrigation systems and the implications of increased competition, market integration and state intervention. Cohen and Pearson (1998: 109) report undermined autonomy and unity through state intervention, conflicts with urban water users, serious labour shortages for maintenance and increased reliance on external support from the state. Shivakoti (2000: 13) notes changes in resource mobilisation from labour to cash for maintenance work. Bastakoti et al. (2010) as well as Dawe (2005b) observe that farmers are opting for more individualised systems such as private wells, which impinge on collective action in irrigation management, or groundwater pumps, which negatively impact on drinking water supply (Shivakoti and Bastakoti 2006). Neef et al. (2006: 20) remark that with increased competition regulations for water management and tenure institutions are changing, resulting in a higher degree of legal complexity of local water tenure regimes. Both Bastakoti et al. (2010) and Shivakoti and Bastakoti (2006) emphasise, however, that local institutions are crucial in maintaining overall performance.

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[7] See for example Lienert and Fischer, 2003: 'Habitat fragmentation affects the common wetland specialist Primula farinosa in north-east Switzerland' (*Journal of Ecology*) or Knutson et al., 1999: 'Effects of Landscape Composition and Wetland Fragmentation on Frog and Toad Abundance and Species Richness in Iowa and Wisconsin, U.S.A.' (*Conservation Biology*). Land fragmentation of agricultural land is also a major focus of studies in Switzerland.

[8] A study in Europe, for example, showed, that rice fields play an important role in wildlife conservation, as they are habitat to several species of waterbirds (Toral and Figuerola 2010).

Overall, all authors seem to highlight similar issues of lower system performance due to increased competition for water, and difficulties in maintaining irrigation structures due to labour shortages that result in impairment of collective action. Their main preoccupation is, however, with the irrigation system and its performance, and none have mentioned issues of land conversion and outmigration of labour affecting the production systems. It is the intention of this thesis to fill these gaps with the examination of a specific case, the irrigated rice production system that exists in Bali.

BALI AND RICE

Bali is one of 17,000 islands that form the Republic of Indonesia, the largest archipelago in the world (Figure 1.6). The island is located east of Java and west of Lombok and is part of the Lesser Sunda Islands. Bali is 145 kilometres long and 80 kilometres wide with a total land area of 5,637 square kilometres, lying 8 degrees south of the equator and 115 degrees east. The landscape is characterised by hilly terrain and is dominated by a chain of volcanic mountains extending from east to west, of which two are considered still active. One of these two, Mount Agung, is the highest peak on the island at 3,142 metres. Cradled in this mountain range lie four caldera lakes formed from earlier ancient volcanic eruptions. These caldera lakes are considered to be sacred by the locals as providers of all fresh water on the island.

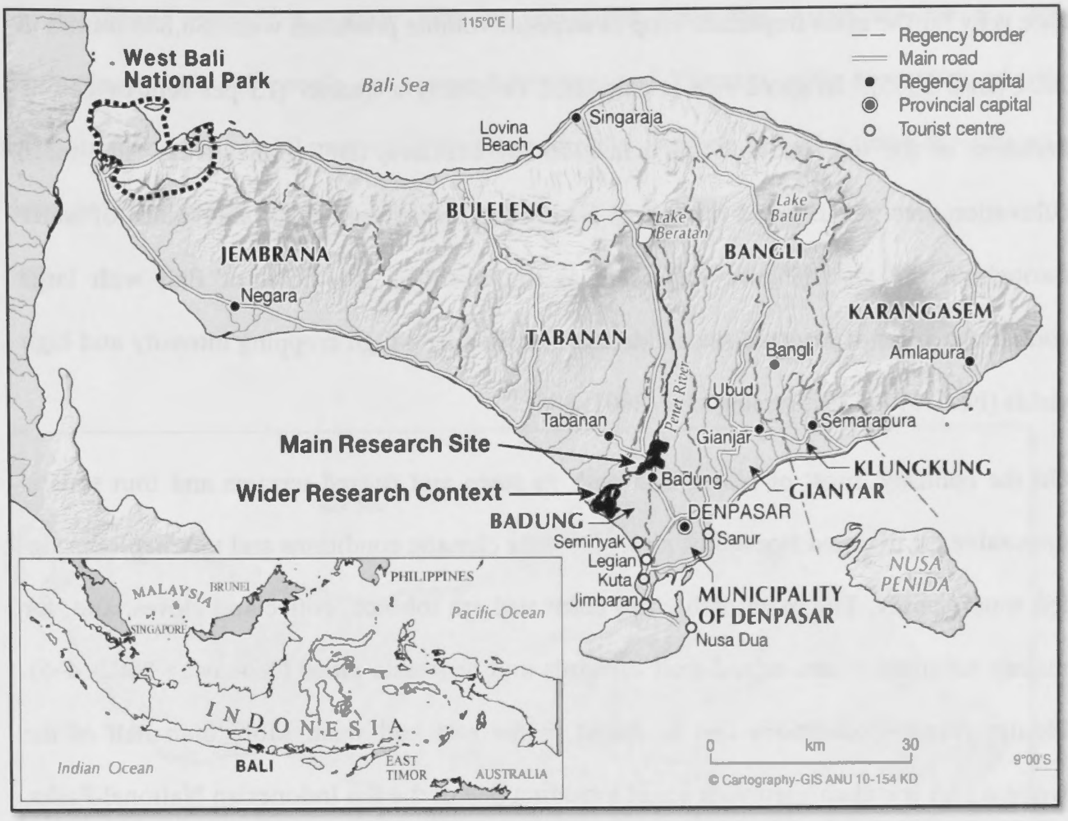

Figure 1.6: Map of Bali with regencies, main tourist centres and research areas

Bali has a tropical monsoon climate with two distinct seasons: a dry season that lasts from April to September and a wet season from October to March. Average annual precipitation is between 1,700 and 2,200 mm with an average relative humidity of 80 per cent and an average temperature range of between 23° Celsius to 32° Celsius (BPS 2010c). The volcanic mountain range divides the island into distinct climatic regions: a dryer northern part, with dry rivers in the dry season, and a larger and wetter southern part, with perennial rivers. The rivers have cut deep ravines into the soft volcanic rock on either side of the range, dividing the slopes into distinct ridges and valleys that gradually expand to form large alluvial plains in the lowlands close to the sea. It is on these ridges and plains that the rice terraces have been built.

Rice is by far the most important crop in terms of volume produced with 788,883 tonnes in 2004 (BPS 2005).[9] Irrigated rice is cultivated on nearly a quarter (23 per cent or 81,482 hectares) of the total arable land area (356,237 hectares) (BPS Bali 2010a). The main cultivation areas of irrigated rice are in South Bali, which enjoys an abundance of water throughout the year (Figure 1.7). This is the so-called rice bowl of Bali with large contiguous areas of irrigated rice fields characterised by a high cropping intensity and high yields (Fox 1993: 136; Lansing et al. 2001: 385).[10]

On the contrary, most of North Bali with its steep and rugged terrains and thin soils is unsuitable for irrigated rice fields, given the drier climatic conditions and unreliable spring-fed water supply. The main cash crops cultivated are tobacco, coffee and cloves, and, for mainly subsistence use, mixed fruit orchards and vegetable crops (Jennaway 2002: 4–5). Similar climatic conditions can be found in the east and west. More than half of the western part is still covered with forest including one of the ten Indonesian National Parks, the Bali Barat National Park.

The majority of the people are Hindu (91.4 per cent), and the rest are Muslim (5.9 per cent), Buddhist (0.6 per cent), and Christians (2.1 per cent) (BPS Bali 2005: 78).[11] In 2008, the population of the province Bali was 3.4 million with an average population density of 605 inhabitants per square kilometre (Table 1.1). Bali is quite densely populated compared to the national average of 125 inhabitants per square kilometre. According to both the definition of the OCED and the US Census Bureau, the whole of Bali would be classified

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[9] Other important crops produced in Bali are tree fruits (358,580 tons), cassava (142,221 tons), sweet potato (72,562 tons), maize (68,423 tons), peanuts (19,256 tons), coffee (19,082 tons), soy beans (11,129 tons), cocoa (6,053 tons) and cloves (5,451 tons) (BPS 2005).

[10] South Bali's soils are classified as yellowish brown Latosols (Badung and Tabanan) and Regosols (Gianyar) of clay to silty loam texture originating from the fertile volcanic ashes which form the basis of intensive agriculture (Shimano 1992: 28; Winaya 1992: 66–8).

[11] While Muslims first came to Bali centuries ago, there is a new wave of migrants arriving on Bali from the neighbouring islands Java and Lombok drawn primarily by employment opportunities (Pringle 2004: 9).

as an urban region.[12] Similarly densely populated Southeast Asian regions are the Philippines, with 303 people per square kilometre, and Vietnam, with an average of 278 inhabitants per square kilometre.[13] Population growth, moreover, is five times the national average (Putu Suasta 2001: 45–6).[14]

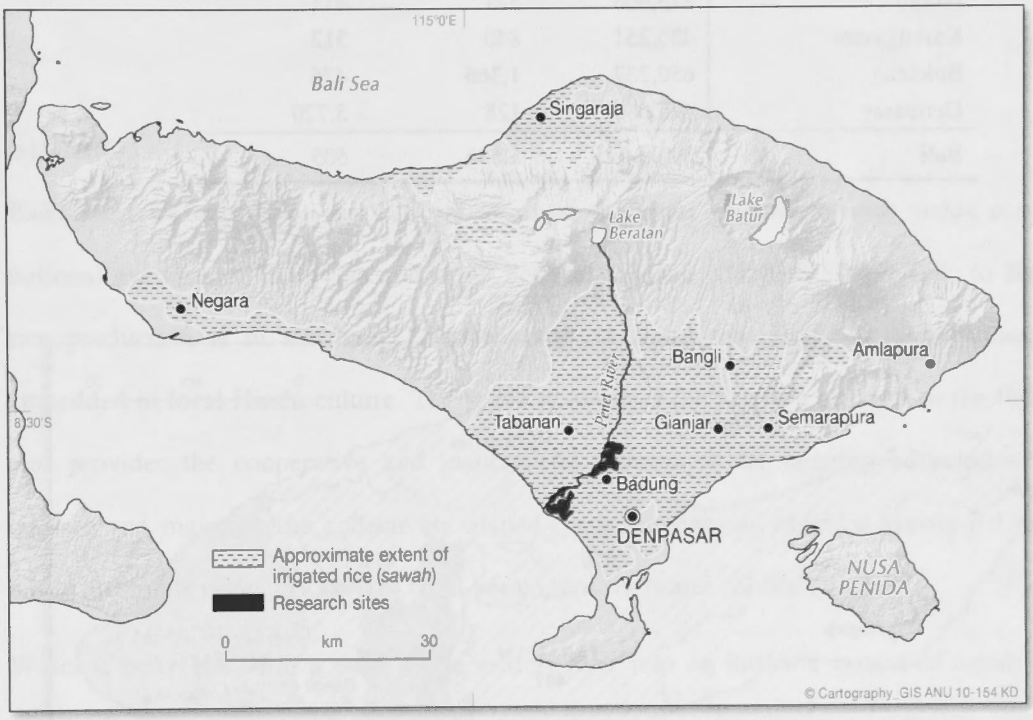

Figure 1.7: Extent of irrigated rice cultivation in Bali

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[12] According to the OECD, urban areas have population densities above 150 inhabitants per square kilometre, while the US Census Bureau stipulates that urban areas have a population density of at least 386 inhabitants within the core settlements and at least 193 in core settlement surrounding areas (converted from square miles) (US Census Bureau ; OECD 2006: 24, 26).

[13] (World Development Indicators (WDI) 2011).

[14] According to Putu Suasta the high population growth can be linked to the prospering tourism industry.

Table 1.1: Bali population, area and population density

Regency/Municipality	*Population*	*Area km2*	*Population Density*
Jembrana	268,269	842	319
Tabanan	416,743	839	497
Badung	383,880	418	918
Gianyar	394,755	368	1,073
Klungkung	176,822	315	561
Bangli	213,808	521	411
Karangasem	430,251	840	512
Buleleng	650,237	1,366	476
Denpasar	475,080	128	3,720
Bali	3,409,845	5,636	605

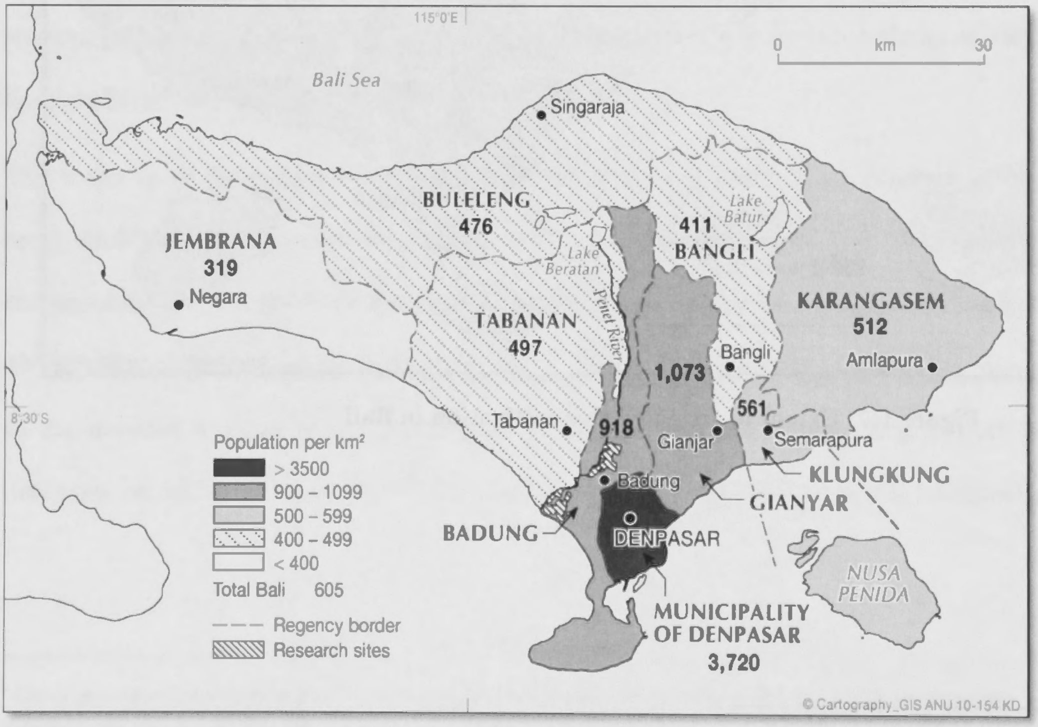

Figure 1.8: Map of Bali with population densities for each regency

Administratively, Bali is one of the 33 provinces of Indonesia, further divided into eight regencies: Badung, Tabanan, Jembrana, Buleleng, Bangli, Karangasem, Klungkung, Gianyar and the capital city Denpasar as a separate administrative area (municipality). Most Balinese live in the southern part of the island, which is also the most densely populated part with Badung (918 inhabitants per square kilometre), Gianyar (1,073 inhabitants per square kilometre) and Denpasar municipality (3,720 inhabitants per square kilometre) (Table 1.1, Figure 1.8).

Subak

Bali's wet rice cultivation systems are amongst the most productive with yields above national averages of Indonesia and other Southeast Asian countries (Table 1.2). In Bali, rice production is in the hands of the subak, a communal irrigation system firmly embedded in local Hindu culture. The subak guarantees the delivery of water to the fields and provides the cooperative and institutional framework for farming households to operate and maintain the collectively owned irrigation system, which is gravity-fed and based on simple principles such as fixed permanent weirs and continuous flow.

Water is conveyed from a dam at the nearest river into an intricate system of canals to deliver the water to each rice field. Because the rivers run in deep canyons to the sea, water has to be fetched at considerable distance away from the areas to be irrigated and often tunnels are constructed for better access to river water. There are an estimated 1200 to 1600 subaks still existing in Bali today ranging in size between 50 to 700 hectares with regional and local variations in terms of their institutional framework (Pitana 1993: 3; Gany et al. 2004: 176).

Table 1.2: Average irrigated rice yields in Southeast Asia, 2008

2008	*Tonnes per hectare*
Myanmar	3.72
Philippines	3.77
Thailand	2.97
Vietnam	5.22
Southeast Asia	4.05
Indonesia	4.89
East Java	5.90
Bali	5.84

Source: (BPS Indonesia 2010b; FAOSTAT 2011)

The subak's organisational structure is composed of the council (*krama*), with between 40 to a couple of hundred members, and a board elected by the members which includes the subak head (*pekaseh*) and administrative staff. Larger subaks are often divided into smaller units (*munduk*) mainly for management purposes.[15] Every household that cultivates rice is by default a member of the subak in which their field is located regardless of whether they own and crop or sharecrop their rice field.[16] Members provide labour and time for maintenance and operation, meetings and religious activities with the amount of labour and time invested depending on the size of their field.[17] Male and female household members take on work related to the subak according to type of activity and their availability. Representative positions in the subak, however, are occupied by men only.

The subak head is responsible for the overall operation and maintenance of the system including monitoring water flow into the subak, dispute resolution among subak members, water negotiations with neighbouring subaks, scheduling of cropping patterns and

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[15] Depending on the region in Bali these sub-units are also called *tempek*.

[16] There are several sharecropping arrangements found around Bali which vary in terms of the ratio to which costs and benefits are shared. These arrangements are usually very loose contracts which can be potentially discontinued after every harvest.

[17] This is the most simplified explanation of membership also accepted by other scholars of the subak (Geertz and Geertz 1975: 48, 90; Lansing 1991: 80). Local subak law and practice however, if studied in detail, lends itself to considerable ambiguity and a variety of interpretations of who exactly is in what format a member of a subak. For a detailed discussion of membership issues see Jha (2002b).

organising subak and inter-subak rituals. Nowadays, the pekaseh is also the contact person for government agencies involved in either irrigation or cultivation. In larger subaks with sub-units, there is equally a sub-subak head responsible for these matters on their level. The subak head, although elected, has no formal authority as leader but is expected to serve subak members based on principles of collective priority and unity and is under constant scrutiny to justify his actions (Warren 1993: 125–6; S. Lorenzen 2008: 41–2).[18]

In 1972, subaks attained official recognition as 'customary law societies with socio-agrarian-religious nature' under the provincial regulation on irrigation (Pitana 1993: 210–15; Pemerintah Propinsi Bali 1997: 5).[19] Customary laws as opposed to state law are a set of localised rules designed by the people who use these rules. Geertz (1980a: 195) defines them as 'public statements of long-established … practices'. These rules set out the organisational structure, membership rights and duties, including communal labour commitments, methods of water allocation and distribution, issues of cultivation, and sanctions for rule violations. These laws are approved by all members by consensus before they are put into effect (Sutawan 2004: 3).

Subaks are deeply embedded in Balinese culture and Hindu religion. Rituals are performed on the field and on the subak level to honour and thank the gods, to mark different stages of the cultivation cycle, and to prevent or reduce pest and disease damage of the rice crop. The rituals are associated with ideas of fertility, growth, loss of potency, decay and renewal and are seen as assuming an important role in maintaining a balance between the profane impure world and the pure and sacred supernatural realm (S. Lorenzen 2008: 141). They are an inherent part of the subak and the cultivation of rice in Bali, and range from short

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[18] The ways in which organisational structures and principles are set up are similar to those of other Balinese social corporate groups such as the village, the hamlet, and kinship groups (Geertz 1980a: 49).

[19] Peraturan Daerah Propinsi Bali No 02/PD/DPRD/1972 (Pasal 4-7, 14-16) tentang Irigasi Daerah Propinsi Bali (Bali Provincial Regulation on Irrigation, articles 4-7 and 14-16).

and simple to quite elaborate performances and often require time-consuming and costly preparations.

Subaks have joint responsibilities for several temple structures which are integral to the entire irrigation system and which facilitate performance of subak rituals dedicated to the worship of the water goddess and various agricultural deities. Temple structures are generally located at each diversion weir where water is divided into individual subaks, sub-units and individual fields, though the form and existence of these structures varies.[20] The water temples also function as gathering places to coordinate water use amongst those who share water from the particular diversion weir to which the temple is linked (Lansing 1991; Lansing 2006a).

Subaks and rice cultivation in Bali have a long history of at least a thousand years (Lansing 2006b). According to Christie (2007: 236), bunded rice-field systems which enable a systematic irrigation had come into existence by the ninth century CE in Bali. The first appearances of words related to the subak and cultivation of irrigated rice were found in inscriptions dated around the first millennium CE (Dinas Kebudayaan Propinsi Daerah Tingkat I Bali 1999: 9; Lansing et al. 2009: 114). The first reports sighted in Europe about the subak came from Dutch seafarers in the sixteenth century (Spiertz 2000: 165, 193). Most detailed studies about the subak that are available now were, however, undertaken between the late nineteenth and twenty-first century.[21]

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[20] Temple structures on the inter-subak, subak and sub-unit level are permanent, while those on the field level are usually temporarily erected at the time of a ritual, made from wood and other plant materials.

[21] Earliest detailed accounts are from Liefrinck (1969[1927]), Korn (1924), Wirz (1929), and Grader (1960[1939]), which are studies undertaken shortly before or after Dutch colonial rule, between 1886 and 1939. Later accounts of scholars who undertook studies of pre-colonial times are from Hauser-Schäublin (2003; 2005), Schulte Nordholt (1996), Geertz (1980a), as well as archaeological studies carried out by Schoenfelder (2000; 2003) and others. Geertz's extended studies and several publications on the subak (1959; 1964; 1972; 1980b; a) rely mainly on fieldwork undertaken in 1957–58 (except for his book 'Negara'). Others who have looked at post-colonial Balinese subak are Stingl (1969), Birkelbach (1973a; b), Poffenberger and Zurbuchen (1980), Foley (1987), and Ramseyer (1988). Authors who studied the subak of the early 1980s and onwards are foremost but not exclusively Lansing (1991; 2003; 2006a), Bundschu (1985; 1987), Horst (1996), Jha (2001; 2002a; b; 2004), MacRae (2003; 2005a; b; 2006; 2011), and S. Lorenzen (2008). Indonesian and more specifically Balinese scholars who have studied the subak are Pitana (1993; 1997; 2003a; b; 2005), Sutawan (2000a; c; 2004; 2005),

As for many other communal irrigation systems, there is little evidence of how the subak evolved in the past centuries and what the exact form of operation was. For instance, the extent of influence by a central authority above the subak is a highly contended issue amongst Balinese scholars (S. Lorenzen 2008: 1). Geertz (1980a: 85), for example, describes the subak as an almost 'acephalous' (headless) organisation —egalitarian and independent of any state influence and support. Others, on the contrary, argue that the subak was and is dependent on a central authority either politically (Hauser-Schäublin 2005) or ritually (Lansing 1991; 2006a).[22] Regardless of the subak's interdependencies, the actual day-to-day labour invested into cultivation of rice and the irrigation of individual fields is in the hands of farmers as I have experienced first-hand while in the field.

Green Revolution and the Subak

The Green Revolution which intensified and commercialised rice production in Bali, on the other hand, is well-documented. Lansing (1991: 112), in particular, intensively studied the subak at the time, concluding that the changes introduced by the Green Revolution did not only affect the socio-economics of farming but also had a lasting impact on the basic structures of the subak.

The Green Revolution in Bali had its beginnings in the late 1960s. Farmers were encouraged to ignore subak customary regulations and abandon traditional cooperative cultivation methods (rotational irrigation schedules and cropping patterns) in favour of continually growing the new high-yielding varieties (Lansing 1991: 113; Sutawan 2000c). Moreover, considerable alterations were made to the irrigation infrastructure with the aim

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Arthawiguna (2002) and Windia (2006), and several others. Authors who studied subaks of Balinese origin in Sulawesi are Vermillion (1986; 2000) and Roth (2003; 2006).

[22] According to Geertz (1980a: 85) and Lansing (1991; 2006a) the kings and their bureaucracies were never engaged in any matters related to day-to-day rice cultivation. This view is contested by Hauser-Schäublin (2003; 2005) and Schulte Nordholt (1996; 2010), who conclude that the control over the flow of water and thus over the irrigation system was essential for the establishment of power for royal houses —and often the origin of conflict between different royal houses.

to improve operation and reduce maintenance costs (Horst 1996: 41; ADB 1997: 2). Although yields were substantially increased, the interventions had various negative impacts, such as for instance the replacement of the diverse local varieties of rice with a few high-yielding ones, the abandoning of the rotational crop schedule, and loss of inter- and intra-subak communication in scheduling water flow (Lansing 1991; Sutawan 2000c). This eventually resulted in massive pest infestations, substantially reduced yields and inter-subak conflict (Ramseyer 1988; Lansing 1991).

Amazingly, however, the subak system did recover once the government decided to interfere less in irrigation and rice cultivation. Lansing's revelation of the functioning and importance of the water temples and the introduction of inter-subak federations allowed for the reinstitution of the subak, its rules and regulations (Lansing 1991; Sutawan 2000c). The cultivation of the new varieties was taken on board and the system adapted. Though they were now planting the new varieties, farmers went back to their traditional cropping and irrigation patterns based on customary regulations, including the many rituals that accompany the rice plant through its growing stages on the rice field. With the subak regulations adapted but reinstituted, rice yields increased again and the subak system continued to exist and thrive.

Present Challenges with Rural Diversification

In Bali, the main drive of rural economy diversification was the marketing of the island as a tourist destination. At about the same time as the Green Revolution packages arrived, systematic promotion of Bali as a mass tourism destination began. The Indonesian government implemented a Master Plan for tourism development in the early 1970s that included the adoption of a 'cultural tourism' policy, the establishment of major resorts in the south of the island and the further development of the provincial road network and other infrastructure (Piccard, 1996).

With the Master plan in place, an international airport was built and tourists started arriving en masse (Leemann et al. 1987: 179).[23] Tourism developed rapidly, from 5,000 foreign visitors arriving at Bali's international airport *per year* in 1968 to more than 5,000 tourists *per day* forty years later (Wall 1996: 127; BPS 2010f) (Figure 1.9).[24] Bali became one of the prime destinations in Indonesia for international as well as domestic visitors. In 1994, Bali's income from tourism represented a quarter of Indonesia's total tourist industry income (Rieländer 2002: 97). As a result, Bali changed from a relatively poor province to one of the wealthiest in Indonesia (Pringle 2004: 184).

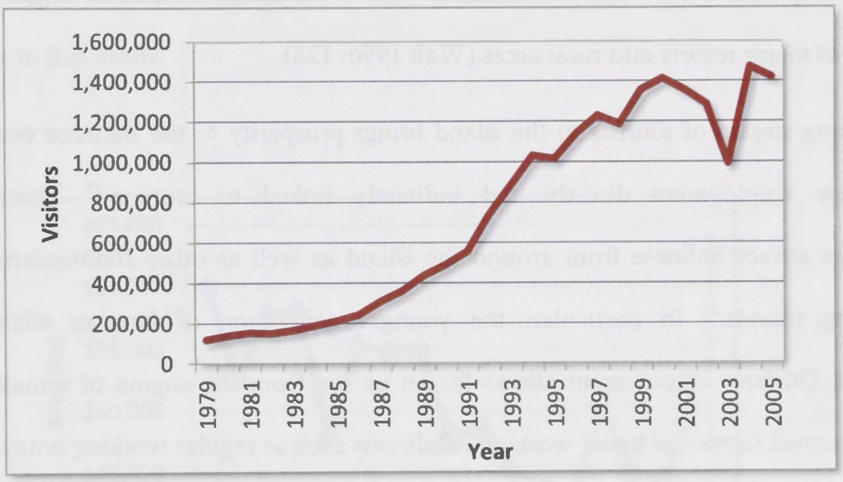

Figure 1.9: Number of Foreign Visitors directly arriving on Bali, 1979–2005

Today, Bali attracts resort tourists, backpackers, cultural and eco-tourists, conference and meeting organisers and participants, furniture and garment traders and expatriates alike. In the early stages, tourism centres were concentrated in the south of Bali. With the constant

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[23] According to Leemann et al. (1987: 179), the first tourists started arriving in Bali as early as 1914 with arrivals in the 1920s and 1930s mainly from cruise trips.

[24] In the wake of the two Bali bombs (2002 and 2005), tourist arrivals dropped significantly. Numbers have since recovered and are exceeding those pre-Bali bombs. When I returned back to the field site for short visits in 2006 and 2007, many Balinese, however, complained that tourists now preferred to stay in the main centers and were less inclined to 'cruise' the island and that, as a consequence, most tourist dollars were spent in these main centres.

arrival of more tourists every year, tourism can now be found all over Bali, although Badung regency harbours the prime tourist centres along the south coast and is consequently the richest regency with its main income from tourism: Nusa Dua and Jimbaran on the most southern point, Kuta, Legian, Seminyak along the south-western coast and Sanur to the east. Smaller tourist centres are located in the south-centre (Ubud), on the north coast (Lovina) and in eastern Bali (Candi Dasa) (Figure 1.6). The poorer and less developed areas are located in the regency of Buleleng, Bangli and Jembrana, where tourist destinations are more sparsely distributed. Tourism nevertheless intersects with and has implications for most areas of Balinese life and the economy such as the agricultural landscape, the production of handicrafts and the rich cultural tradition, all of which attract visitors out of major resorts into rural areas (Wall 1996: 128).

The increasing stream of tourists to the island brings prosperity to the Balinese economy creating new employment directly and indirectly linked to tourism.[25] These new opportunities attract Balinese from around the island as well as other Indonesians from neighbouring islands.[26] In particular, the younger generation of farmers seizes this opportunity. Off-farm employment allows for an escape from the stigma of remaining a 'dirty, uneducated farmer' to better working conditions such as regular working hours, fixed monthly wages and, most importantly, better pay. As the industry matures, the education system adapts for specific skills development which further contributes to younger Balinese finding jobs off-farm. The emigration of young labourers from agriculture entails the danger of losing the skills and knowledge base attached to rice production (Rieländer 2002: 321).[27]

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[25] Employment indirectly related to tourism is in those industries which produce goods used in the tourist industry, such as the building or textile industries.

[26] There are no official statistics available for immigrant arrivals in Bali. Estimates of immigrant arrivals on Bali from Java and Lombok range between 60,000 to 100,000 per year (Rieländer 2002: 96).

[27] While I was in the field, many young Balinese working in non-agricultural industries I talked to raised the possibility of returning to the rice fields once they retired. Whether this return will actually happen and whether the skills and knowledge base can be preserved, will remain to be seen.

The prospering tourist industry, together with general urbanisation and industrial development, not only draw labour away from agriculture, but these industries also compete for land. Attractive land prices create alternative possibilities to working in the mud. In addition to construction of tourist facilities and a general urbanisation process, there has also been a growing development of housing estates built at the fringes of the capital city as well as on the outskirts of traditional villages near tourist centres to accommodate the many migrants arriving for work from other regions. This land conversion has mainly taken place on fertile rice fields. The harvested rice area has accordingly decreased (Figure 1.10). The impact that land conversion has on the functioning of the subak has so far not been further investigated and thus will be subject to scrutiny in this thesis.

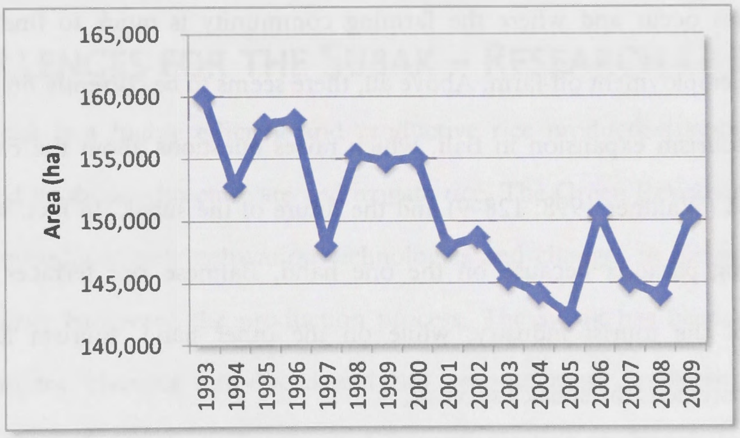

Figure 1.10: Harvested area of irrigated rice in Bali 1993–2009

Source: (Bali dalam Angka / Bali in Figures 2005; BPS Indonesia 2010b)

Increased demand for water from non-agricultural industries and domestic water use is another issue of a growing rural economy. These competing water users not only claim water at the expense of agriculture, they also produce waste that pollutes and clogs the waterways, affecting irrigation efficiency. Reports of water shortages and pollution have become frequent online news items especially in the densely populated and economically most active region of south-central Bali.[28]

Irrigated rice depends on a continuous flow of water throughout most of the cultivation season for a good harvest. With increased competition and the resulting diminished water flows, the high yields for which Bali is famous may become soon part of the past, especially in areas close to urban centres. Additional waste in irrigation canals generated by growing housing and industrial estates implies an increased workload for the subak to maintain the irrigation system at a functional level. Although the provincial government has become aware of the challenges ahead, implementation of newly issued regulations to monitor urban and industrial development often lag behind reality.

In summary, there are clear challenges ahead for the subak to face, especially for those at the fringes of urban areas, along main transport routes and tourist centres where most development activities occur and where the farming community is quick to find more attractive alternative employment off-farm. Above all, there seems to be currently no end to the propagation of tourism expansion in Bali, which raises questions about the carrying capacity of the island (Waldner 1998: 128–9) and the future of the subak. In fact, we can observe an interesting paradox because on the one hand, Balinese rice terraces are a marketing feature of the tourist industry, while on the other hand, tourism and its expansion seriously threatens the subak's survival.

Only a few studies so far however have touched on issues of rural diversification, deagrarianisation and the subak. S. Lorenzen's thesis (2008), for example, concentrates on

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[28] See for example: 'Bali's Lakes are shrinking', 22/8/2009, accessed at http://www.balidiscovery.com/messages/message.asp?Id=5446 on 29/10/2009; 'Bali's diminishing Water supply', 9/7/2009, accessed at http://www.balidiscovery.com/messages/message.asp?Id=5482 on 29/10/2009; 'Bali's growing water crisis', 11/1/2010, accessed at http://www.balidiscovery.com/messages/message.asp?Id=5751 on 1/6/2010; 'Den Flüssen geht das Wasser aus', 1/07/2010, Zeit Online - Reisen, accessed at http://www.zeit.de/reisen/2010-07/bali-tourismus on 3/9/2010; 'Der Tourismus trocknet Bali aus', 12/5/2009, fairunterwegs, accessed at http://www.fairunterwegs.org/aktuell/news/article/der-tourismus-trocknet-bali-aus.html?cHash=80ff1f1232 on 5/9/2010; '2020 Bali diprediksi Alami Krisis Air Bersih', 17/4/2009, Berita Bali, accessed at http://www.beritabali.com/index.php?reg=&kat=&s=news&id=200904170007 on 9/8/2009.

present-day farmers' perspectives within contemporary subaks in a peri-urban area as opposed to the views of external agencies, their household strategies in the everyday cultivation and irrigation of rice and their approaches to the technologies of agricultural modernisation. He refers to issues of labour and water stress but focuses mainly on the household level. MacRae (2005a; b; 2011) follows specific cases of present-day small-scale local initiatives that explore alternative marketing options for individual farmers and a subak in the uplands. He examines rural diversification issues only marginally with a focus on livelihood strategies and less on impacts on the subak.

With this thesis, I aim at a comprehensive and interdisciplinary investigation of the subak using a past event (the Green Revolution) and current challenges to understand what mechanisms have led to the subak's survival.

CHALLENGES FOR THE SUBAK – RESEARCH QUESTIONS

The subak is a highly efficient and productive rice production system which is locally managed by those who cultivate and irrigate rice. The Green Revolution, one focus of my thesis, introduced new cultivation technologies and changes to the irrigation system and temporarily hampered the production process. The subak has been able to recover and adapt to the changes introduced and has become more productive than before. The implications of rural diversification and deagrarianisation on the subak and rice cultivation, the second emphasis of my thesis, are however of a different nature. These changes are more subtle, and not only affect agriculture, but are slowly creeping into Balinese society.

The subak, once one of the four main constituents of Balinese village polity together with the hamlet and the temple congregation and kinship groups, experiences decreasing importance in Balinese social organisation.[29] Rice farming is no longer the main preoccupation in a Balinese village and even in farming households its importance in contributing to the family income has decreased. The declining interest in agriculture challenges not only the subak but many other communal systems as the labour force required for system maintenance vanishes and, in some instances, individual technologies such as pumps offer better avenues to increase crop productivity (Barker and Molle 2004b: 10). Yet although diets are changing, rice will remain the staple crop for the foreseeable future and populations continue to grow (Dawe 2005b; Pingali 2006).

The decline in the importance of rice production in Bali's economy and society combined with a need to continue to produce rice give rise to a number of challenges. Closely connected to these challenges is the question whether the subak, famous for its efficiency and sustainable resource management, is able to adequately adapt to these new developments and survive. Sutawan and Pitana, two of the leading Balinese researchers on subak, disagree on their assessment of the situation. Whereas Pitana (1993) believes that farmers' traditional institutions are very flexible and can integrate new institutions and technology, Sutawan (2000c) thinks that they are very rigid and inflexible because they have evolved over a long period of time and therefore react very sensitively and unpredictably to change. Although the institutional framework of the subak plays an important role in the quest for survival there are other factors that will influence the outcome such as, for example, the diminishing resource base.

In my thesis, I propose that the subak as this rice production system has the necessary tools to adapt to contemporary and future challenges because the subak has been able to survive

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[29] For a more detailed description of Balinese social life see Geertz (1980a: 45–86) and Warren (1993), who note that the customary village (*desa adat*) is not a single bounded entity but an overlapping non-coordinated mix of interrelated social groups which include the hamlet (*banjar*) as the civic community, the *subak*, the kinship group (*dadia* or *soroh*) and the temple congregation (*pemaksan*), which are all prescriptive, plus various other voluntary social groupings (*seka*). The three main spheres are the hamlet, which orders the public aspects of community life, the subak, which maintains and regulates irrigation facilities, and the temple congregation, which organises the popular ceremonies (Geertz 1980a: 47).

and learn from past events such as the Green Revolution. My investigation addresses the following questions:

- **What were the specific changes to rice production that the Green Revolution imposed and how did the subak manage to adapt and persist?**

  Modern technologies that were introduced as part of the Green Revolution significantly changed the way rice was produced, and intensified production from one or two rice crops to three or four rice crops annually. While rice output increased significantly over the 20-year period of the Green Revolution, the first years were marked with significant temporary drops in production caused by two major pest outbreaks that destroyed thousands of hectares of rice all across Indonesia (Oka 1991).

- **How does the subak deal with a membership that has become more diversified and significantly less focused on rice farming?**

  A well- functioning irrigation system will need continued investments of labour and finances. Labour mobilisation may become increasingly difficult with farm households engaged in more off-farm work and a generally aging farming community. In addition to a potentially reduced workforce there is a common trend to more limited support and funding from governments and other external funding agencies for investments into irrigated agriculture (Dawe 2005b; Turral et al. 2010). Thus, profitability might become an issue if maintenance costs surpass benefits, with farmers less inclined to invest as they have plenty of off-farm alternatives.

- **How can the subak maintain or increase its high production levels (or diversify production) with a declining resource base?**

  Farmers will have to increase water productivity to adapt to diminishing water supplies. According to the literature, there is limited scope to increase water productivity such as reducing water loss by adapted cultivation, irrigation and land preparation techniques, by upgrading the irrigation system, using alternative water sources, breeding new rice varieties as well as more sophisticated water management techniques including use of information technology, education, training and institutional changes to include other stakeholders (Rijsbermann 2004: 182–3; Bouman et al. 2007: 17-33, 39–44; Turral et al. 2010: 555–8). Subaks and farmers will need a stronger supportive extension services network for advanced technologies to save water.

With changing diets, farmers may want to diversify their production and access different markets. Diversifying production is constrained by high levels of risk, lack of skills, labour or capital and fluctuating market demands (Barker and Molle 2004b: 8). Those with more off-farm employment will be less inclined or have less interested in diversifying as this would involve more time and investment.

- **Are there limits to this specific production system with respect to availability of land, water and labour and other specific features for the subak to persist? And what are the consequences of limits exceeded?**

  For an irrigation system to be efficient in irrigating the fields connected to it requires a certain amount of contiguous land area, and sufficient available labour, including a vested interest for its maintenance and operation. Rice production requires sufficient water to be productive.

- **What are potential future trajectories of the subak system given an aging farming community, fragmented government support, disinterest by the Balinese community and vanishing resources?**

  There is a role to play for the government in supporting farmers and the subak by protecting the resource base and creating incentives to continue farming. This support can take on different forms depending on the capabilities and interests of both the farming community and government agencies such as, for example, education and training for farmers, regulation of agricultural and non-agricultural resource use, and preservation of the resource base. It will eventually also depend on Balinese society whether there is an interest to conserve this communal rice production system, which was once the mainstay of Bali's culture and which shaped the Bali's particular character.

RESEARCH FRAMEWORK

An irrigated rice production system consists of multiple overlapping dimensions of physical and social nature. These dimensions include the agricultural land and its environment, a physical infrastructure to facilitate and control water diversion from source to crop, farmers' irrigation and cultivation techniques, as well as institutional elements that guide interactions between users for cooperative system management (Geertz 1972: 27; Coward 1980: 15–6; Svendsen and Small 1990: 387–8). To allow for an integration of all these aspects, I aim at a holistic approach to an agro-ecological study of the socio-economic and ecological challenges that contemporary subaks face in Bali.

I construct my research framework upon resilience and social-ecological systems theories, loosely following the resilience workbooks for scientists and practitioners as a basis as well as other resilience scholarly literature.[30] I define the subak as a farmer-managed irrigated rice production system consisting of four dimensions of physical and social nature which expand the social-ecological system view. These four dimensions are an ecological (the agricultural land and environment), physical (irrigation infrastructure), technical (irrigation and cultivation techniques which include the practiced rituals) and institutional dimension (rules and regulations that guide the cooperative management). The analysis of the developed model of the subak is supported by one and a half years of research in the field complemented with literature analysis from several disciplines such as agricultural science, agricultural engineering, agricultural economics and agricultural policies, ecology,

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[30] These workbooks were published on the Resilience Alliance website in June 2007 (Resilience Alliance 2007a; b).

hydrology, as well as institutional theories, political ecology and anthropology, to allow for a comprehensive understanding of this specific rice production system.

RESEARCH METHODOLOGIES

During my field research in Bali, I followed several subaks and their practices during two rice cultivation cycles.[31] These subaks are located in a semi-rural area close to urban and tourist centres where attractive employment opportunities await farmers. The data gathered consists of interviews, surveys, participant observation, observing participation[32] and statistical data collection. For the Green Revolution impact, I mainly refer to the literature as well as information gathered through interviews with farmers in the field.

Research methodologies were built upon understanding the different dimensions of the subak and interdependencies amongst components, as well as the dynamics of the resources of land, water and labour. I relied on both qualitative and quantitative methods for the data collection and analysis to approach the subak on different levels: the farm-field level including the farming household, the sub-unit level, the subak level and the inter-subak level.[33]

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[31] Refer to the appendix I for a detailed summary of methodologies used.

[32] By observing participation I would like to emphasise that I actively participated in village and agricultural life while in the field: I cultivated a sharecropped rice field of 0.2 hectares supported by a local farmer and my anthropologist husband. I also attended village meetings, ceremonies and preparations for ceremonies.

[33] I undertook fieldwork in a family context. My husband, a cultural anthropologist, concurrently worked on his own PhD project, focusing on present-day farmers' perspectives within *subaks* as opposed to the views of external agencies, their household strategies in the every-day cultivation and irrigation of rice and their approaches to the technologies of agricultural modernisation. He submitted his thesis 'Seeing like a farmer' in 2008 (S. Lorenzen 2008). In several of the data-gathering activities we therefore collaborated and shared data. It was especially helpful where activities were gendered. During our time in Bali we lived in one of the six villages together with a Balinese family accompanied by our own children, Cedrik (13 years), Jael (7 years) and Anya (1 year), and participated in most of the village activities such as communal work and religious ceremonies, which helped us to gain further insights on general cultural aspects of the Balinese.

THESIS STRUCTURE

This thesis is divided into eight chapters. This chapter provided an introduction to the issues at hand, the subak and the wider context.

Chapter 2 introduces social-ecological systems and resilience theories and the analytical framework based on these theories which supported me in developing a four-dimensional model of the subak system to examine past and current challenges to the subak.

Chapter 3 describes the model of farmer-managed irrigated rice production systems such as the subak. Key thresholds that demarcate the boundaries of this model are discussed in each of the four dimensions. I also explore interrelations between these key thresholds.

Chapter 4 introduces the field site where I spent eighteen months studying the subak. I highlight specificities of the subak system using the key thresholds identified in chapter 3 in my model of farmer-managed irrigated rice production systems.

Chapter 5 considers the Green Revolution and its impact on the subak. Key factors that have caused the subak to move closer to the thresholds are highlighted, and how the subak has managed to adapt to the changes. This chapter is mainly based on a literature review complemented with personal accounts of farmers from the field research area.

Chapter 6 discusses the impacts that rural diversification has on the subak. After an introduction to rural diversification I focus on current key trends and how they impact on the subak. The second part of this chapter relies on data gathered in the field.

Chapter 7 examines possible future pathways of the subak taking current key trends into account. The three scenarios developed assume different developments in terms of the current key trends.

Chapter 8 is the concluding chapter with final remarks on the contemporary subak and the usefulness of the theoretical approach I have adopted.

CHAPTER 2

ANALYTICAL FRAMEWORK

> Thus, the subak is at once a technological unit, marked out by the collectively owned dam and canal; a physical unit, an expanse of terraced land with a defined border around it; and a social unit, a corporation consisting of people owning land in that expanse, serviced by the dam and canal. It is also, as we shall see, a religious unit (Geertz 1972: 27).

INTRODUCTION

As I have demonstrated in the introductory chapter, the subak is a highly productive and efficient rice production system that not only includes the physical structures (rice fields, irrigation canals and environment) in which rice is cultivated and irrigated but is also interlinked with farmers' cultivating and irrigation techniques and the rules and regulations that guide their collaboration. Thus, an analytical framework for a comprehensive analysis of the subak that includes multiple overlapping dimensions, interactions amongst these dimensions and implications of change calls for a systems approach that is interdisciplinary, integrating both the natural and the social nature of the subak.[34]

A system can be considered as a set of components which behave as a whole in response to stimuli to any part (Spedding in: Stephens and Hess 1999: 4). A systems approach takes into account all features of a defined system including interactions amongst the

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[34] Calls for systemic approaches that integrate social and natural science theory to the sustainable management of natural resources have emerged from the realisation that dualistic and linear study approaches have become insufficient and inappropriate (Ison et al. 1997; Stephens and Hess 1999).

components, allowing for a holistic system view (Berkes and Folke 1998: 6–7). Understanding how a system functions is derived from examining how components react and relate to each other rather than analysing parts in isolation and neglecting the dynamic interplay between system components (Berkes et al. 2003a: 5; Gallopin 2006: 294).

The social-ecological systems theories offer such an integrative framework which merges natural and social science for it emphasises the integrated concept of humans-in-nature to better understand complex interactions (Berkes and Folke 1998; Redman et al. 2000; Walker et al. 2002; Berkes et al. 2003a: 3). The linking of social and ecological systems implies that humans, or more specifically the social system, are seen as part, and not external to, an ecosystem perspective (Berkes and Folke 1998: 9). These merged human and natural systems are considered complex and adaptive because of the multiple interconnected elements and non-linear dynamics as well as their capacity to change and learn from experience.

The subak can be considered complex and adaptive because of its multiple dimensions and its capacity to adapt and learn from the changes imposed by the Green Revolution. The subak is complex because all parts are interconnected with each other: if farmers do not adhere to the rules-in-use[35], water, as one possible consequence, is no longer equitably shared, which leads to possibly lower rice yields. Or, the ecology of the subak system may be seriously disturbed if farmers overuse pesticides that kill not only pests but also harm the environment and pose a risk to farmers' health, again leading to possibly lower rice yields. Using multiple dimensions as well as my field research experience to analyse the subak acknowledges the complexity and adaptability of this particular social-ecological system in line with Berkes et al. (2003a: 5–7), who stress the need to supplement the quantitative analysis with qualitative data and a multiple perspectives view.

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[35] Used here interchangeably with institutions, in line with Ostrom's definition (1992).

SOCIAL–ECOLOGICAL SYSTEMS

Social-ecological systems are an interconnection of social systems and ecosystems. The ecosystem is defined by the Convention on Biological Diversity as a 'dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit' (MA 2003: 51). The definition of the social system seems to allow for a more open interpretation since scholars of social-ecological systems differ in their opinion what it constitutes. According to Berkes et al. (2003a: 2–3) and Adger (2006: 268), for instance, the social system encompasses the rules and institutions that mediate human use of resources, the different knowledge systems about the environment and resource use as well as world views and ethics concerning human-nature relationships. Other scholars (Seixas 2002: 3; Redman et al. 2004: 163), define the social system to include social institutions that address social challenges, temporal and cultural patterns of human activity and interaction, as well as economic activities. Depending on the study focus, a social-ecological system can be defined on the global, regional or local level (Gallopin 2006: 294).

For the purpose of this study, I define the subak and similar rice production systems as social-ecological systems that include an ecological component and social components (Table 2.1). The ecological component is a specific agroecosystem[36] or cultivated ecosystem[37] that includes the resource base, the resources that are being extracted and used as well as the physical infrastructure for the irrigation and celebration of the rice. The social components include farmers' cultivation and irrigation techniques, their invested labour, their knowledge system about resource use and the specific agroecosystem they use, as well as the institutions which direct farmers to work cooperatively.

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[36] An agroecosystem is defined as a dynamic association of crops, pastures, livestock, other flora and fauna, atmosphere, soils, and water contained within larger landscapes of uncultivated land, drainage networks, rural communities and wildlife (FAO et al. 2005).

[37] Cultivated ecosystems as defined by the Millennium Ecosystem Assessment are ecosystems that have been transformed by humans for the production of food, fibre and or fuel (Hassan et al. 2005: 18, 745).

Table 2.1: Social and ecological components of the subak and similar rice production systems

Ecological components	*Social components*
Agroecosystem, including bunded rice fields and accompanying flora and fauna, soils and water	Cultivation and irrigation techniques including knowledge, Invested labour
Physical structures, such as a gravity-fed irrigation system and temple structures	Rules and regulations for collaboration Water and rice rituals

As per definition, systems are composed of sub-systems and are equally components of larger systems (Patten 1978: 207). These multiple layers of systems are hierarchically interlinked and constrained by systems on levels above or below a particular system (Stephens and Hess 1999: 4). The influences of such cross-scale interactions and linkages need to be taken into account in the analysis (Resilience Alliance 2007b: 8, 26). For instance, government regulations and interventions such as irrigation and crop yield improvement projects instigated from levels above have an influence on how rice is produced. Or in a rice field, the biochemical processes of submerged soils can only take place when water is available to flood the field.

Conceptually, I suggest that Southeast Asian farmer-managed irrigated rice production systems are embedded in larger overlapping systems of social (such as the wider economy, cultural values) and/or physical nature (such as the tropical ecosystem) specific to Southeast Asia, and that they respond to changes and events that are occurring in these larger systems (Figure 2.1). There are other neighbouring ecosystems, social systems and linked social-ecological systems such as forests, neighbouring rice fields, villages and the individual household as sub-system that interact with the rice production system such as, for example, the farming household that provides labour. There are several sub-systems to the subak, such as, for instance, the individual farm-rice-field level and the soil chemistry level.

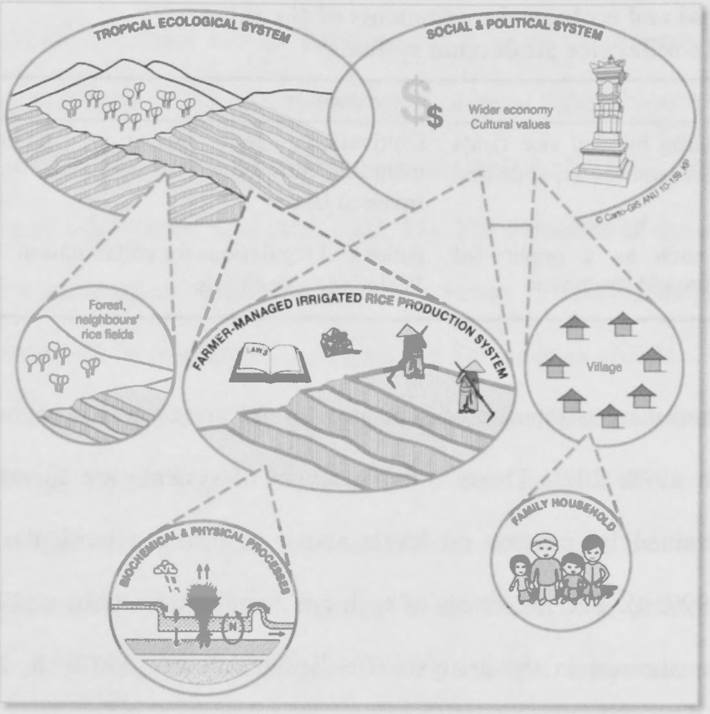

Figure 2.1: Southeast Asian farmer-managed irrigated rice production system embedded in larger overlapping systems with other sub-systems

here is a debate about to which degree ecological and social components in a social-ecological system are interconnected. Some authors perceive this connection more as a link between social and ecological systems such as, for example, Berkes et al. (2003a: 22) (Figure 2.2). Others emphasise the interconnectedness of both social and ecological components in an integrated social-ecological system such as Redman et al. (2004: 164) (Figure 2.3). In recent years, the integrative approach has been more strongly emphasised (Galaz et al. 2006: 1–5, 25). It is thought that institutions which govern the use of resources in a particular ecosystem are endogenous, that is, they originate from within and have co-evolved with this system (Folke et al. 2007: 2).

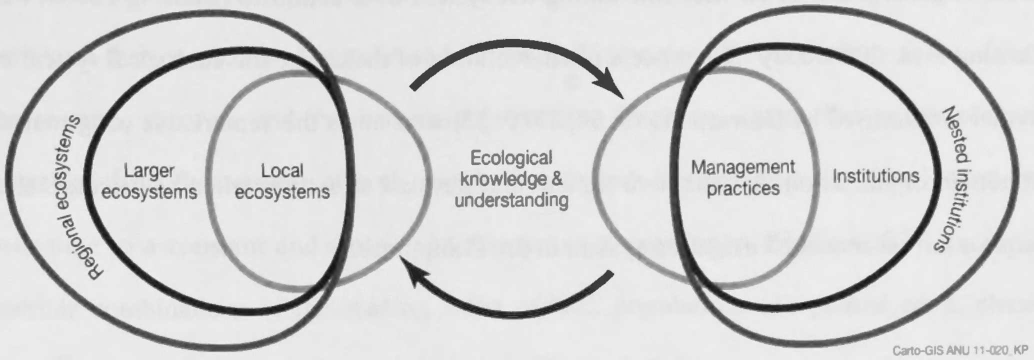

Figure 2.2: Linked social-ecological system

Source: (Berkes et al. 2003a: 22)

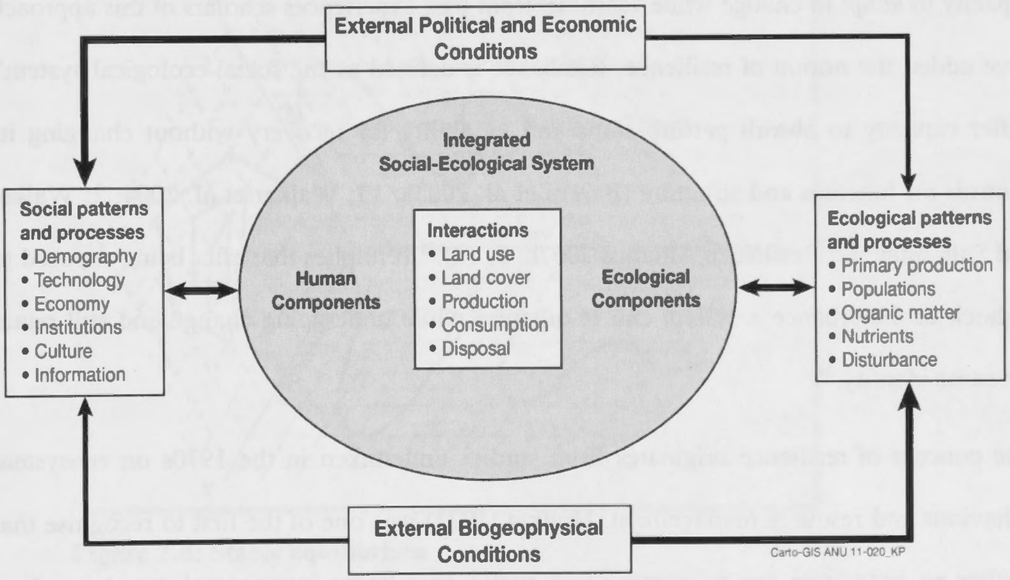

Figure 2.3: Integrated social-ecological system

Source: (Redman et al. 2004: 164)

Using an integrated approach for the study of Southeast Asian rice production systems, I argue, is fundamental because the specific cultural landscape would not exist without the social organisation that maintains it and vice-versa. The co-evolution over several centuries of social institutions that govern the cultivation and irrigation of rice is what the subak and many other communal rice production systems stand for. Endogenous institutions are reflected in the engineered landscape of the rice terraces that has required the combined effort of generations of farmers fine-tuning the system over centuries (Lansing 2006a: 62; Lansing et al. 2006: 331). The process of co-evolution of the social and ecological system is further emphasised by Coward (1979: 34; 1980: 25) who notes the 'remarkable congruence' of human organisation, natural environment and physical structures when he discusses the *zanjeras* farmer-managed irrigation system in the Philippines.

Resilience and Basin of Attraction

To provide a basis for understanding the dynamics of social-ecological systems and their capacity to adapt to change while 'learning' from past experiences scholars of this approach have added the notion of resilience. Resilience is defined as the social-ecological system's buffer capacity to absorb perturbations and its ability for recovery without changing its controls on function and structure (Berkes et al. 2003a: 13; Walker et al. 2004: 2; Walker and Salt 2006: 32; Resilience Alliance 2007b: 5, 16).[38] It implies that after being exposed to a shock or disturbance a system can re-organise while undergoing change and still retain the same identity.[39]

The concept of resilience originates from studies undertaken in the 1970s on ecosystem behaviour and resource management. Holling (1973) was one of the first to recognise that neither an ecosystem nor its components evolve in a linear incremental way toward an equilibrium state. In a simplified model of an ecosystem that consists of two populations

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[38] In some of the definitions of resilience a further term called 'feedbacks' is added. I have decided to exclude it for the sake of clarity. Feedbacks basically reiterate and reinforce a system's identity; they are signals within the system which loop back to control the system, either stabilising or destabilising it (Resilience Alliance 2007a: 35). Feedback relates to the amount of different components, such as for example depending on the amount of grass in a pasture that has built up, it takes the cattle longer or shorter time to eat through it. The amount of grass growing again depends on the amount of rain and other climatic and soil conditions. However, on the whole, a pasture-cattle system will remain a pasture-cattle system as long as the grass grows and the cattle feed on the grass.

[39] I am using the term 'identity' here to summarise what Berkes et al. (2003a: 13) call 'retain control over functions and structures' and what Walker et al. (2006) list as 'functions, structures, feedbacks, and therefore identity' and which Cumming et al. (2005: 976) define as the 'property of key components and relationships and their continuity through space and time'.

only in a constant environment, a herbivore population and its resource regulate each other in a linear dynamic way. This linear development implies that when food is plentiful, the herbivore thrives until food is gone and so the herbivore population declines again. Then the resource recovers and the herbivore population increases again. The amplitude (or range) of these fluctuations of both populations (which lag one after the other) decrease over time to a constant and sustained value for each population (Holling 1973: 2). If all possible combinations of the starting value of both populations are plotted on a 'phase plane'[40], trajectories emerge that spiral inwards (Figure 2.4).[41]

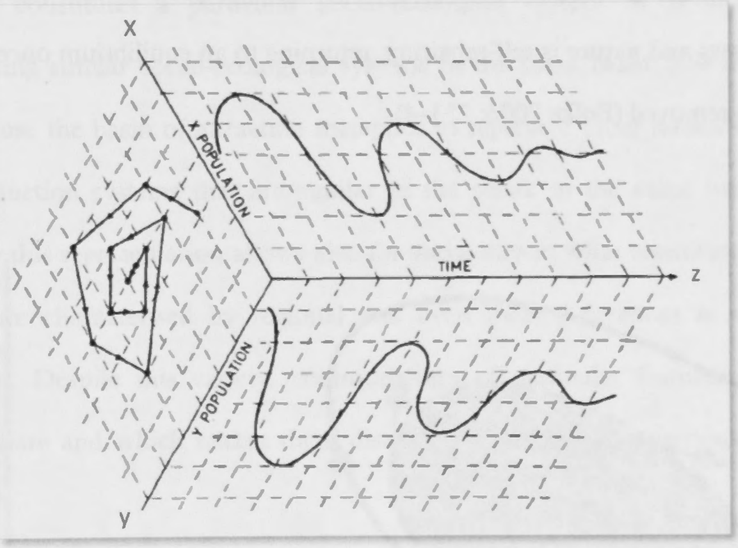

Figure 2.4: Stable equilibrium

Source: (Holling 1973: 3)

Models of natural systems that develop towards equilibrium with fluctuations decreasing over time, as Holling (1973: 1–5) explains, are however not an adequate representation of

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[40] A phase plane is a particular type of graph used in mathematics for the visual representation of changing states of physical systems.

[41] The two x population and y population axes in Figure 2.4 represent the density of each population. The z axis represents time. Decreasing fluctuations of each population are shown in relation to time. The trajectories that result from these decreasing fluctuations are displayed on the left. Each point represents the unique density of each population at a particular point in time while the arrows show the direction of change in time. All possible trajectories spiral eventually into an equilibrium.

reality. By studying the behaviour of lake and pasture systems he suggested that under certain conditions ecosystems can collapse and with it whole populations of the innate flora and fauna disappear. Thus, the general structure and identity of a system can completely change and a new equilibrium is established which Holling (1973: 3) calls *domain of attraction* or *basin of attraction*.[42] Representing this behaviour graphically as trajectories results in a region in the centre defined as basin of attraction where all possible trajectories spiral inwards; whereas those outside this specific region spiral outwards and eventually lead to the extinction of one or the other population (Figure 2.5). Accordingly, as long as the system stays within this region while being exposed to external or internal disturbances it is resilient. This insight goes against the previously held perspectives that humans can control resource flows and nature is self-repairing, returning to an equilibrium once human stressors have been removed (Folke 2006: 253–4).

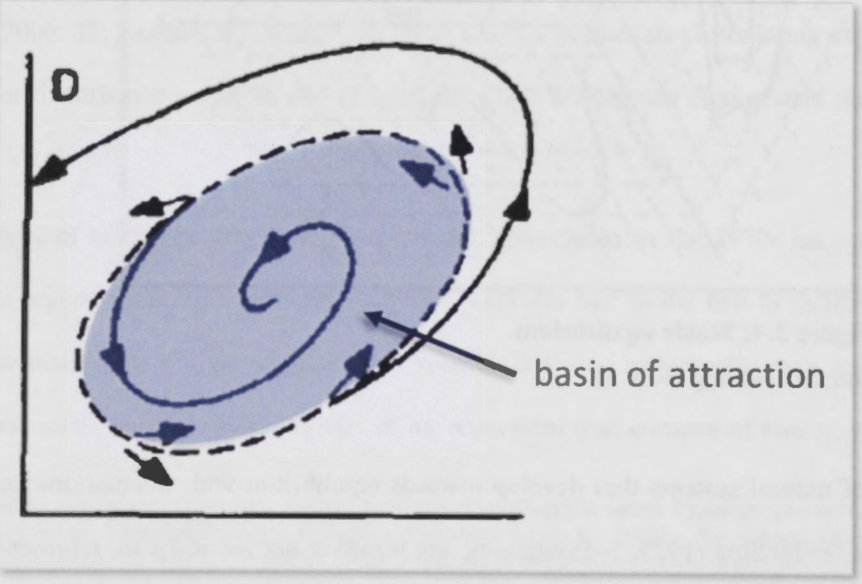

Figure 2.5: Holling's basin of attraction
Source: (adapted from Holling 1973: 4)

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[42] There are several substitute terms that are used in lieu of 'domain of attraction' such as 'basin of attraction', 'alternate stable state', 'regime', 'stability domain and attractor' (Walker et al. 2002: 5; Redman and Kinzig 2003: 9; Cumming and Collier 2005: 4; Folke 2006: 2; Walker et al. 2006: 6). Here I will be using 'basin of attraction'.

The addition of resilience to the concept of social-ecological systems provides the missing element which could help to understand how the subak evolved over the past couple of decades, how it managed to survive the impacts of the Green Revolution and adapt to the changes imposed, and how the subak handles contemporary challenges of rural diversification. In applying the resilience concept to the analysis of the subak as a social-ecological system I suggest that the subak was resilient to the inflicted shock of the Green Revolution and was able to adapt to the changes while basically maintaining its identity.

Resilience scholars use the basin of attraction concept as a figurative representation of the resilience of social-ecological systems which allows for a certain bandwidth of or flexibility in what constitutes a particular social-ecological system. It is also convenient for representing similar social-ecological systems in the same basin. For the purpose of this thesis, I use the basin of attraction metaphor to represent other farmer-managed irrigated rice production systems that are similar to the subak in the same basin of attraction.[43] Likewise this representation allows also for variability in what constitutes a subak. In fact, subaks are characterised by regional and even local differences in the way they are organised. Despite this variety, commonalities of particular features remain which all subaks share and which makes them distinctively unique as a particular rice production system.[44]

In exploring the subak's resilience I emphasise the strong interconnectedness of social and ecological components in an integrated social-ecological system. Thus, if speaking of resilience I specifically refer to the resilience of this combined social-ecological system with all its complexity. Many scholars of social-ecological systems and resilience do break the two apart and speak of either social or ecological resilience: the ecological resilience of the ecosystem towards changes inflicted by the human community living in this area (Anderies

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[43] This will be discussed in detail in chapter 3.

[44] This will be discussed in detail in chapter 4.

et al. 2004: 7; Adger 2005), or, the social resilience of the community to survive and adapt when an ecosystem collapses (Adger 2000; Adger et al. 2002; Adger 2005). I argue that in the case of the subak and its resilience, it does not make sense to break the two apart. The subak as a social-ecological system cannot 'move' if, for example, the local agroecosystem collapses because its social components are very much part of the agroecosystem. The subak would simply cease to exist if the option of producing rice was impossible or if rice was produced in an entirely different way due to either the collapse of the ecological components, the social components or both. Folke (2006: 263) points out that research on social-ecological resilience is still in the explorative phase. I believe this thesis may serve as a good example for studying the 'combined' social-ecological resilience.

Multiple Basins of Attraction

The concept of resilience and its representation as a basin of attraction imply that if a system loses its resilience it can move across to another basin of attraction where it expresses a different identity (Resilience Alliance 2007b: 15). For a visualisation of alternative identities resilience scholars use the metaphor of a matrix shaped with basins and ridges (Figure 2.6). The matrix in this context is usually called 'stability landscape' or 'state space' (Carpenter et al. 2001: 766; Walker et al. 2002; Gallopin 2006: 297; Walker et al. 2006; Resilience Alliance 2007b: 14–6, 19, 30, 40). The basins represent different basins of attractions in which a social-ecological system could theoretically exist.

The boundaries of the basin are marked as dotted lines. The ball that rolls around in that stability landscape represents the social-ecological system. The ball is constantly moving but staying in the same basin. External and internal disturbances of varying strength push the ball around, at times closer to the ridge and the boundaries to another basin. If the ball rolls back into the basin it implies the social-ecological system is resilient to change.

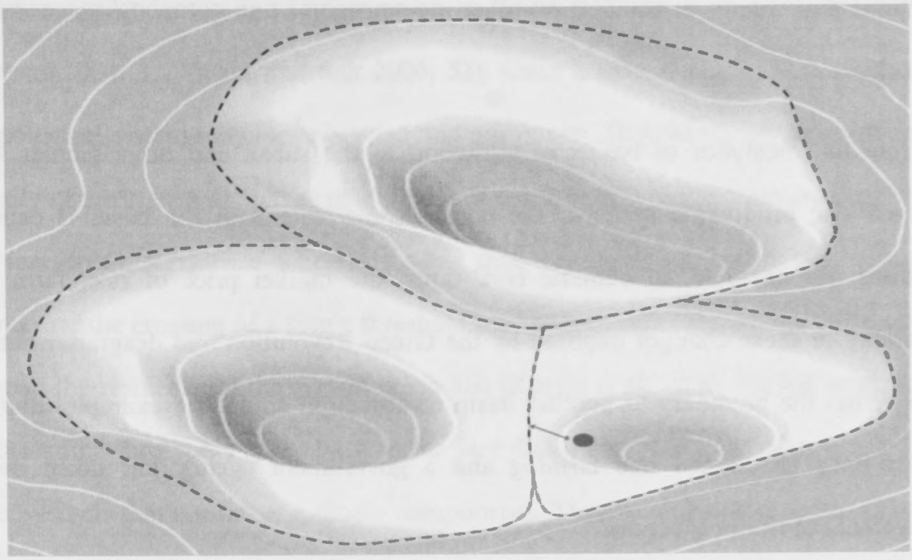

Figure 2.6: Stability landscape with three basins of attraction

Source: (adapted from Resilience Alliance 2007b: 16)

The disturbances can set off positive or negative reactions, reinforcing the system's identity or destabilising it; or in figurative words make the ball stay in the basin or push it closer and eventually over the ridge. A push over the ridge can be gradual or rapid depending on the developments that precede the event. A rapid push could be in form of a natural disaster whereas soil fertility decreasing over a long period of time could represent a slow and gradual push over the edge. Once a system has moved beyond the boundaries of a particular basin of attraction into another basin, a qualitatively different pattern of behaviour emerges, displaying a different identity characterised by a change in dominant components, system structure and processes that reinforce this new identity (Walker et al. 2004; Allen et al. 2005: 958; Resilience Alliance 2007a: 38; 2007b: 5).

A simple example that explains this conceptual visualisation is a pasture system being overgrazed (too many cattle or cattle grazing for too long) which leads to a change in the composition of the flora formerly consisting of mainly grass varieties (of desirable quality to be fed to cattle) to shrubs or weeds no longer deemed suitable (or even harmful) as cattle feed. Disturbances that cause the system to be overgrazed would be, for example, climatic conditions that change or the farmer's time management to attend to the pasture and his livestock.

Applying the metaphor of basins of attraction to the subak and other similar farmer-managed rice production systems, the constant 'movement' in the basin is caused by variations, for example, in climatic conditions, the market price of rice, farm labour availability or those changes imposed by the Green Revolution and deagrarianisation. A move across the boundary to another basin of attraction could, for example, imply that farmers have abandoned rice farming and a government agency has taken over the management of rice production.

Thresholds

Resilience theory further implies that the stability landscape of the system is defined by 'state variables' that constitute the system (Walker et al. 2004: 3). These state variables characterise the function and processes of the system (that is the identity of the system) and are measureable or can be tracked (Suding et al. 2004; Resilience Alliance 2007a: 78). Because social-ecological systems are highly complex systems, a visual representation would necessitate a multidimensional stability landscape with multiple axes (defined by the multiplicity of variables) with multiple basins of attraction each of which exhibits a complex and constantly changing shape (Resilience Alliance 2007b: 40).

Changes in the value of the state variables affect the state space and may lead a system to move to another basin of attraction. The value of the state variables that evokes this move is the threshold. Each state variable has a threshold and the summary of all thresholds demarcates the boundaries of one particular basin of attraction (dotted lines in Figure 2.6) or in other words the resilience of a social-ecological system. Determining the thresholds of a basin of attraction is crucial to the process of defining the identity of a system.

Losing resilience will move a system closer to thresholds or across thresholds, potentially altering a system's identity and impacting on its future (Holling et al. 1998: 353; Walker and Meyers 2004: 3; Walker and Salt 2006: 53). Once a system threshold is crossed the social-ecological system may move beyond and not return. This movement depends on the complexity of the system as well as on the kind of reaction that results from crossing one or several thresholds. Resilience scholars suggest that thresholds are interacting with each other and that the crossing of a single threshold may induce other thresholds to be crossed resulting in the resilience of the system being lost (Kinzig et al. 2006; Walker et al. 2006). These cascading thresholds relate back to the fact that social-ecological systems *per se* are complex systems that consist of multiple components. These multiple components interact with each other in non-linear ways, inducing reactions that can reinforce or destabilise the system's identity.

With respect to the Southeast Asian rice farming system, the stability landscape is first and foremost defined by land suitable for wet rice cultivation, by water available in adequate quantities and fed by gravity through the irrigation system, by sufficient supply of nutrients and labour that is required to cultivate and irrigate the rice. These variables not only define the landscape by their quantities but also by their qualities.[45] Thresholds that define the identity of the Southeast Asian rice farming system are a certain level or range of values of these variables. If, for example, labour is not sufficiently available or not enough water available to irrigate the rice fields, the subak may have difficulties existing as per the definition of its identity —an efficient and productive farmer-managed irrigated rice production system. If the threshold for water is crossed, rice yields would decrease, which both may impact on the willingness to cooperate in sharing water (another threshold), and impact on the finances of the farming household (another threshold), which may lead to

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[45] For instance, soil fertility (land quality indicator) and water quality (for example the content of silt and dissolved run-off fertilisers from fields above or pollution) have an impact on rice yields which equally influence the type of production system.

farmers giving up rice farming thus reducing the membership numbers (another threshold) of the subak. In so doing, several thresholds are then crossed. If the subak can regain its former identity when water flow is returned to normal, that is, farmers return to grow rice and cooperate again in sharing water, then the subak can be termed resilient.

Alternative Basins of Attraction - Scenarios

A social-ecological system moving to another basin of attraction implies that it loses its identity and therefore its resilience.[46] This move can have considerable implications for the people that are part of this particular social-ecological system. The 'flip' may therefore be desirable or undesirable. This can be again simply illustrated with the example given earlier: A farmer would have to invest a considerable amount of time and effort into turning shrub-dominated land back into a pasture. Yet managing the pasture to restore the flora to its former composition may be difficult or impossible. It may not be enough to just give the patch a rest for a while and it may require a considerable effort to remove some of the shrubs manually. So here the pasture has 'flipped' from a 'desirable' basin of attraction into a different 'undesirable' equilibrium which is entirely undesirable to the farmer, unless she would give up that patch of land as pasture or would move on to do other things than keeping livestock. Applying the concept of multiple basins of attractions to the subak suggests that the subak would, when losing its resilience, move across thresholds and end in another basin of attraction. In this new basin of attraction the 'subak' would display a completely different identity and would function entirely differently and therefore could no longer be named a subak, which may not be desirable for the Balinese. For example, if irrigation water flow was considerably reduced, farmers may turn to alternative, more

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[46] Resilience scholars also use the term 'regime shift' to describe a system's move across thresholds into an alternate basin of attraction. The term 'regime' refers to the 'set of states' that define a basin of attraction, also called 'configuration' of a system with the same structure and functions (Walker et al. 2004). In my opinion, it is basically another explanation of the term 'identity'. The 'set of states' refers to different positions in a particular basin of attraction or in figurative words the forces that make the ball move around implicate slight changes to the current 'identity' of a particular social-ecological system.

individualistic ways of irrigating their fields such as groundwater pumping, which will impinge on collaborative efforts in maintaining the irrigation systems and eventually lead to the dissolution of the subak's identity.[47]

The dynamic complexity of social-ecological systems implies that they behave in unpredictable and uncontrollable ways when variables change and thresholds are crossed, which makes it difficult to predict their future. Resilience scholars suggest using scenario tools which help to address these challenges. Scenario building has been used by corporate enterprises to construct alternative ways of thinking about the future, which allows a company to prepare for a wider range of eventualities (Davies 1998: 3). Scenarios are not a forecast, rather a structured narrative about possible future pathways (Resilience Alliance 2007b: 32). The objective is to get an understanding of the future in terms of fundamental trends and uncertainties by simplifying complex aspects into separate scenarios (Shoemaker 1995: 28). These scenarios, which represent alternative basins of attraction, allow exploring several possible futures using particular assumptions about how variables that influence a social-ecological system change.

Resilience scholars also highlight the possibility of initiating transformation so as to change the basin of attraction that a social-ecological system occupies or push the system into another basin of attraction that is more desirable than the previous one. In other words, scenario development as instigator of a creative thinking process may help to develop alternative policies and ways of management that change a system's identity to a more desirable one (Peterson et al. 2003; Cumming et al. 2005; Resilience Alliance 2007a; b). Research into how to initiate change to transform a social-ecological system is, however, still in its infancy. Different disciplines are studying separate aspects such as the role of learning, social networks and institutional flexibility, but do not yet fully understand the interdependent dynamics of social-ecological systems (Olsson et al. 2010).

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[47] The trend to farmers using more individualistic irrigation options has been reported in other regions by Dawe (2005b), Bastakoti et al. (2010) and Turral et al. (2010: 553).

Anderies et al. (2006) suggest that transformation is based on people's capacity for learning and adapting and 'the capacity of a social-ecological system to reinvent itself, to become a different kind of system when the existing one is no longer tenable'. Olsson et al. (ibid. 2010) expand these suggestions, proposing that social-ecological system transformation also involves agency for changing management paradigms, institutional settings, underlying norms and values, and knowledge production as well as developing social networking abilities to access different levels of society for building support. They (ibid.) further argue that transformational change is most likely to occur at times of crisis but can also develop from an understanding of and capacity to respond to ecosystem dynamics.

For the Balinese subak, scenarios development offers a planning device to start thinking of alternative possible futures and the subak's place in and value for Balinese society. The current trends that rural diversification has caused by withdrawing its main resources from the subak may well represent a time of crisis. According to Carpenter et al. (2001: 777) the likelihood that a social-ecological system will stay within a basin of attraction is related to slowly changing variables and the magnitude of disturbances that may push the system across boundaries. While the order of magnitude appears to be small, the emerging trend of increased withdrawal of land, labour and water may act as slow changing variables to trigger a move. The uncertain future of the subak opens up pathways of possible transformations of the subak to reinvent itself and to invigorate its position in Balinese society.

ANALYTICAL FRAMEWORK

In applying resilience theories to the analysis of the subak I need to develop an understanding of what the basin of attraction looks like for the subak and similar Southeast Asian rice farming systems. This comprehension also implies exploring possible thresholds that demarcate the boundaries of the basin of attraction. Defining the boundaries is an essential step in the process of examining social-ecological systems.

Representing the subak and similar rice farming systems as social-ecological systems acknowledges that these are complex systems of overlaying dimensions consisting of ecological and social components which are interconnected and which interact with each other in non-linear ways. This representation further acknowledges that these systems have an adaptive capacity to learn from disturbances in the past to adapt to changes imposed in order to continue to exist. The stability landscape in which these rice farming systems exist is defined by multiple variables of quantitative and qualitative nature with multiple basins of attractions.

The complexity and multidimensional character of the stability landscape necessitates a simplification to define the basin of attraction of the subak and similar Southeast Asian rice farming systems. Considering an interdisciplinary approach including multiple perspectives for the analysis I develop a model of these rice farming systems using four overlaying dimensions that contain the ecological and social components of these rice farming systems (Table 2.2). Each dimension contains state variables with a set of thresholds that define the boundaries of this specific basin of attraction (Figure 2.7). The four dimensions overlaying each other define the basin of attraction and its four-dimensional boundaries (Figure 2.8).

Table 2.2: The four dimensions of the Southeast Asian rice farming system model

Dimension	*Components*	*State variables*
Ecological	Agroecosystem, including bunded rice fields and accompanying flora and fauna, soils and water	Water, nutrients, biodiversity
Physical	Physical structures, such as a gravity-fed irrigation system and temple structures	Land, type of irrigation, type of water conveyance
Technical	Cultivation and irrigation techniques including knowledge Invested labour	Invested labour, labour techniques, mobilisation of labour
Institutional	Rules and regulations for collaboration Water and rice rituals	Principles of water sharing

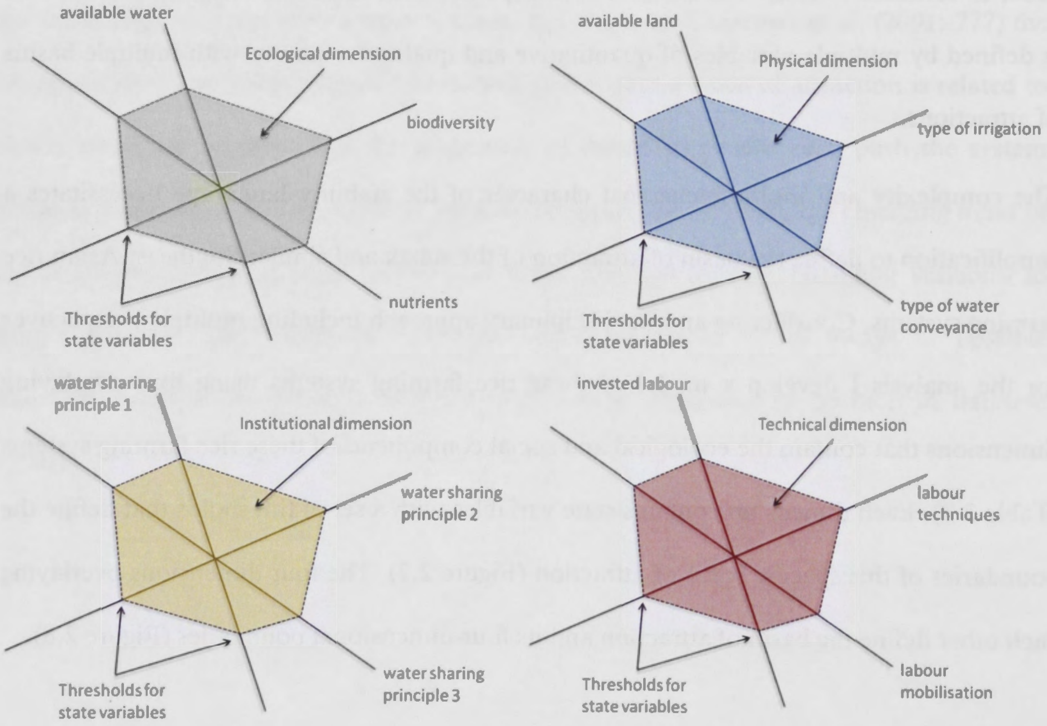

Figure 2.7: The four dimensions, state variables and thresholds

Specifically I define the four dimensions of the Southeast Asian rice farming system model as follows:

- **Physical dimension or *how the physical infrastructure works***

  The physical dimension includes basic resources that are required for the cultivation and irrigation of rice: a contiguous area of rice fields organised in rice terraces, a gravity-fed canal irrigation infrastructure with a dam at the river, and in some of these rice production systems also temple structures. Water is fed by gravity to individual fields with the supply of water reliant upon the natural flow of the source. Depending on the topography and location of rivers in relation to the fields, highly developed skills are required to construct such an irrigation infrastructure.

- **Ecological dimension or *how the physical and biochemical processes of the rice field ecology work***

  The ecological dimension comprises the underlying ecology of the wet rice agroecosystem that enables the cultivation of rice: sufficient water, high nutrient availability due to continuous flooding of the fields as well as due to sediments carried in irrigation water, and a rich biodiversity which keeps rice pests at bay.

- **Technical dimension or *how the rice fields are irrigated and cultivated***

  The technical dimension encompasses the ways in which resources are mobilised to grow rice: labour that is invested and techniques that are applied, which also includes rituals practiced in rice cultivation and irrigation. These particular rice production systems necessitate high labour input to transplant, weed and harvest the rice, and to maintain the physical infrastructure as well as the ability to coordinate peak labour requirements amongst household members.

- **Institutional dimension or *how farmers collaboratively work together to grow and irrigate rice***

  The institutional dimension considers the incentives and guiding principles under which communities collaborate to grow and irrigate rice and to maintain the irrigation facilities at an operational level. Farmer-managed irrigated rice production systems are characterised by a hierarchically nested organisational structure, consensus-based locally devised and adaptable rules guided by principles of equity, egalitarianism and transparency, and a set of rituals as coercing element symbolically binding members to cooperate.

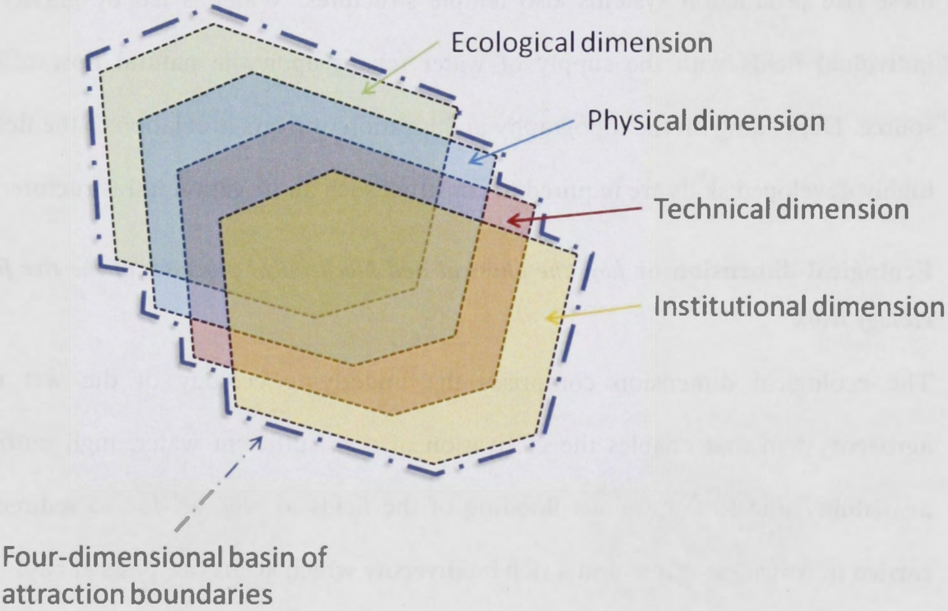

Figure 2.8: Basin of attraction of the rice farming system model

With these four dimensions I define the identity of my model of Southeast Asian rice farming systems. In so doing, I combine quantitative and qualitative data using my extensive field research knowledge combined with surveys and interviews I have conducted with farmers in my field site supplemented with references from the literature. Although I split the analysis into four dimensions I acknowledge interactions between these dimensions and their respective thresholds.

I have used the term identity to summarise all characteristic features including the system's function and structure. Within the boundaries of this specific basin of attraction the primary function of these systems is to produce rice by relying on certain amounts of land, labour and water.[48] The structure relates to who the main managers of these systems are, the set-up of how rice fields are irrigated, how the physical irrigation infrastructure works, how farmers collaboratively work to grow and irrigate their rice, and how the physical and biochemical processes of the rice field ecology support the growing of rice. In the next chapter (chapter 3) I discuss these four dimensions in detail for a comprehensive understanding of what constitutes a Southeast Asian rice production system. I also define thresholds for each dimension which demarcate the boundaries of this specific basin of attraction. In chapter 4 I situate the subak of the field research site in the defined basin of attraction for each of the four dimensions.

Applying the added element of resilience implies that these social-ecological systems are exposed to disturbances which can potentially change their development trajectory. If a system is resilient to an imposed disturbance, it retains its identity. If a system loses its resilience it transforms and its identity changes. In my discussion of the impacts of the Green Revolution and current challenges caused by deagrarianisation in chapter 5 and chapter 6, I focus on particular key issues and their dynamics that affected the four dimensions and their thresholds in various ways. I examine whether thresholds have been crossed or are approached and what the implications are of the changes that occurred, respectively how the subak adapted to these changes and how it retained its identity.

Losing resilience implies that the thresholds that demarcate the boundaries of a system's identity are crossed. This transformation may be found desirable or undesirable by those whose livelihoods depend upon the system. I argue that if the subak loses its resilience it could turn, for example, into a government-managed irrigated rice production system with farmers giving up rice cultivation, or into a production system of dry land crops if water

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[48] I acknowledge that there are other functions to these specific rice production systems such as, for example, the preservation of cultural heritage or the maintenance of ecosystem services. For the purpose of the analysis, I mainly focus on these systems as rice production systems. I touch briefly on these additional functions in the discussion of the scenarios.

was insufficient. Such developments may not be desirable for the Balinese for whom the subak has been such an inherent part of their culture. Studying past events that impacted on social-ecological systems but allowed for a recovery enables a detailed analysis of how a system remains resilient and how it adapts to imposed changes. This adaptive capacity may support such systems in facing future challenges. In a last chapter (chapter 7), I define alternate basins of attractions that serve as scenarios of potential future trajectories for the subak, given current trends and issues and the experiences of the past.

CONCLUSION

The resilience concept is a way to understand nonlinear dynamics of system processes in the face of change and perturbations, allowing for the analysis of the adaptive capacity towards sustainable development (Berkes et al. 2003b). I have used social-ecological systems and resilience theories to develop an analytical framework to examine past and contemporary challenges to the subak. The analytical framework consists of a four-dimensional model that represents the basin of attraction for Southeast Asian rice farming systems. I use this model to examine whether there are any indications that thresholds have been approached in the past or are presently being approached.

Times of crisis and transformation evoke responses from social-ecological systems. Discrete events such as, for example, the Green Revolution reveal a system's ability to cope and adapt and demonstrate how resilient the system is towards change (Adger 2006). With the impact of the Green Revolution the subak showed such an adaptive capacity in that it changed and adapted without losing its identity and moving to another basin of attraction. With rural diversification ongoing, the subak so far again shows signs of adaptive capacity to respond to the changes imposed. A resilient system is open for innovations following disturbances, whereas in a vulnerable system, in contrast, even small disturbances may lead to dramatic social consequences (Adger 2006; Folke 2006). The subak's potential future lies in that adaptive capacity.

The capacity to adapt to change depends on the ability to re-organise or self-organise, which in turn relies on a system's inherent individuality and diversity. Self-organisation is a process in which an apparent randomness of parts of the system spontaneously results in complex organisation without external intervention, creating 'order out of chaos' (Ison et al. 1997: 261; Lansing 2003: 192). Lansing (1991; 2000; 2006a) demonstrated by means of computer models and simulation that the way in which water is shared among subaks on the watershed-level is self-organised. Accordingly, this process of self-organisation which seems to be governed by chance on the individual level becomes strikingly predictable on the watershed level (Figure 2.9) (Lansing 2003: 185):

> [S]ubaks do not consciously attempt to create an optimal pattern of staggered cropping schedules for entire watersheds. Yet the actual patterns …observed in the field bear a very close resemblance to computer simulations of optimal solutions (Lansing 2000: 313).

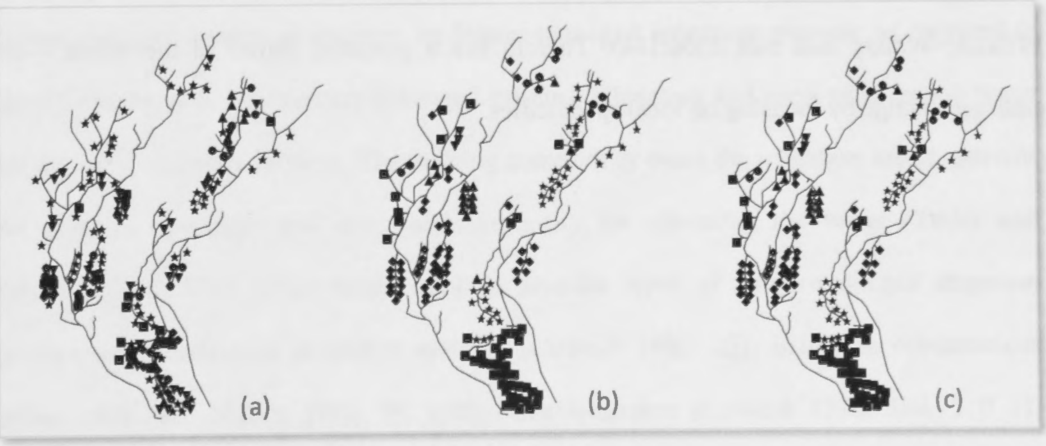

Figure 2.9: Process of self-organisation: coordinated cropping schedules in subaks

Symbols indicate subaks, different symbols indicate different cropping patterns: (a) Initial conditions for a simulation model (b) Computer simulated cropping pattern after 11 years (c) Actual observed cropping patterns (adapted from Lansing 2006a: 79–81)

The ability of self-organisation is only possible in systems where diversity and individuality on the component level is maintained (Folke 2006: 257; Walker and Salt 2006: 121). This heterogeneity is certainly maintained in subaks with respect to ecological components: irrigated rice fields are characterised by a high species diversity (both flora and fauna) that is unmatched by most other agroecosystems (Settle et al. 1996: 1976; Bambaradeniya and Amarasinghe 2004: 7–13). In terms of social components, subaks are characterised by regional and even local differences in the way they and their sub-groups are organised. Geertz and Geertz (1975: 32) remarked that it is precisely these 'surface variations' of the subak that exemplify and illuminate the underlying level of profound common agreement on fundamental values, belief systems, and social definitions.

Resilience scholars argue that the key to sustainability lies in enhancing resilience: a resilient social-ecological system that can buffer change and perturbation is sustainable (Walker et al. 2002; Berkes et al. 2003b; Bingeman et al. 2004; Walker and Salt 2006). This conceptual model emphasises the point that disturbances are in fact essential for the system and part of development (Folke 2006). Central to resilience thinking is the idea that rather than optimising single components of a system the focus should be on 'embracing change', keeping the options open and an emphasis on spatial heterogeneity or diversity (Holling 1973:21; Walker and Salt 2006:114). Therein lies a potential future of the subak —to embrace change by focusing on local specificities.

CHAPTER 3

SOUTHEAST ASIAN COMMUNAL RICE FARMING SYSTEMS

INTRODUCTION

For my analytical framework I have proposed a model of Southeast Asian rice production systems as a social-ecological system being in a specific basin of attraction. I use four overlaying dimensions as basis for the analysis of the basin of attraction in which these Southeast Asian rice production systems exist. Each of the four dimensions is demarcated by thresholds of the state variables that define the dimensions. In this chapter I discuss this basin of attraction for each of the four dimensions in detail and suggest key thresholds for each of the dimensions.

The subak and similar rice production systems in Southeast Asia can be described as farmer-managed irrigation systems. In farmer-managed irrigation systems, as opposed to agency-managed or bureaucracy-managed systems, allocators and users of irrigation water are almost exclusively farmers. The farming community owns the irrigation assets, governs the system's operation and commands authority for allocating the water (Yoder and Pradhan 2005: 473). Other terms used to describe types of farmer-managed irrigation systems are community irrigation systems (Coward 1980: 25), irrigation communities (Hunt 1988: 80; Mabry 1996: 9), indigenous irrigation (Coward 1980: 204, 210–11; Groenfeldt 1991: 115) or locally managed irrigation systems (Yoder 1994: 2–3; Dayton-Johnson 2003: 316). Each of these terms basically indicates who holds the charter of authority or, in other words, who mainly controls and operates the system. Some scholars use the terms interchangeably (Coward 1980: 25, 204). Irrigation communities, indigenous irrigation or locally managed irrigation systems are more inclusive as the charter of authority can also be with local government or other local entities (private non-farmers or businesses) and not exclusively with farmers. Yet all of these terms imply that the irrigation system has originated from a local initiative, developed by farmers' own initiation and investments.

Describing the subak and similar Southeast Asian rice farming systems as farmer-managed irrigation systems fails, however, to indicate the type of irrigation and their main production focus. Thus, a more precise description would be a farmer-managed canal-irrigated rice cultivation system. The irrigation water is diverted from a river by gravity into a series of canals to the rice fields, organised in rice terraces. Irrigated rice is grown at least once a year, usually during the wet season when more water is available. There are also some variations. In *zanjeras* studied by Siy (1982: 111), 94 per cent of farmers grew a second crop of rice in the dry season in addition to other crops, as most farmers have several parcels of land that allows them to make separate production decisions for each parcel. In Northern Thailand, farmers grow one crop of rice mainly or exclusively in the wet season while the dry season is dedicated to other non-rice crops due to the limited availability of water for irrigation (Cohen and Pearson 1998: 87; Walker 2003: 953–4; Neef et al. 2006: 8).

The representation of these farming systems in a basin of attraction permits this flexibility in rice cropping intensity (how many crops of rice per year). The basin of attraction is a visualisation of the major commonalities to all these specific rice farming systems. Due to each location's specific landscape, topography, environmental and human history and human culture a distinct farmer-managed canal-irrigated rice cultivation system has evolved (Chambers 1988: 211). Accordingly, if represented in a basin of attraction, these systems would be situated at different locations within the basin.

What makes a system a farmer-managed canal-irrigated rice cultivation system? What features would indicate that this system has changed and can no longer be identified as a farmer-managed canal-irrigated rice cultivation system? What keeps this system in this specific basin of attraction and what would move it out of the basin? To answer these questions I discuss each dimension and suggest key thresholds to define the boundaries of the basin of attraction. In some instances I choose proxies to measure or define whether a certain threshold is reached or crossed as some measurements are difficult or impossible to obtain. In using proxies it is important that they are highly correlated to the actual variable (Small and Svendsen 1990: 304). Because thresholds can have cascading effects, by triggering other variables to reach the threshold, I also examine cross-dimensional linkages between thresholds.

The discussion of this specific basin of attraction is focused on how these Southeast Asian rice farming systems existed before the introduction of Green Revolution technologies. This historic focus will provide a basis for situating the subak of this time in the basin of attraction in chapter four and the discussion of the impacts of the Green Revolution on the subak that follows in chapter five.

PHYSICAL DIMENSION

The physical dimension includes the basic resources which are required for the cultivation and irrigation of rice: the irrigation facilities and the land to be irrigated. In several of the rice production systems, other physical structures exist which serve as meeting points for their members, as storage facilities or joint places of worship (Geertz 1972: 30; Siy 1982: 53; Lansing 1991; Jha 2004: 555; Sutawan 2004: 2; Lansing 2006a).[49]

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[49] As I have discussed in the previous chapter, the representation of these systems as basin of attraction allows for this kind of variation.

Farmer-managed canal-irrigated rice cultivation systems are typically found in the valleys of hilly to mountainous terrain (intermontane basins). To create bunded and levelled fields on the slopes of hills or mountains, a more sophisticated technique to convey the water and keep it in the fields is required. To this end, terraces are constructed which follow the contour lines of the slopes. This technique allows for the maximisation of cultivation area and reduces risk of soil erosion. It requires great skills and a collective effort by the community in terms of time and labour. Building of terraces has a long history in Southeast Asia. The engineered landscape of rice terraces and gravitational waterway networks has evolved over centuries through continuous labour of generations of farmers mending and refining the system (Lansing 1991: 128; Tanaka 1991: 568–9). In many regions where these rice farming systems are found, terraces have become an integral part of the landscape.

Figure 3.1: Traditional dam at the river

Source: (Brouwer et al. 1992: fig. 7)

The irrigation facilities include an acquisition structure for water intake at the river (Figure 3.1), a conveyance canal (also called primary canal) and a network of distribution canals (also called secondary and tertiary canals) with suitable division structures and individual field inlets. As the river water is dammed, part of the flow enters the irrigation system and part of the flow continues down the river where possibly other farmer-managed canal-irrigated rice cultivation systems access irrigation water. The structural set-up of the canal network which subsequently delivers water to the individual field level can be compared to a tree: the primary canal (stem) distributes the water to smaller secondary canals (branches) diverting it to the tertiary canals (twigs) and eventually delivering it to the fields (leaves) (Bosch et al. 1992: 3). Horst (1998: 16) calls this type of distributional layout a 'bifurcating system' (Figure 3.2).

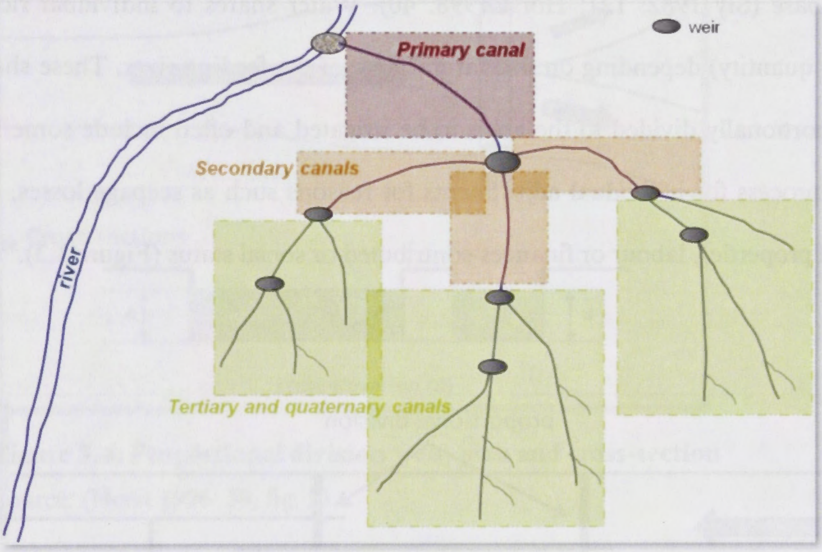

Figure 3.2: Bifurcating canal distribution system

Canals are positioned in a way that the natural hill slope is used to let the water flow by gravity through the irrigation network. According to Brouwer et al. (1988), these systems can be classified as surface basin irrigation systems. In surface basin irrigation systems water is applied by gravity flow to the surface of flat areas of land that are surrounded by bunds to allow the flooding of the entire field. Water in such systems is constantly flowing, with outflow of water from higher fields reused in fields further down the hill. Reuse is either directly through seepage and leakages or indirectly with water collected in drainage canals eventually returned into irrigating canals and fields further downstream. Water allocation and distribution in these rice farming systems is supply-driven, that is, fluctuations of the incoming flow are passed on to all canals in the system. In peak demand times and in the dry season when water supply is generally lower, rotational delivery may be used (Siy 1982: 121–2; Ostrom 1992: 50; Horst 1998: 40, 50). With rotation, water is delivered to fields at certain times or upon request, either with fixed rotation, or varied frequency and/or duration. Rotation is undertaken on the irrigation system unit or sub-unit level by negotiation among different groups, but not on an individual field inlet basis.

Water is divided equitably and all fields receive water simultaneously, that is, on a continuous base (Siy 1982: 121; Horst 1998: 40). Water shares to individual rice fields fluctuate (in quantity) depending on the natural flow of the feeding river. These shares are usually proportionally divided to the areas to be irrigated and often include some form of negotiation process for individual adjustments for reasons such as seepage losses, specific soil physical properties, labour or finances contributed or social status (Figure 3.3).[50]

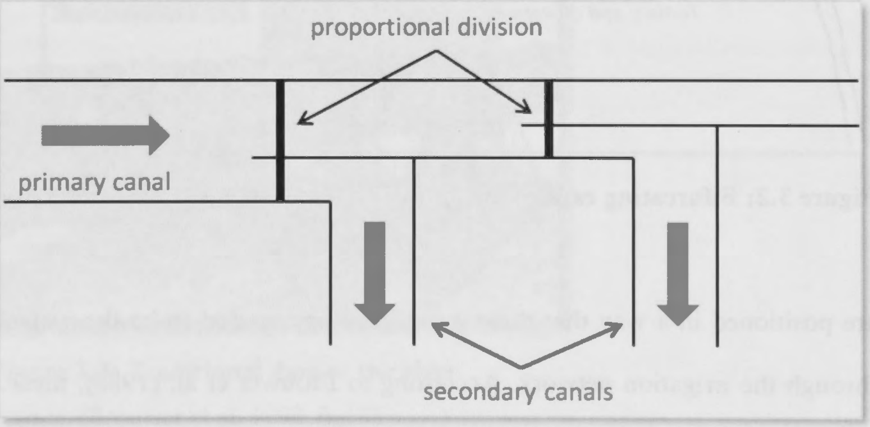

Figure 3.3: Proportional flow division

Source: (adapted from Horst 1998: 51)

To accommodate proportional division, most farmer-managed canal-irrigated systems have fixed proportional weirs which require very little operation (which will be discussed in the

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[50] In agency-managed irrigation systems, in contrast, water requirements are frequently calculated on the basis of climatic, geographic and crop factors and are therefore varying in place and time (Horst 2000: 7–8).

technical dimension). Fixed proportional weirs are usually placed perpendicular to the canal flow with shares determined by crest elevation (each weir has to have the same crest elevation) and weir width (proportional to total flow and irrigated area) (Bosch et al. 1993: 17–9; Horst 2000: 7–8) (Figure 3.4). The advantage of this type of division structure is that it is transparent, because it is simple to understand and manipulation is difficult to hide.

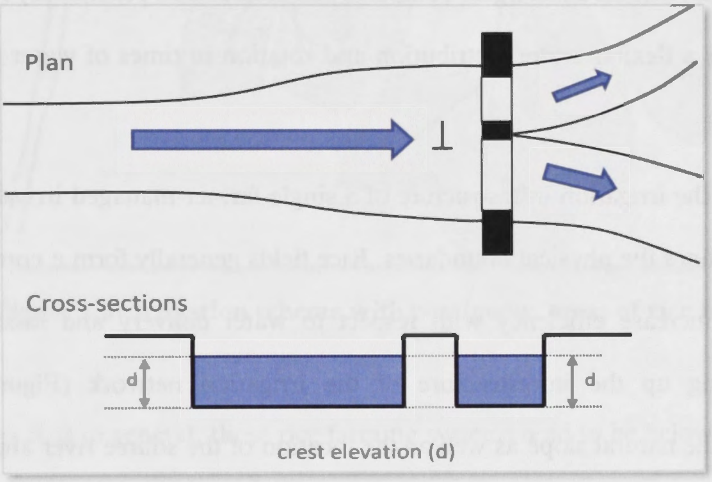

Figure 3.4: Proportional division weir, plan and cross-section
Source: (Horst 1996: 39, fig. 2)

Traditionally, all irrigation structures were built using locally available material, such as for example boulders, rocks, tree trunks and branches, bamboo sticks, clay, mud and weeds which required frequent maintenance (Geertz 1959: 995; Siy 1982: 121; IIMI and WECS 1987: 87). The network of waterways used to be built from earthen canals. Earthen canals are more prone to seepage, leakages and erosion compared to lined canals yet the degree of damage depends on the quality of the building material (soils with less sand content are less prone) as well as on flow velocity and slope degree of canal walls (Bosch et al. 1992: 26).

In some of these farmer-managed irrigation systems permanent irrigation structures had already been built before the Green Revolution. Upgrading of irrigation facilities to more permanent structures began at the turn of the twentieth century.[51] Permanent structures are built of concrete or cement, which reduces maintenance and repair time and costs. From a technical irrigation point of view, permanent structures including lined canals may be preferred as water loss can be minimised. In traditional systems, on the other hand, provisions have been made for these water losses. Ambler (1993), for example, describes a case in West Sumatra, where leakages were intentionally created on upstream weirs to adjust to the reduced dry season discharges. Temporary structures also permit easy removal or repair, allowing for a flexible water distribution and rotation in times of water scarcity (Siy 1982: 121).

The land irrigated by the irrigation infrastructure of a single farmer-managed irrigated rice production system defines the physical boundaries. Rice fields generally form a contiguous area as a means to increase efficiency with respect to water delivery and losses, and convenience in setting up the infrastructure of the irrigation network (Figure 3.5). Topography, that is, the natural slope as well as the location of the source river and water flow quantities in the river, influence this set-up. Ostrom (1992: 69) recognises clearly defined boundaries of serviced areas as one of the key principles that underlie many long-enduring, self-organised irrigation systems.

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[51] In Thailand, first investments into expanding and improving existing farmer-managed irrigation systems started in 1903 (Shivakoti 2000). In Northern Thailand, on the other hand, it was only in the 1970s when cement was first used to build more permanent structures in farmer-managed irrigation systems (Cohen and Pearson 1998: 87). In the Philippines, the first upgrades were initiated by the government in 1938 with full government support for the recovery of funds for construction and rehabilitation authorized in 1974 (Tapay et al. 1987: 132). From the 1960s onward, large investments all over Southeast Asia took place as part of agricultural modernisation to increase rice production for rapidly growing populations.

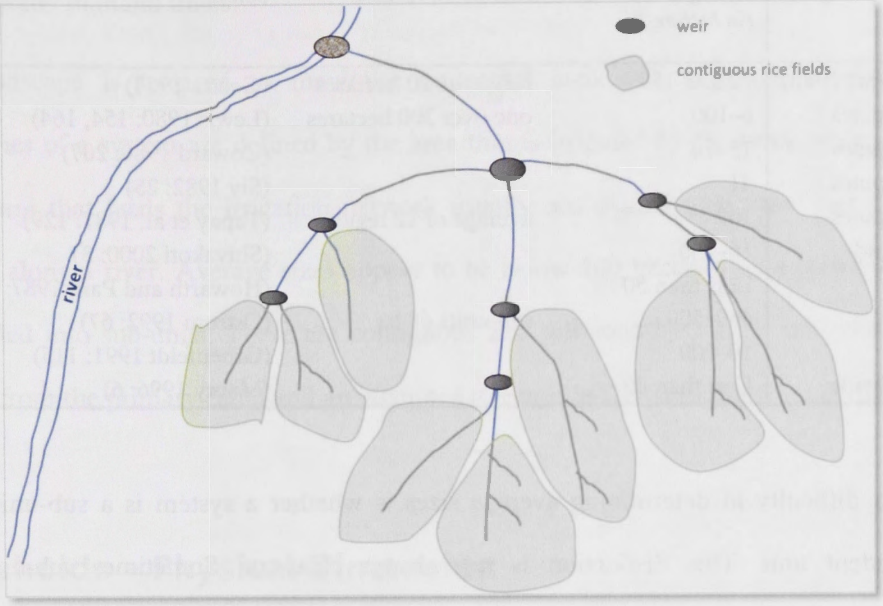

Figure 3.5: Irrigation scheme with contiguous areas of rice fields

It appears that in general, these rice farming systems tend to be below 100 hectares in total size. It is, however, difficult to generalise due to the limited examples found in the literature (Table 3.1). What seems to be a more general rule is that larger systems are divided into a nested series of sub-units (Hunt 1989: 82). This is likely given the rugged terrains these systems exist in and the need to create contiguous units for an effective and efficient irrigation system. Normally these sub-units are self-contained or discrete physical units served with an inflow of water (from a primary canal) independent of other sub-units (Coward 1980: 207). According to Coward (1980: 208) properly functioning units of farmer-managed irrigation systems service between 70 to 80 farmers. The fact that farmers on average cultivate rice on less than half to one hectare (Siy 1982: 22; Tapay et al. 1987: 128; Groenfeldt 1991: 115) suggests that unit sizes or sub-unit sizes would generally range between 35 to 80 hectares.

Table 3.1: Average sizes of rice farming systems

Country/Region	*Average sizes (in hectares)*	*Additional remarks*	*Source*
Indonesia (Bali)	72 and 159	sub-units 20 hectares	(Geertz 1964)
Philippines	6–100	one over 300 hectares	(Lewis 1980: 154, 164)
Philippines	15–70		(Coward 1980: 207)
Philippines	41		(Siy 1982: 25)
Philippines	109	average of 12 regions	(Tapay et al. 1987: 129)
Thailand	16–160		(Shivakoti 2000: 3)
Nepal	Less than 50		(Howarth and Pant 1987: 220)
Nepal	460–500	sub-units 68 ha	(Ostrom 1992: 67)
Asia	10–100		(Groenfeldt 1991: 115)
Worldwide	Less than 40		(Mabry 1996: 6)

Another difficulty in determining average sizes is whether a system is a sub-unit or an independent unit. This distinction is not always clear-cut. Sometimes sub-units are considered independent units. I suggest that traditionally these rice farming systems can be regarded as independent units if they maintain a separate acquisition structure at the river. I acknowledge that there are systems that underwent rehabilitation before the Green Revolution which share a concrete dam for their acquisition structures. They are, however, still independent units which will need to be carefully considered in the analysis.[52]

Summary

The common features of the physical dimension to all farmer-managed canal-irrigated rice production systems is a canal irrigation system with a dam as intake at the river and a bifurcating network of canals that deliver the water to the fields. Before the Green Revolution, these facilities were mainly built from local natural material and accordingly required frequent maintenance. Water is proportionally subdivided, often including a

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[52] With improvement works undertaken by governments to increase irrigation capacity as early as 1900, dams built from natural material were replaced by concrete structures which often resulted in former entirely independent farmer-managed rice farming systems now sharing the main intake at the river.

negotiated process depending on the area to be irrigated, and with rotational arrangements in peak water demand times.

The landscape is terraced to maximise cultivated area and minimise erosion. The boundaries of a system are defined by the area that is irrigated by the same system and a single dam that feeds the irrigation network usually not shared with other rice farming systems along a river. Average sizes appear to be below 100 hectares with larger systems subdivided into sub-units. These are contiguous and self-contained areas with individual inflows from the primary canal and are assumed to range in size between 35 to 80 hectares.

Thresholds - Physical Dimension

I propose that the physical dimension boundaries of the basin of attraction are determined by the following key thresholds: a contiguous area of bunded fields, a gravity-fed supply-driven irrigation system and the principle of proportional water sharing (Figure 3.6).

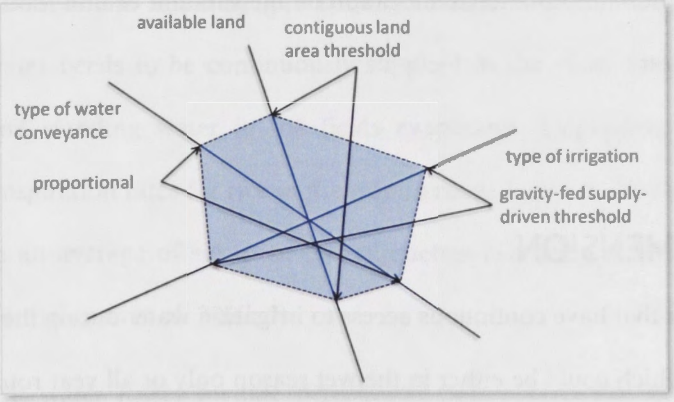

Figure 3.6: Physical dimension thresholds

Contiguous area of bunded rice fields

The contiguous area of bunded rice fields for the creation of water ponds is organised in rice terraces, which combined with the irrigation water network, are clustered in self-contained sub-units of a nested hierarchy with clearly defined boundaries. Unit sizes tend to be typically around or below 100 hectares with sub-unit sizes between 35 to 80 hectares.

Gravity-fed supply-driven irrigation system

These canal-irrigated rice production systems depend on the natural flow of the source river (supply-driven) and on gravity for the delivery of water to the fields.

Principle of proportional allocation and distribution of water

The principle of proportional water shares is maintained on each level of the irrigation system calculated proportionally to the incoming water flow and area to be irrigated. Weirs are typically fixed-proportionate. Rotational allocation on the sub-unit or unit level may be used in times of water stress.

ECOLOGICAL DIMENSION

Rice is cultivated in fields that have continuous access to irrigation water during the periods in which rice is grown, which could be either in the wet season only or all year round. The fields are inundated for most of the rice growing season but are drained before the harvest. This type of cultivation creates an artificial swamp alternating between wet and shorter dry phases which can be defined as a temporary seasonal wetland agroecosystem or semi-aquatic agroecosystem (Bambaradeniya and Amarasinghe 2004: 3).

A contiguous area of levelled and bunded fields is required in order to retain the water. In addition, soils need to be puddled to reduce water loss through percolation. The puddling technique involves tillage of soil while water is standing on the field. Soil aggregates are destroyed and soil particles reduced to mud. As a consequence, underlying soil layers are compacted and a plough-pan is produced which seals the ground and increases water holding capacity. This creates a perfect environment for the rice plant to thrive with minimal nutrient loss, protection from high temperatures, reduced weed pressure and improved water use efficiency (Lansing 1991: 39; Netting 1993: 42; Norman et al. 1995: 113; Greenland 1997: 92).

To calculate total water requirements a variety of factors need be taken into account such as crop water requirements, soil and landscape characteristics, type of variety planted (duration of the cultivation season of a variety), land preparation and farmers' bund construction skills as well as quality of the irrigation system (Grist 1975: 40; Levine 1980: 54–5; Brouwer et al. 1989; Greenland 1997: 141; Dayton-Johnson 2003: 316). The usual standing water levels for rice fields are 50–100 millimetres (De Datta 1981: 300; Bambaradeniya and Amarasinghe 2004: 2; Bouman et al. 2007: 3). To maintain these levels, water needs to be continuously supplied as the plant transpires water through its leaves and standing water in the fields evaporates. Depending on the season, typical evapotranspiration rates for rice in the tropics range between four to twelve millimetres per day with an average of six to seven millimetres (Tomar and O'Toole 1980: 103; Tuong 1999: 244; Bouman et al. 2007: 4).

Additional water losses include percolation (water vertically lost to lower soil layers), seepage (water lost sideways through bunds) and surface run-off (bund overflow) (Figure 3.7). Seepage rates are influenced by soil physical properties, water levels in surrounding fields and canals, and maintenance quality of the bunds, while percolation rates depend on soil physical properties and the quality of soil preparation techniques (Brouwer et al. 1989; Bouman et al. 2007: 4; Kim et al. 2009: 876–7). Tuong (1999: 245), for example, suggests these losses can range between 6.5 to up to 30 millimetres per day depending on the type of soil.[53] Together, evapotranspiration, seepage, percolation and run-off add up to an estimated range of between 450 and 1600 millimetres of water for one cultivation season of irrigated rice (Grist 1975: 40–2; Levine 1980: 54; Brouwer and Heibloem 1986; Greenland 1997:141–2; Facon 2000).

However, this range of seasonal crop water requirements does not yet include water required for land preparation nor consider water return flows and irrigation scheme efficiency. Greenland (1997: 142) estimates an additional 300–700 millimetres of water to completely saturate soils for the preceding preparation of the land. A substantial amount of water lost to surface run-off, seepage and percolation is returned to other fields or recharges groundwater. A few studies have attempted to estimate these return flows at around 25 per cent (Wu In: Liu et al. 2004: 604; Kim et al. 2009: 882). Irrigation scheme efficiency accounts for how much water is lost while the water is transported from the dam through the canal system to the fields, which depends on the quality of the irrigation system (conveyance efficiency) and on farmers' irrigation methods (field application efficiency) (Brouwer et al. 1989). Estimates of scheme irrigation efficiency range between 35 to 60 per cent with 50 to 60 per cent efficiency considered good, 40 per cent reasonable, and 20 to 30 per cent poor (ibid. 1989).[54] Accordingly, total irrigation water requirements (gross crop irrigation needs) for one cultivation season could potentially range between 1,688 millimetres per cultivation season in optimal environments to 18,375 millimetres under very poor conditions (Table 3.2).[55]

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[53] Percolation rates are higher in sandy soils and lowest in clay soils.

[54] An irrigation scheme efficiency of 40 per cent indicates that 60 per cent of the supplied water is lost, while 40 per cent reaches the field where the crop stands.

[55] Ranges given in the literature for total water consumption which includes evapotranspiration, seepage, percolation, surface run-off and land preparation vary considerably but are not as high as the maximum calculated in the table.

Table 3.2: Irrigation water needs range for a 100 day rice crop

100 days cultivation	*Minimum*	*Maximum*	*Average*
Evapotranspiration	400	1,200	800
Seepage, percolation and surface run-off	650	3,000	1,825
Land preparation	300	700	500
Net crop irrigation needs	1,350	4,900	3,125
Water return flow ratio	0.25	0.25	0.25
Total including return	1,013	3,675	2,344
Irrigation scheme efficiency ratio	0.6	0.2	0.4
Gross crop irrigation needs	1,688	18,375	5,859

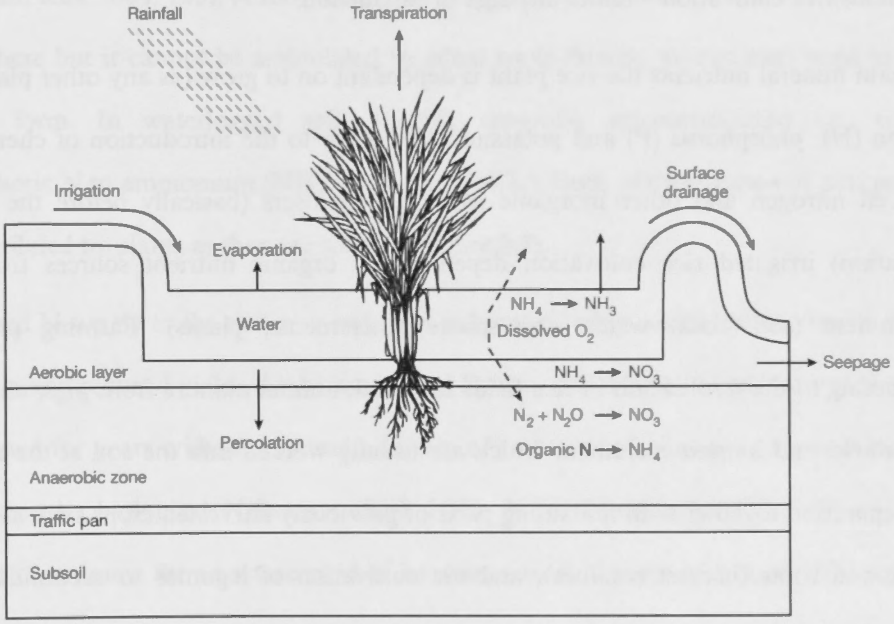

Figure 3.7: Water and nitrogen flows in a submerged rice field

Source: (adapted from Yoshida 1981: 105; Greenland 1997: 83, 110), drawn by K. Pelling, Cartography ANU.

Although rice is not an aquatic plant, it can stand in water for long periods of time, unlike most other crops. The flooding of the soil depletes the oxygen, creating an anaerobic environment (Figure 3.7: Anaerobic zone). Only the surface layer remains oxidised because of the continuous oxygen supply from the irrigation water (Grist 1975: 18) (Figure 3.7: Aerobic layer). Chemical processes in waterlogged soils differ greatly from those in aerated soils and nutrients become more readily available for plants to uptake through their roots. Organic matter disintegrates less quickly and release of nutrients is slow but continuous.

Silty particles (rock or soil derived granular material) carried in irrigation water is another important source of plant nutrients although nutrient content varies considerably. Sedimentation rates (silt deposited in rice fields) are estimated at 0.1 to 5 millimetres annually (Greenland 1997: 107–9). Agus et al. (2006: 183) measured annual sedimentation rates of 0.75 millimetres over two rice cropping seasons in Indonesia.[56] The swamp-like environment and the silt deposits from the irrigation water have enabled long-term stable yields without or with only limited addition of external fertilisers over many centuries of continuous rice cultivation without any sign of exhaustion.

The main mineral nutrients the rice plant is dependent on to grow (as any other plant) are nitrogen (N), phosphorus (P) and potassium (K). Prior to the introduction of chemically produced nitrogen and other inorganic (mineral) fertilisers (basically before the Green Revolution) irrigated rice cultivation depended on organic nutrient sources from the environment (soil, rock, water, atmosphere, excrements, plants). Farming practices contributing to the fertilisation of rice fields included: animal manure from pigs, chickens, cows, ducks and human excrement which are usually worked into the soil at the time of soil preparation together with remaining parts of previously harvested crops such as straw, stubble and roots (harvest residues), and the cultivation of legumes to accumulate soil nitrogen (green manure).[57] In some of these rice production systems harvest residues are burnt instead of being ploughed under, which reduces N and P content and available organic material for the soil but increases K availability.

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[56] I used Greenland's (1997: 107) bulk density of 1.0 for the sediments which translates to 1 mm of soil per 10 tons and hectare.

[57] The timing is important as soil microbes need two to three weeks to break down the manure before N is available to plants (Dobermann and Fairhurst 2000). Leguminous plants have the ability to fix nitrogen with the help of bacteria living in root nodules.

Nitrogen is by far the most limiting factor for growth. Nitrogen promotes growth of biomass (plant height and number of tillers) and increases protein content in grains, which both positively correlate to increased yield (De Datta 1981: 350; Dobermann and Fairhurst 2000: 41). The main sources of N before the Green Revolution for farmer-managed irrigated rice cultivation systems were animal manure and biological fixation of atmospheric nitrogen. Other sources of N, yet with a lower content, are harvest residues, green manure, irrigation water and rainfall.

Biological N-fixation is one of the key processes of flooded soils and has greatly contributed to this remarkably stable long-term productivity of wetland rice systems (Norman et al. 1995: 115; Kirk 2004: 135). Atmospheric nitrogen (N_2) is abundantly available in the earth's atmosphere but it cannot be assimilated by plant roots directly as nutrients need to be in soluble form. In waterlogged soils specific anaerobic microorganisms can convert atmospheric N to ammonium (NH_4^+) or nitrate (NO_3^-). Both of these forms of nitrogen can be assimilated by plants as they are soluble (Figure 3.7).

A reduced N supply to the rice crop results in reduced tillering, small leaves, shorter plants, less grain and reduced yields (Dobermann and Fairhurst 2000: 42). However yields can be maintained for years without external addition of any form of N as soils are continuously replenished by biological N-fixation (Kirk 2004: 206). Greenland (1997: 126) and Kirk (2004: 205) estimate for a hectare yield of 2 tonnes a total N input of around 130 kilograms per hectare and cultivation season, assuming a single crop of rice and a legume crop in the rice fallow season with the main source of N derived from biological N-fixation. Doberman and Fairhurst (2000: 15) estimates for N input per cropping season range between 120–250 kilograms per hectare with the main N source from manure or inorganic fertilizer (Table 3.3).[58]

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[58] Inorganic fertilisers, which were rarely used before the Green Revolution, have a significantly higher nutrient content concentration than organic fertilisers (see chapter 5 for a detailed discussion).

Phosphorus (P) is needed for the supply and transfer of energy for all biochemical processes in the plant (De Datta 1981: 350; Dobermann and Fairhurst 2000: 60). In most soils, P is present in solid form in rock minerals. When the soils are flooded, P becomes available to plants because its solubility increases in anaerobic conditions (Grist 1975: 37; Kyuma 1995; Norman et al. 1995: 118). Other relevant P sources in these rice production systems are organic manure and straw. Phosphorus deficiency results in reduced tillering, leaves, panicles and grains per panicle (Dobermann and Fairhurst 2000: 60). Total P input estimates range between 7–32 kilograms per hectare depending on the type of fertiliser applied (Greenland 1997: 126; Dobermann and Fairhurst 2000: 15; Kirk 2004: 205) (Table 3.3).

Potassium (K) is a key ingredient in physiological and chemical processes in the plant and K deficiency can increase the rice crop's susceptibility to pests and diseases, adverse climatic conditions and lodging, resulting in reduced yields (De Datta 1981: 351; Dobermann and Fairhurst 2000: 72). Prior to the introduction of chemical fertilisers major sources of K were sediments in the irrigation water, manure and straw residues (Grist 1975: 37; Kyuma 1995; Norman et al. 1995: 118). Total K input is estimated at 24–167 kilograms per hectare depending on the sources (Greenland 1997: 126; Dobermann and Fairhurst 2000: 15; Kirk 2004: 205) (Table 3.3).

Table 3.3: Nutrient input into rice cultivation (kilograms per hectare)

Nitrogen (N)	*Phosphorus (P)*	*Potassium (K)*
120–250	7–32	24–167

Units: kilograms per hectare

Soil organic matter content plays an important role in the provision of soluble nutrients to the rice plants: organic matter serves as nutriment (nourishment) for soil microbes which convert the material and slowly release soluble plant nutrients from that organic matter.

Soil organic matter content is also important in that it reduces soil erosion and helps maintain soil fertility, soil structure and water holding capacity (Matson et al. 1997: 506; Komatsuzaki and Ohta 2007: 104). Both harvest residues and organic manures incorporated into the soil not only provide mineral nutrients but also organic matter for the soil (Cassman et al. 1998: 25).

The remarkable stability of rice yields year after year in these long-enduring irrigated systems is not only due to the continuous nutrient supply to the plants, but also due to the agroecosystem's rich biodiversity. This ecological complexity consists of a wide array of weeds, algae, fungi, spiders, insects, and aquatic invertebrate species (Settle et al. 1996: 1976; Bambaradeniya and Amarasinghe 2004: 7–13).[59] There are numerous natural enemies to pests of rice plants which, if undisturbed, prevent large pest infestations.[60] Natural enemy insects that are prevalent early in the rice season, such as spiders, water striders, dragonflies, damselflies and carabid beetles, are considered crucial in stabilising the rice field pest ecology (Matteson 2000: 551–2; Sigsgaard 2000: 58; Thorburn 2007: 4). The importance of this natural balance has only recently been recognised (Whitten et al. 1996: 577).[61] Settle et al. (1996) observed that populations of natural rice pest enemies are increased in rice fields where organic matter such as cow manure is added.

A wide range of rice varieties well adapted to local conditions is grown. In Indonesia, for example, at least 8000 different varieties were cultivated before the Green Revolution; though this might be a low estimate (Fox 1991: 63–4). Often different varieties were planted in the same cultivation season or even on the same field. Growing multiple varieties of rice on the same field and at the same time is a traditional method to increase

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[59] According to Settle (1996: 1976) the complex rice field ecology is unrivalled by any other agroecosystem.

[60] According to Raheja (In: McClelland 2002: 192) a typical rice field supports 800 species of beneficial organisms which when undisturbed by pesticides can control up to 95 per cent of rice insect pests.

[61] Common pests to rice are stemborers, caterpillars, rice bugs and leaf hoppers, which attack the plant at various growth stages and various parts of the plant. They can also be carriers of bacterial or fungal diseases. For more details on common pests and diseases, see for example Grist (Grist 1975: 311–82) or visit IRRI's Rice Knowledge Bank website on http://www.knowledgebank.irri.org/ipm/, viewed on 15/2/2011.

yield stability, reduce pest and disease infestation and for on-farm conservation of genetic resources (Cleveland et al. 2000: 381, 385; Wolfe 2000).[62] Selection of seeds for the next crop, exchange of seeds amongst farmers' groups as well as testing of new varieties in the field are also practices commonly applied by farmers in these irrigated rice farming systems (Vaughan and Chang 1992: 376; Cleveland et al. 2000: 388).

Both flora and fauna serve as complementary food sources for farmers. In particular, eels, snails, fish and frogs provide an important source of protein in local diets. Bouchery (1999) lists as many as 48 plant species that the Hani in China collect as a supplement to their diet around the rice fields, apart from many other plants they use as forage for their livestock or as medicinal plants. While this is certainly a special case, it nonetheless exemplifies the species-richness of these semi-aquatic rice agroecosystems and farmers' particular knowledge in using this richness for complementary food sources.

Summary

The common features that farmer-managed canal-irrigated rice cultivation systems display in the ecological dimension can be summarised as follows: Rice is cultivated in an artificial swamp reliant on a continuous supply of water which is kept in the fields by bunding and levelling techniques. This semi-aquatic environment is characterised by continuous availability of sufficient plant nutrients through anaerobic soil chemical processes, silt deposits and farming practices which provide for long-term stable yields of rice without eroding the resource base. The rich biodiversity of these semi-aquatic agroecosystems contributes to stable yields and at the same time acts as a supplementary food source for farmers.

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[62] I am using 'traditional' throughout the thesis in line with Hunt (2000: 262) to distinguish generally the time before the Green Revolution where farmers grew domesticated rice with locally generated seed, with only human or animal sources of power and without industrially produced chemical fertilisers or pesticides as opposed to modern agriculture.

Thresholds — Ecological dimension

I suggest the following three thresholds as the most important thresholds that delineate the borders of the ecological dimension of the basin of attraction for these specific rice production systems: Reliable water supply, sufficient nitrogen input and maintained biodiversity. These thresholds have a quantitative as well as qualitative character.

Reliable water supply

To obtain sustained yields year after year, continuous flooding of the fields while rice is growing is required. Water stress at any growth stage can impact negatively on rice yields (Yoshida 1981: 108; Pasaribu and Routray 2005: 489). The main factors of water stress are drying out of the soil and consequent increased soil permeability, reduced biochemical processes due to aerobic conditions and consequent less nutrient availability to plant as well as increased weed pressure. Thus, reliable water supply is crucial. The hypothetical range of gross water needs, including the irrigation efficiency degree given earlier, is between 1,688 and 18,375 millimetres per season. Assuming that soils where these farmer-managed canal-irrigated rice cultivation systems operate have a high water holding capacity, and that irrigation efficiency is good, gross irrigation water needs would be at the lower end, ranging between 1,688 and 2,313 millimetres for one cultivation season. This range can serve as one threshold.

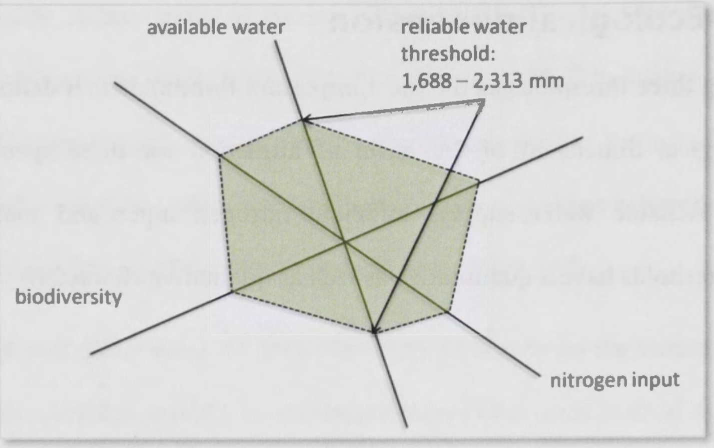

Figure 3.8: Reliable water threshold, ecological dimension

Another option to determine the water threshold would be to use rice yield as a proxy since water stress impacts on rice yields. In systems where production solely relies on rainfall (rainfed rice production systems) yields are significantly lower compared to irrigated rice with continuously flooded soils (Table 3.4). In these rainfed systems variability in amount and distribution of rainfall is the most important factor limiting yields (De Datta 1981: 18). Thus, a rice farming system with less water available producing less than expected average yields would move to a basin of attraction characterised by rainfed rice production.

Table 3.4: Average rice yields for irrigated and rainfed rice (before the Green Revolution)

Type of rice production system	*Tonnes per hectare*
Irrigated rice	1.5-2.5
Rainfed rice	0.8-1.5

Source: (Grist 1975: 181, 481; De Datta 1981: 5; Greenland 1997: 12, 60–1)

Sufficient nitrogen input

Nitrogen is by far the most important nutrient required for sustained yields. Nitrogen is readily available for the rice plants in submerged fields due to biochemical processes which fix atmospheric N. Using the references as discussed, N supply would have to be at least

120 kilograms per hectare with one rice crop per year. The applied N originates from organic sources mainly.

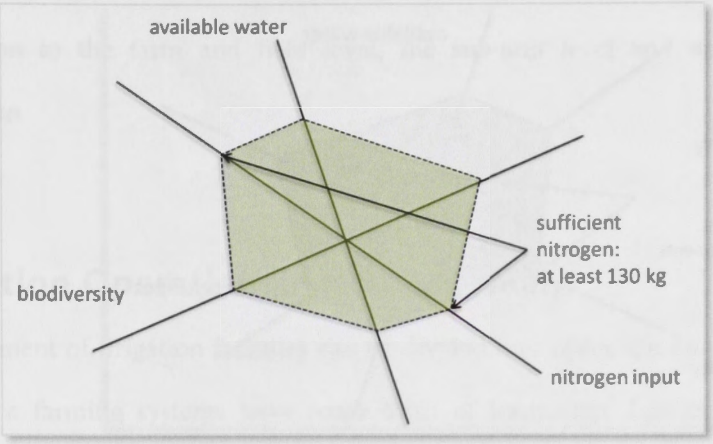

Figure 3.9: Sufficient nitrogen threshold, ecological dimension

Rich biodiversity

Biodiversity in fields is characterised by the number of local rice varieties that are planted, the balanced ecology of natural enemies to rice pests, and the availability of protein sources for local diets. I therefore suggest a biodiversity threshold consisting of three factors:

- Several different rice varieties planted in one area,
- High abundance and diversity of natural enemy populations to rice pests (encouraged by the addition of organic matter), and
- The practice of collecting and gathering complementary food in and around the rice fields.

To measure and qualify high abundance and diversity of natural enemy populations, I suggest focusing on those species recognised as most important to the rice field ecology, for example, spiders, water striders, dragonflies, damselflies and carabid beetles. A proxy for qualifying whether natural enemy populations are abundant could be whether organic matter is applied to rice fields.

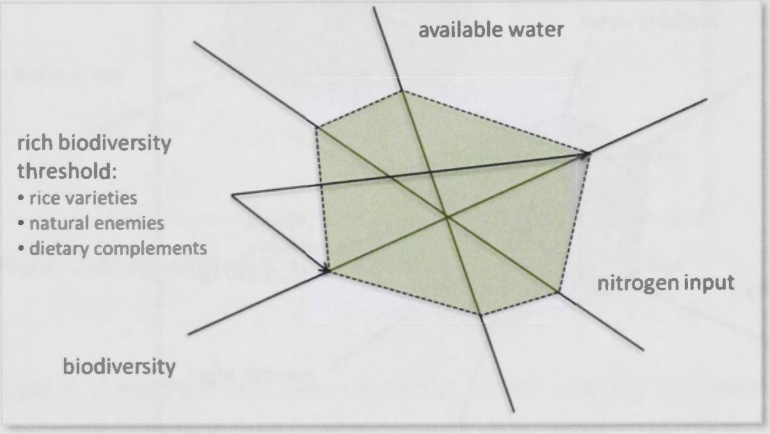

Figure 3.10: Rich biodiversity threshold, ecological dimension

TECHNICAL DIMENSION

The technical dimension consists of the ways resources are mobilised to grow rice: the cultivation and irrigation techniques, the labour invested in the cultivation and irrigation of rice and in the management of the irrigation facilities, as well as the knowledge and experience base that farmers in these rice farming systems have acquired. Many of these farming systems include a ceremonial component which takes on a more or less important role depending on the local culture and religion. The more important this component is, the more time, finances and labour are invested in worship and the preparation of ceremonies, rituals and religious festivals. Culture and religion not only demand labour, time and finances but also influence the way operational choices and decisions are made in terms of managing such rice farming systems, which is part of the discussion in the institutional dimension.

All decisions made and activities undertaken relating to the management of the irrigation facilities and irrigation and cultivation of rice are dealt with by the farmers themselves in cooperation, although responsibilities and degree of cooperation take on different forms on different levels of the system. It is therefore necessary to disaggregate the technical dimension to the farm and field level, the sub-unit level and the unit level for the discussion.

Irrigation Operation and Management

Management of irrigation facilities can be divided into operation and maintenance. All of these rice farming systems have some form of leadership. Leaders are elected by the members and are responsible to organise and delegate all management and operational activities on the sub-unit and unit level including mobilising labour and resources (building material and/or finances). Labour mobilisation to maintain the irrigation system is crucial to a well-functioning farmer-managed irrigation system, especially where streams are prone to flooding (Groenfeldt 1991: 117).

Recurrent activities that are necessary for the capture, allocation and delivery of water to the fields are operational activities (Hunt 1988: 80; Small and Svendsen 1990: 294). Operation is minimal given the simplicity of the irrigation facilities (as discussed in the physical dimension). These structures do not require continued presence for their operation and therefore demand little skill and minimal labour input (Horst 1998: 31; 2000: 8–9).[63] Decisions and activities on the system level mainly involve meetings to schedule water delivery to the fields, whether rotation is required, and the passing on of decisions made to individual members. Once decisions are made, farmers have no influence on how much

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[63] Agency-managed irrigation on the contrary is often quite sophisticated, requiring trained staff to operate gated structures and record measurements of flow because it is demand-driven (Horst 2000: 8–9).

water flows into the field. Farmers can however regulate in-field water levels by regulating off-flow from their fields.

Maintenance activities include rehabilitation and improvement of irrigation infrastructure such as repair of leakages and erosion, and replacement of broken parts as well as regular cleaning.[64] Maintenance can demand significant labour input as well as sophisticated skills for the repair and rehabilitation of infrastructure especially where irrigation facilities are built of natural material (as discussed in the physical dimension). Maintenance is generally organised in groups between cultivation seasons. Maintenance frequency can increase with bad weather events such as torrential rains and flooding.

References in the literature with respect to labour inputs into irrigation are scant. Most studies focus on rice cultivation only, with little or no indication of irrigation operation. The averages indicated range between 20 and 80 days of labour per year and member, which seems to be quite high (Siy 1982: 44; Martin and Yoder 1988: 150; Ostrom 1990: 86; 1992: 68).[65] Labour investments are presumably higher for those systems with a higher percentage of non-permanent structures, and also depend on the size of the system and number of irrigation structures.

Cultivation

Cultivation of irrigated rice is a highly sophisticated and intensive type of agriculture which farmers have perfected through knowledge from previous generations as well as hands-on everyday experience in the field. Examples of this sophistication are: the minute use of

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[64] Silt, debris and weeds can accumulate in the canal network or get trapped behind diversion structures. These deposits obstruct water flow and reduce water quantity flowing through the network, which makes the irrigation infrastructure less effective. Plant growth on canal embankments can hide damage to the irrigation structures and cause development of leakages (Bosch et al. 1992: 30).

[65] Siy (1982: 92–5) reports an average of 31.6 person-days per hectare total labour contribution across nine Philippine *zanjeras* in 1980. Of this 31.6 person-days approximately half the time is spent in maintenance and operation, while the other half involves non-irrigation-related activities such as cultivation work on communal land, attendance of meetings and rituals and payment of water charges (ibid. 1982: 93–5).

every inch of land,[66] the perfection of 'groomed' rice field bunds, the practice of transplanting seedlings, and harvesting in some areas with a hand knife. Several studies undertaken on intensification of agriculture have noted that irrigated rice cultivation can absorb large amounts of additional labour and at the same time maintain if not increase land productivity (Conelly 1992: 204; Bray 1994: 5; Hunt 2000: 252–4). This phenomenon is what Geertz (1963: 32–5) observed in Java and which he called 'agricultural involution', emphasising that unlike swidden agriculture wet rice cultivation productivity can increase without expanding the cultivated land area. Thus, these specific rice farming systems feature a high 'carrying capacity', as Henley (2008: 275) puts it, with a remarkably sustained productivity and a high elasticity for labour input.

The degree of labour intensity varies across different countries (Table 3.5). The data I found in the literature on labour input growing irrigated local rice varieties show that on average 97 person-days are spent per hectare and cropping season across the region. In Java, labour requirements are on average about twice as high with 195 person-days per hectare and cultivation season. This distinct difference exemplifies the point made above. The more intensive labour input is the result of higher population densities combined with a labour force that needed employment in agriculture (Geertz 1963: 77; Prabowo and Sajogyo 1975: 192). Productivity, on the other hand, compared to other regions is not significantly higher but also not lower. Although labour input numbers have to be treated with caution they nevertheless represent a basic frame of reference for the labour requirements for rice cultivation.[67]

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[66] Every tiny fraction of land is turned into terraces in which even just a few rice plants can be cultivated.

[67] Hunt (2000: 265, 272), in a study on labour productivity in rice farming, points to several problematic aspects such as accuracy of recording, limitations in terms of measurement units and unaccounted for externalities such as commuting, and distortion of numbers due to use of animal traction. There are also no indications as to what conversion rates from person-hours to person-days were used. All labour must have most likely been initially recorded in person-hours. Whether there are six or eight hours in one day makes a difference. Numbers could have been further distorted from extrapolating labour input from actual land sizes to the unit person-days per hectare in a linear way. There are certain activities on a rice field, where one labourer spends basically the same amount of time whether his field's size is 0.1 or 0.5 hectares, such as, for instance, guarding the ripening rice crop against flocks of birds. Whether attending to work that is related to the irrigation on the field level is

Table 3.5: Labour used by farmers per hectare and cropping season growing irrigated traditional rice varieties[68]

Country/Region	*Year*	*Person-days per hectare*	*Yield (tonnes per hectare)*	*Source*
Across regions	n.a.	About 100	2	(Barker et al. 1985: 128)
	n.a.	100	2.5–3	(Hunt 2000: 268–71)
Java (Indonesia)	1875–78	225	1.6	(Barker et al. 1985: 126)
	1920	72–262	1.2–5.4	(Booth 1988: 113)
	1955–61	189	1.2	(van der Eng 2004: 355)
	1968–71	158	2.7	(Barker et al. 1985: 126)
	1969–70	360	3.5	(David and Barker 1982: 123)
	1971	170, 256	2.6, 3.6	(Prabowo and Sajogyo 1975: 192, 194)
Philippines	1966	60, 88	2.2, 2.5	(Bray 1994: 149)
	1971	70–130	2.2–2.5	(IRRI 1975: 192, 290, 336)
	1974	105	2.4	(David and Barker 1982: 123)
	1975	82	3.5	(Bray 1994: 149)
Taiwan	1926–27	96	2.1	(Bray 1994: 149)
	1936–37	126	3.1	(Barker et al. 1985: 126)
	1967	113	5.1	(Bray 1994: 149)
Thailand	1906–09	63	1	(van der Eng 2004: 355)
	1930–34	50	0.9	(van der Eng 2004: 355)
	1972	83	2	(Bray 1994: 149)
	1975, 1979	103	2.6	(Bot and Gooneratne 1982: 88, 'North')

A comparison of rice with other crops with respect to labour use shows that rice cultivation is clearly more intense. In a survey undertaken in India between 1954 and 1970 cultivation of wheat and maize required on average only 67 and 60 person-days per hectare and cultivation season respectively, while labour input into irrigated rice was similar to the Southeast Asian average with 99 person-days per hectare (Chattopadhyay 1984). A survey of labour use in several crops in East Java over three planting seasons (1978 and 1980)

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included in the numbers given is yet another aspect which has not been clearly stated in the referenced literature. In chapter 6 I present detailed data on contemporary irrigation operation and management for the field study area which I have gathered with detailed time use surveys of two households over the cultivation period.

[68] Indications in hours in reference material are converted to person-days using 8 hours a day.

shows that farmers spent on average 137 (rice), 70 (maize) and 57 (soybean) person-days per hectare and cultivation season (Collier et al. 1982: 22–3).

Cultivation of wet rice involves land preparation; planting such as sowing and transplanting; crop management while the plants are growing such as weeding, protection from pests and perhaps application of fertilisers;[69] harvesting; and threshing. Land preparation was traditionally undertaken using draught animals such as cattle or water buffaloes to pull the plough, or manually by hoe. After ploughing and harrowing, fields need to be levelled to create a slight gradient so that water can flow evenly through the field from intake to outlet. The entire process usually spans one to one-and-a-half months in which the soil is broken down continuously until a fine, evenly distributed mud has been produced.

Transplanting has been practiced in many of these rice farming systems for centuries. Seeds are sown in separate small beds before they are transplanted into the main field at 30 to 40 days after sowing. Although this is a more labour intensive technique, land productivity can be substantially increased: weak and diseased seedlings are deselected at the time of transplanting, the cultivation period of the rice crop in the main field is shortened, the root system strengthened, tillering encouraged, and weed pressure diminished (Bray 1994: 20, 46; Greenland 1997: 92). Transplanting has a high labour demand and needs to be done in a relatively short period of time.[70]

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[69] Before the Green Revolution organic manures were used and mainly applied at the time of land preparation. See ecological dimension for more details.

[70] Direct seeding (also called broadcasting) is mainly practiced in flooded (mainly in river deltas) and rainfed (mainly upland) rice production where the rice is sown into the field before the fields are flooded. In recent decades, there has been a trend in the adoption of direct seeding techniques in irrigated rice cultivation as a response to rising labour costs and the availability of herbicides to control weeds (Pandey and Velasco 2005). Hanks (1972: 63) compared direct seeding and transplanting cultivation in the Philippines and concluded that over the entire cropping season the transplanting method used on average more than a third more than the labour input needed for direct seeding.

Another sophistication of rice cultivation is the reaping of single ripe panicles by a hand knife at harvest time.[71] This technique ensured maximising yield (Geertz 1963: 35). It also proved useful for selecting seeds for the next cropping season. The hand knife was used solely or in conjunction with the sickle in Indonesia and Thailand as well as in the Philippines (Ingram 1971: 11; Miles 1979: 225; Siy 1982: 24). Harvesting with a hand knife is the most labour intensive of all agricultural activities because it requires a large supply of labourers at concentrated periods in the agricultural cycle (Stoler 1977: 681).

The variability in labour demands is significant in the cultivation of wet rice and requires a flexible workforce: a workforce that is available in high numbers in peak times and which can be redistributed to other work outside of rice farming in low labour demand times. Peak labour demand cannot be sufficiently supplied with household labour (Hanks 1972: 58; Bray 1994: 5). Examples given in the literature range between 75 to over 80 per cent of the work in the rice fields being carried out by non-family labour (Prabowo and Sajogyo 1975: 192; Barker et al. 1985: 128).

Traditionally, the workforce required has been mobilised using exchange labour which is paid in kind and based on the principle of reciprocity, either organised through neighbour, kinship or village-based groups. The proportion of paid hired labour is consequently very low in traditional farmer-managed canal-irrigated rice cultivation systems because exchange labour is mainly used to accommodate peak labour periods. Barker et al. (1985: 128) report less than 20 per cent of the total labour force was hired in Taiwan before the 1960s.

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[71] Also known as 'fist knife'.

Summary

Irrigation management activities at the system level are coordinated by some form of leadership. While operation requires minimal input, maintenance demands frequent (at least seasonal) mobilising of labour to attend to repairs. Annual labour input may range between 20 to 80 days per member, depending on the degree of permanent irrigation structures and on the size and number of structures. Wet rice cultivation is labour intensive but the degree of intensity varies across regions with between 97 and 200 person-days per hectare and cultivation season. Traditional techniques are labour intensive. Peak labour demand in cultivation is accommodated by a flexible workforce of exchange or hired labour paid in kind. Where farming systems include a ceremonial component, time, finances and labour are required to be invested for worship and preparation, with the level of input depending on rituals' importance in the cultivation and irrigation of rice.

Thresholds - Technical Dimension

I suggest the following key thresholds for the technical dimension: intensive cultivation techniques, intensive labour input into irrigation maintenance, and ability to mobilise labour on the system level for irrigation maintenance and on the farm-field level for cultivation (Figure 3.11).

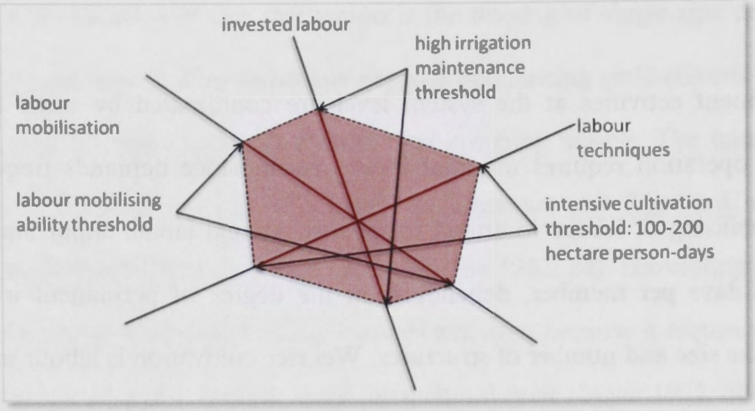

Figure 3.11: Technical dimension thresholds

Intensive cultivation techniques

These rice farming systems are characterised by farmers using techniques that reflect labour intensive cultivation, in particular transplanting and harvesting. While transplanting is used across different regions, harvesting with a hand knife is only used in some. Labour input into cultivation of rice is higher than for other cereal crops. Labour intensity depends on population density (in highly populated regions labour input tends to be significantly higher) ranging on average between 97 to 200 person-days per hectare and cultivation season.

High labour input into irrigation maintenance

Depending on the degree of permanent structures, labour input into the maintenance of irrigation facilities tends to be high with 20 to 80 person-days per year.

Ability to mobilise labour

These rice farming systems are characterised by a high efficiency in the delivery of water to the fields, which is dependent on a well-maintained irrigation system. Irrigation infrastructure in turn can only be well-maintained if a qualified leadership can mobilise and coordinate labour. A proxy to measure this ability could be to assess the quality of irrigation facilities. Farmers are effective in organising labour on the farm-field level to attend to the variability in labour input required for the cultivation of rice.

INSTITUTIONAL DIMENSION

The institutional dimension of the basin of attraction concerns the incentives and guiding principles under which communities collaborate in an efficient way to grow and irrigate rice and to maintain the irrigation facilities at an operational level. The incentives and guiding principles are organised in the form of formal and informal institutions.[72] Formal institutions are written rules and regulations that have been made official. Informal rules regulate everyday decision making on allocation and delivery of water to fields. These rules-in-use are location-specific. The institutional dimension also includes an organisational structure to attend to the management of the system on different scales: the farm-field level, sub-unit level and unit level. The organisational structure is an inherent part of irrigation institutions that defines relationships among actors in irrigation systems (Small and Svendsen 1990: 286).

There is a wealth of literature on common property resources and their sustainable and successful management from various perspectives (anthropology, economics, environmental science, political science, and rural sociology) such as the works of Agrawal (2001), Ostrom (1990; 1992), and Meinzen-Dick and Bruns (2000). Ostrom (1992)

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[72] North (1990: 3) defines institutions as the 'rules of the game in a society, or, more formally, the humanly devised constraints that shape human interaction.' Douglas (1986: 46) includes the social grouping or organisation into the institutions while Ostrom (1992: 19) defines institutions more narrowly as 'a set of rules that is actually used, working rules or rules-in-use, by a set of individuals to organise repetitive activities that produce outcomes affecting those individuals and potentially others.' I refer to Ostrom's working rules as the informal institutions while North's definition includes both formal and informal institutions. I argue further that organisational structure is an essential part of institutions.

developed eight design principles which she considers the key for long-enduring,[73] successful, efficient and self-organising farmer-managed irrigation systems such as the rice farming systems described here.[74] According to her, these principles are the foundation (or incentives) for the repeated willingness of users to invest labour and other resources to maintain the irrigation infrastructure with little coercion (Ostrom 1992: 68). Agrawal (2001: 1660) criticises Ostrom's eight principles as being insufficient and concludes that one should consider at least 30 or 40 factors to analyse successful management of common property resources. Taking into account these many factors for the institutional analysis would go beyond the scope of my thesis. I hereafter focus on a few principles which I regard as key features of the institutional dimension and which partially cover several of the factors Agrawal and Ostrom set out:

(1) hierarchically nested organisational structure,

(2) consensus-based locally devised and adaptable rules guided by principles of equity, egalitarianism and transparency,

(3) a set of rituals as supporting elements symbolically binding members to cooperate, and

(4) limited external control over allocation and distribution of water.

1. Hierarchically nested organisational structure

Membership of a farmer-managed canal-irrigated rice cultivation system can consist of farmers of only one village or several villages surrounding one serviced area of irrigated rice

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[73] At least several generations of farmers.

[74] Her eight principles are as follows: (1) clearly defined boundaries in terms of membership and resources: who is a part and what resource belongs to the system, which is a measure to exclude possible free riders; (2)'good-fitting rules': rules for water allocation are adapted to the local conditions and are based on agreed labour and financial share by members; (3) modification of rules is possible based on a consensus of all members; (4) any member can monitor rule violations: with transparent structures in place such as fixed proportional diversion structures, alterations to the structures are visible to all members and can be dealt with *in situ* and immediately; (5) gradated sanctions exist for rule violations: initial sanctions are surprisingly low, writes Ostrom (1990: 94; 1992: 71). This quasi-voluntary compliance, she argues, exists because enforcement of rules is warranted through all members participating in monitoring activities; (6) low cost conflict resolution mechanisms are in place and conflicts are usually internally managed; (7) minimal external influence on how users devise their user rights; and (8) all activities within the system are organised into nested layers, that is work maybe organised on the sub-unit level (Ostrom 1990: 88–102; 1992: 67–79).

fields. They can be landowners and tenants alike.[75] Membership is, however, clearly defined by those who cultivate their fields within the boundaries of the area serviced by the irrigation network. This is in line with Ostrom's (1992: 69) first design principle, which she argues, is crucial in that benefits are not reaped by free riders.

The hierarchic nested organisation is reflected in clearly defined roles which are appointed to different members according to their place in the organisational structure, their capabilities and the needs of the irrigation system. Responsibilities mainly include monitoring of the proper functioning of the irrigation facilities, mobilising labour and decision making with respect to irrigation management. The organisational structure is ultimately dependent on the size of a particular rice farming system, the technical design and durability of the irrigation structures and the nature and extent of work required (Siy 1982: 42). In smaller units, for instance, structure and responsibilities are less complicated and less developed.

Leadership responsibilities vary but generally include: mobilising labour, material and tools for the maintenance and repair of irrigation facilities; monitoring of water distribution; determining water distribution schedules; accounting and record keeping; and conflict resolution (Coward 1980: 205–6; Upreti 2000: 158, 160). Coward (1979: 31–2) too, suggests, using as an example the Philippine *zanjeras*, that leadership roles occur at multiple levels with each role associated with a discrete territory of the total serviced area which reflects the nested hierarchical organisation inherent to these farming systems. Leaders elected by members are subject to review and replacement and usually receive compensation in form of labour exemption, financial retribution, land to cultivate or a share of the harvested crop (Coward 1980: 206).

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[75] There exist various tenure arrangements and some of these are attached to members' roles in the irrigation system (Siy 1982: 84).

2. Consensus-based locally devised and adaptable rules guided by principles of equity, egalitarianism and transparency

The formal and informal institutions set out the framework in which members collaborate and/organise irrigation and cultivation of rice. These institutions have developed and evolved over time, and are specific to each system shaped by local knowledge, customs and culture (Upreti 2000: 156–7). Devising of rules is consensus-based and involves an ongoing process of negotiation and renegotiation because of the inherent nature of human and ecosystem dynamics (Ostrom 1992:14; Meinzen-Dick and Bruns 2000: 27, 35; Upreti 2000: 155). These rules and regulations can exist in written or only in oral form. Rules generally set out membership (who can become a member), water rights (share of water), labour commitments, some form of gradated sanctions for rule breakers and avenues for conflict resolution.

Membership is defined by a share of water or land and a share of labour obligations. In addition, financial or material contributions as a means of cost sharing are a further component of membership. How much labour a member has invested into construction, and is investing into maintenance and operation of the system may be attached to that membership share (Yoder 1994: 25–6). Guiding principles in defining these shares are based on equity, egalitarianism and transparency. Costs and benefits are distributed in a transparent and equitable way (Siy 1982: 27, 49, 53). The physical irrigation structures reflect these guiding principles in that they have a transparent set-up and equally divide water flow. Farmers' entitlements of rights to water and use of the system are consolidated by farmers participating in operation, maintenance and repair (Upreti 2000: 153).

According to Svendsen and Small (1990: 394), equity is the most decisive factor for an efficient irrigation system. It is a measure of fairness in terms of water allocation especially in times of water shortages. Most agricultural systems are subject to considerable variations in the amount of water available throughout time due to drought, flood and environmental degradation (Hunt and Hunt 1976: 392). Conflicts over water, when demand is higher than supply, is thus a normal phenomenon. With clear definitions of water rights and proper design and construction of irrigation facilities, water conflicts are usually solved within the system.

Farmer-managed canal-irrigated rice cultivation systems are embedded in a larger social system including local culture and customs. These indirectly influence the way people interact with each other, how they cooperate, and how rules are devised. Together they form the trust base that minimises free riders and allows for reasonable sanctions and monitoring of the rules. Trust is a prerequisite for members' commitment and cooperation which, according to Siy (1982: 154), is 'best gained and preserved when members recognise fairness or justice in the distribution of members' obligations and benefits.'

3. A set of rituals as supporting element symbolically binding members to cooperate

Celebration of irrigation and cultivation of rice has a long history across Southeast Asia. Rituals can be quite elaborate or very simple depending on the local culture. It can involve celebration of rice and/or water, and celebrations can be carried out on the farm-field level only or on both system and farm-field levels. In Northern Thailand annual rituals to the weir spirits to protect the entire irrigation system and rituals to the rice for a good cultivation season were common celebrations (Groenfeldt 1991: 116; Shivakoti 2000: 4).

Rituals derived from local culture and customs are defined as 'formalised socially predescribed symbolic behaviours' (Winthrop 1991: 245). These symbolic performances demonstrate the shared values of participants (S. Lorenzen 2008: 136). They are an integral part of many of these rice farming systems, representing a symbolic emphasis on the collaborative effort that is invested.

4. Limited external control over allocation and distribution of water

Farmer-managed rice cultivation systems are distinguished in that they are autonomous units. It is the farming community that operates and maintains the irrigation facilities and cultivates the rice. This autonomy, however, does not exclude a certain type of relationship with the state or an agency (Dayton-Johnson 2003: 317). Farmers may appeal to local government agencies for assistance in maintenance or reconstruction of irrigation infrastructure or in settling disputes over water rights (Coward 1980: 65; Hunt 2007: 199–200). On the other hand, governments have an interest in investing into these systems to maintain rice production levels. For instance, many of these rice farming systems underwent rehabilitation of their irrigation facilities, which entailed some restructuring of operational aspects, before the Green Revolution. Interventions by external authorities also occurred in the pre-modern era (before the twentieth century) where kings intervened in construction and extension work (Cohen and Pearson 1998: 88).[76]

The careful balance of proportional allocation of costs and benefits negotiated over several generations of farmers collaborating in sharing water can be significantly disturbed by external intervention with lack of understanding. The wealth of literature that studies institutional arrangements in irrigation systems was also born from recognising that external interventions can be detrimental to communal farming system performance.[77]

In these particular rice farming systems external control is generally limited to support for investments in renovation or extension of irrigation facilities and possibly extension services to farmers with respect to the cultivation. Representing these systems as being

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[76] The main rehabilitation work occurred during the Green Revolution which I discuss using the example of Bali and the subak in chapter 5. In present times, most of these rice farming systems have become part of national legislation in some form, with agrarian law, natural resources law and property laws all influencing the way these systems operate. This coexistence of multiple legal frameworks, formal state law and customary local law which both regulate the same resources, has made tensions and contradictions common (Meinzen-Dick and Bruns 2000: 24–5).

[77] Anderies et al. (2004) describe a case of farmer-managed irrigation systems in Taiwan where the government dismissed members from having to pay irrigation fees, which promptly resulted in unexpected adverse consequences such as declining maintenance with farmers unwilling to contribute voluntary work and finances.

located in a basin of attraction allows for some bandwidth. Each of these rice farming systems can either be positioned in a fixed location or float around, some closer to the bottom, some nearer to the edge depending on their dependency on the state with respect to the management of their system. Absolute default —at the bottom of the basin of attraction— would be complete autonomy and no support or dependency from outside at all. It is debatable whether such absolute autonomy ever existed.

Summary

The common features of the institutional dimension of the basin of attraction for such rice farming systems are characterised by a framework of informal and formal rules that regulate the use and maintenance of the irrigation system and set out an organisational structure to attend to activities at different levels of the system. The guiding principles of equality, egalitarianism and transparency are reflected in rules and regulations which define each member's share of rights and obligations to receive water. Both elected leaders and members are locals from nearby villages familiar with local customs and culture. Rituals which in symbolic performance unify members in their collective action can be part of these rice farming systems and can involve additional work commitments. External governmental control is limited yet the extent of intervention varies.

Thresholds - Institutional Dimension

I suggest key thresholds that determine whether a particular farmer-managed canal-irrigated rice farming system is situated in the basin of attraction are: local origin of members, relative autonomy and negotiable rules, and guiding principles maintained at all times. The three thresholds of the institutional dimension are all of a more qualitative nature. Clearly, the institutional thresholds influence most other dimension thresholds and if any of these are crossed there is a great risk that thresholds of other dimensions are crossed as well (Figure 3.12).

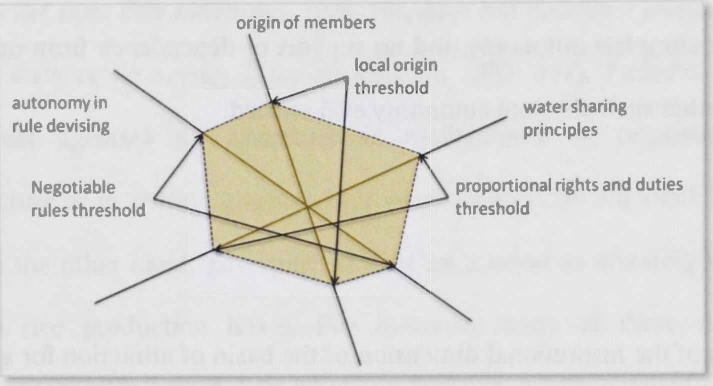

Figure 3.12: Institutional dimension thresholds

Local origin of members

An understanding of how formal and in particular informal institutions work comes from knowledge of local culture and customs. Members from villages surrounding the serviced area know the history of a particular rice farming system and are accustomed to the local rules of the games. As it is difficult to define a minimum percentage for how many members need to be of local origin, I suggest that the nature and frequency of conflicts could be used as a proxy.

Negotiable rules and relative autonomy

Rules, whether in oral or written form, require constant adaptation to changing circumstances with respect to the natural and human environment. A degree of informal rules warrants that rules arrangements remain flexible. In order for rules to remain negotiable, relative autonomy from any government agencies is crucial. Farmers need autonomy to devise and adapt their rules to manage the irrigation system.

Guiding principles maintained

Equity, egalitarianism and transparency are the guiding principles of these farming systems. These principles set out the proportional share of benefits and costs for all members which create the incentives to collaborate. These principles are also reflected in the physical (division structures) and technical (labour input) dimensions.

CROSS-DIMENSIONAL LINKAGES

Representing the subak as social-ecological system consisting of four overlaying dimensions acknowledges that these dimensions are interlinked and interact with each other. For example, the hierarchical structure of the physical set-up of the irrigation system (physical dimension) is reflected in the hierarchical nested organisation of operation and maintenance (institutional dimension). The principle of proportional allocation and distribution of water is likewise mirrored in the operation of the irrigation system requiring minimal skills and labour input (technical dimension). Crop management decisions (technical dimension) impact on the nitrogen supply and the biodiversity levels (ecological dimension). The reliable water supply (ecological dimension) depends on the structure of the physical set-up of the irrigation infrastructure (physical dimension) as well as on the ability of the membership to mobilise labour for the maintenance of the system (technical dimension). The maintenance of the irrigation system technical dimension), again, is dependent on the provision of incentives for members to attend communal maintenance work (institutional dimension).

CONCLUSION

In this chapter I describe farmer-managed canal-irrigated rice cultivation systems by means of four dimensions that shape the basin of attraction using an interdisciplinary approach. I suggest that in using the basin of attraction concept common features can be emphasised yet the degree of diversity that exists within these systems is not being lost.[78]

One of the main incentives for farmers to cooperate is a functioning irrigation system which is based on a reliable supply of water (Chambers in: Svendsen and Small 1990: 391). This reliable water supply is dependent on the ecosystem that supports tropical rice cultivation (as discussed in the ecological dimension) and the type and quality of the irrigation system (which I discussed in the physical and technical dimension). The quality depends on members' skills, their experience and willingness to invest their time, expertise, labour and/or financial contributions (which I have discussed in the institutional and technical dimension). These dependencies between the different social and ecological components to warrant a reliable water supply reflect the complexity of the linkages between the four dimensions.

There are thresholds in all four dimensions that determine the boundaries of the basin of attraction for Southeast Asian farmer-managed canal-irrigated rice cultivation (see for a summary: Table 3.6). These thresholds can be measured quantitatively and/or qualitatively. Depending on the type of threshold crossed, the system may remain on the verge close to the border without moving to another basin of attraction. Once the disturbance has been removed, the system may be able to move back into the basin of attraction. This move back after the exposure to a significant disturbance suggests that the system has proven to be resilient. Some thresholds are connected to others, and, if one is crossed, it has a cascading effect and other thresholds are crossed instantly or as a consequence and resilience is lost. For instance, corruption of the guiding principles in the institutional dimension will have an impact on labour mobilisation in the technical dimension, and cause the deterioration of the physical structure.

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[78] This representation could be extended to allow for the classification of worldwide existing farmer-managed irrigated rice cultivation systems as according to Chambers (1988: 211) a diagnostic typology for such systems is underdeveloped.

Table 3.6: Overview Thresholds of the FMCIRS basin of attraction

Dimension	*Threshold*	*Measure*
Physical	Contiguous area of bunded rice fields	Sub-unit sizes between 35–80 hectares with units around 100 hectares.
	Gravity-fed supply driven irrigation system	gravity fed canal irrigation supply-driven
	Proportional allocation and distribution	Fixed proportional weirs with continuous flow
Ecological	Reliable water supply	Between 1,688–2,313 mm per cultivation season Rice yields as proxy (2–2.5 t/ha)
	Sufficient nitrogen input	130 kilograms per hectare, organic origin
	Species biodiversity	different rice varieties planted in one area, key natural enemy species existent organic matter applied The existence of the practice of collecting and gathering food in and around the rice fields supplementing the local diet, and
Technical	Intensive cultivation techniques	Labour intensive techniques applied, 100 to 200 person-days
	High labour input into irrigation maintenance	20–80 person-days per member and year for irrigation
	Ability to mobilise labour	Labour availability High quality of irrigation system (proxy)
Institutional	Local origin of members	A high percentage of members originated from surrounding villages Type and frequency of conflicts (proxy)
	Negotiable rules and relative autonomy	If written rules exist these can be amended Existence of informal rules
	Guiding principles maintained	Proportionality of costs and benefits sharing for all members

CHAPTER 4

SUBAK AS A SOCIAL–ECOLOGICAL SYSTEM

INTRODUCTION

In the previous chapter I modelled the basin of attraction for farmer-managed canal-irrigated rice production systems using four dimensions (ecological, physical, technical, and institutional). I also introduced key thresholds in each of these four dimensions which delineate the boundaries of this basin of attraction. In this chapter I am situating the subak as a social-ecological system in this basin of attraction. I concentrate on key features which distinguish this particular system from other farmer-managed canal-irrigated rice production systems. This discussion provides the necessary basics for the following chapters where I analyse the impacts of the Green Revolution (chapter 5) and deagrarianisation (chapter 6) on the subak.

The subak as a social-ecological system I am describing here, again using the four dimensions, is the subak that existed before agricultural modernisation. I narrow the focus more specifically on the subaks of the colonial and post-colonial era (1906–1960). I do this firstly, because there is ample literature available that describes the subak of this period. Secondly, there are divergent views among Bali scholars as to the form subaks existed in South Bali before the Dutch occupation[79] and how strong influence and control was from

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[79] The Dutch occupation of Bali began in 1906 and lasted to 1942, quite late in the colonial history of the Indonesian Archipelago, which began in the late 16th century.

the several kingdoms[80] all over Bali. This debate raises questions about whether subaks can be really defined as farmer-managed systems or whether they were rather agency-managed.

Schulte Nordholt (1996: 55–60, 128–9; 2010), for example, who undertook research in Mengwi —a former kingdom and nearby town to my field site— in the 1980s on the history of Balinese politics, maintains that irrigation was controlled by the kings of the time; not only construction and maintenance, but also allocation and delivery of water to the fields. He (ibid. 1996: 246–7; 2010) alleges that it was the Dutch who created a uniform version of subaks across Bali, 'restoring' what they considered the original subak. This, as emphasised further by Hauser-Schäublin (2005: 749–50), allowed for a more independent management 'in their attempt to wipe out all traces of supra-village authorities.' Geertz (1980a: 85), on the other hand, maintains that royal leaders were mainly interested in collecting taxes. He saw the subak as an almost 'acephalous' organisation —egalitarian and independent of any state influence and support during the nineteenth century and onwards. This is supported by Lansing (2005: 305) who insists that 'there were no royal engineers or irrigation officials' apart from tax collectors and that the role of the Balinese nobility was usually confined to encouraging local initiatives in irrigation. Van Setten van der Meer (1979: 42, 97) proposed that kings were mainly involved in larger irrigation projects, providing construction material and controlling irrigation.

It appears that there are substantial regional differences, which also depend on the topography. Schulte Nordholt (1996), for example, did his research in Badung regency, where according to Birkelbach (1973a: 14) the largest flat flood plain of any regency exists, which would invite or enable large-scale irrigation. Lansing (1991; 2006a), on the other hand, did his research mainly in Gianyar regency with a more rugged terrain, only permitting irrigation on a much smaller scale (Figure 1.6). A brief examination of the average sizes of subak shows that they range between 48 hectares (Buleleng regency) and

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[80] Shortly before the Dutch invasion, there were six kingdoms in South-Bali (Geertz 1980a: 11) which Lansing (2005) calls postage-stamp kingdoms for their realms were tiny and their borders shifted continuously.

113 hectares (Badung regency) with Gianyar regency subaks averaging 75 hectares.[81] It is therefore tempting to conclude that in areas where larger-scale irrigation was possible, such as in Badung, kings would have more likely supported construction and extension and would have been interested in controlling water regulation. Yet, as Maurer (1990: 31) and Lansing (2005) point out, the kingdoms in the south were incessantly involved in battles, with kingdom borders often changing, which would have made continuous control over irrigation facilities rather difficult. In addition, Lansing (1991: 26–27), with reference to Liefrinck (1969[1927]: 43–4), emphasises that a single ruler could hardly have been able to control an entire water catchment because rivers in South Bali cross-cut across territories of different sovereigns on their way to the sea.

What is evident however, as Schulte Nordholt (2010) concedes too, is that after the Dutch took over administration of Bali 'irrigation became primarily a local affair' and where it existed 'dynastic control of dam and main conduits was discontinued.' Birkelbach (1973a: 37) made similar observations stating that the Dutch did not interfere in internal subak politics. Thus, I argue that the colonial and post-colonial subaks that existed before the Green Revolution in South Bali had relative autonomy in that they were mostly independent in their decision making regarding allocation and distribution of water. For this reason, subaks can be well situated in the basin of attraction for farmer-managed canal-irrigated rice cultivation systems.

FIELD RESEARCH SITE

Before I highlight the specificities of the subak in each of the four dimensions, I wish to introduce the field research site. The experiences and data I gathered from the extended period in the field, which included observation and participation in two rice cultivation

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[81] This data is calculated from an inventory from 1989 (Suadnya 1990: 5).

seasons, serve as a basis to understand how subaks actually function, how farmers[82] irrigate and cultivate rice and how the institutional framework supports their cooperation. It also allowed me to examine the changes that are occurring in the present day.

I undertook field research for 18 months between July 2004 and December 2005, concentrating on subaks in South Central Bali where urbanisation, tourism and industry are the most apparent developments. This region is concurrently the rice basket of Bali, the principal rice growing area where the highest yields are harvested. The rice bowl region was the main target for the Green Revolution because of its geographically and agro-technically advantageous features with large alluvial plains that are feasible to plough with hand-held tractors and adequate water supply throughout the year for the more water-stress sensitive high-yielding varieties.

- The research site in which I lived with my family lies at the southern tip of the rice bowl an hour by car north of Denpasar (Figure 4.1). This region belongs to Badung, the economically most prosperous administrative regency of Bali and one of the most densely populated areas.[83] The main tourist centres are three quarters of an hour away by car to the south and east of the research site. About a third (36 per cent) of the total agricultural land area of the regency or 10,230 hectares are cultivated with irrigated rice[84] with the remaining agricultural land dedicated to dry land crops (34 per cent), estate crops (21 per cent), forest (4 per cent) and fish ponds, grassland and unused land (5 per cent) (BPS Bali 2010a).

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[82] When I speak of farmers I mean to include all members of a household engaged in farming who work in the fields.

[83] See chapter 1 for details on population density.

[84] This is an eighth or 12.5 per cent of the total area of irrigated rice in Bali.

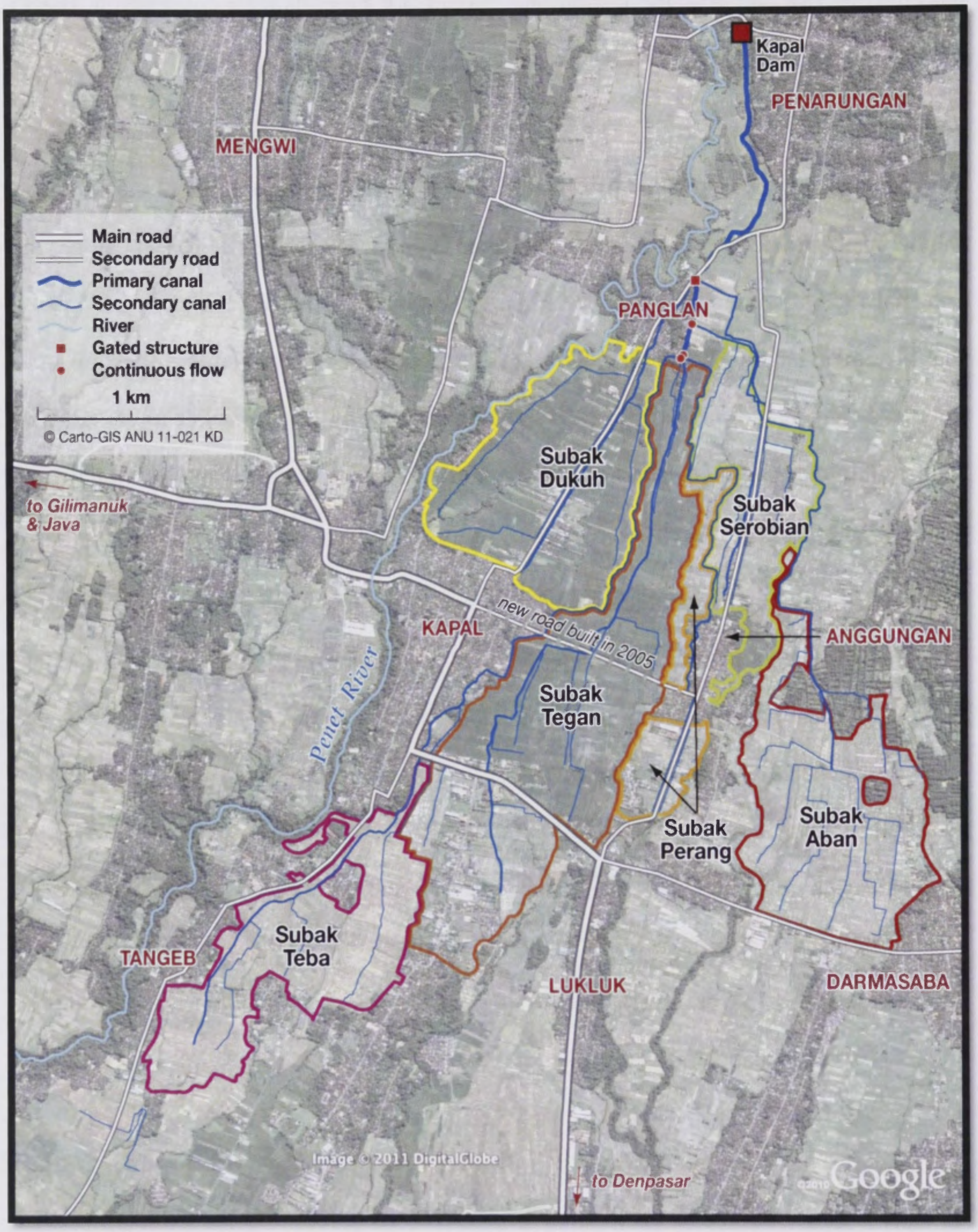

Figure 4.1: Field research site with extent of studied subaks and surrounding villages

Source: Map prepared in collaboration with K. Dancey and S. Lorenzen

Farmers grow five rice crops over two years. They cultivate high-yielding rice varieties as cash crops for two consecutive planting seasons and either leave the field fallow for the third season or plant non-rice crops such as soy, maize, peanut or watermelon, which is then again followed by two seasons of rice.

The research focus was set on subaks along Penet River, which has a total length of 45.3 kilometres (BPS Bali 2005: 24). There are six permanent dams along its course which feed 31 subaks altogether with a total of approximately 3,900 hectares of irrigated rice fields (Figure 4.2). In the upper course where the terrain is more precipitous the average subak areas are smaller, gradually increasing in size towards the lower course of Penet River where the terrain unfolds into larger alluvial plains (Table 4.1).[85]

Table 4.1: The six dams along Penet river

Name of dam	*Admin. level (Regency)* #	*Altitude (metres above sea level)**	*No of* subaks #	*Irrigated area (hectares)*#	**Average irrigated area / subak (hectares)**
Dam Peneng	Tabanan	790	8	370	46
Dam Luwus Carang Sari	Bali-Province[86]	510	8	1018	127
Dam Kacagan	Tabanan	310	2	220	110
Dam Penarungan	Badung	150	2	321	161
Dam Kapal	Badung	137	6	889	148
Dam Munggu	Badung	50	5	1073	215

Source: * Digital earth figure maps of Indonesia (Peta Rupabumi Digital Indonesia) 1:25'000, pages 1707-614 (yr 2000), 1707-334 (yr 2000), 1707-612 (yr 1999), # Public Works Departments of Province Bali and Regencies Tabanan and Badung

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[85] This was also noted by Birkelbach (1973a: 55) in his survey on subaks all over Bali in the early 1970s, where he wrote: 'Topography has its role in size delimitation as well. Ravines tend to divide subaks and in the mountains the ravines are close together.'

[86] Dam Luwus Carang Sari is under the jurisdiction of Bali Province as the subaks that share this dam are located in both regencies, Tabanan and Badung.

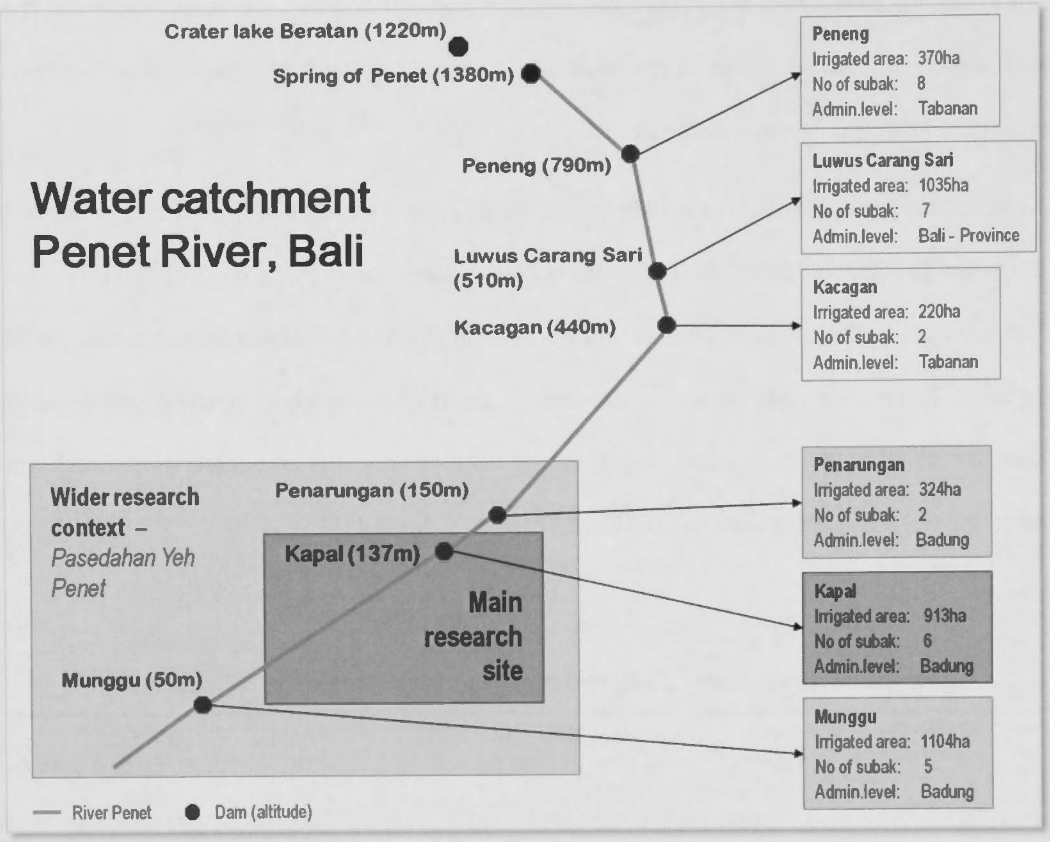

Figure 4.2: Penet river water catchment with research areas

Source: Digital earth figure maps of Indonesia (Peta Rupabumi Digital Indonesia) 1:25'000, pages 1707-614 (yr 2000), 1707-334 (yr 2000), 1707-612 (yr 1999), and irrigation maps from the Public Works Department of Province Bali and Regencies Tabanan and Badung

The course of the river passes through the two regencies Tabanan and Badung on its way from the mountains near Beratan caldera lake to the Indian Ocean. Dams along the upper course of the river are under the jurisdiction of Tabanan regency, while dams along the lower course of Penet River are under the jurisdiction of Badung regency.[87] Luwus Carang Sari dam is managed on the Bali provincial level because the subaks that share this dam are located in both regencies, Tabanan and Badung (Figure 4.2).

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[87] These dams are all permanent these days. They were built between 1940 and 1990 by the Public Works department and have since been managed by this government agency. Water flows into subaks however are maintained at continuous flow at all times except if there are any major repairs needed.

The main research focus was on six subaks on the lower course in Badung regency which share Kapal dam (Figure 4.2: main research area). For comparative reasons and to study existing water interdependencies with another subak, I studied and collected data from a further six subaks along the same river and the same regency which divert their water from Penarungan dam and Munggu dam respectively (Figure 4.2: wider research context). These twelve subaks are administratively bound together in the *pasedahan* Yeh Penet (Table 4.2).[88]

A pasedahan is a particular geographic area of several subaks which can be compared to an administrative district (*kecamatan*) of several villages. The pasedahan's main purpose is the collection of land taxes for the Indonesian Government. They also serve as vehicles for farmer-government dialogue (Birkelbach 1973b: 155). Pasedahans are headed by a *sedahan* who is a civil servant employed by and responsible to the *sedahan agung* (lit. transl. 'grand' sedahan) at the regency level. The sedahan agung is concurrently head of the Tax Office (Dinas Pendapatan) which collects other taxes as well (Pitana 1993: 8). Sedahans have existed since the pre-Dutch colonial period and their role has essentially remained the same (Birkelbach 1973b: 155).[89] In the pasedahan Yeh Penet, the sedahan assists subaks in writing grant applications for major maintenance work to be undertaken in the irrigation infrastructure. He may also help in cases of conflicts or disputes among subaks or members[90] of a particular subak that are not solvable on the subak level.

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[88] Penarungan dam diverts water to two subaks, subak Babakan and subak Penarungan. Note that subak Babakan is not part of the pasedahan Yet Penet.

[89] The role the sedahan played and his power and influence on control over irrigation water pre-Dutch invasion is part of the contentious debates on which I have briefly touched at the beginning of this chapter. Here, it remains to be said that in the research area decisions on schedules of water allocation for each subak appeared to be made amongst the subak heads independently while the outcome of negotiations was passed on to the *sedahan* for his information.

[90] The term subak member refers to the farming household consisting of several family members. It is the farming household which is by default a member of the subak in which they cultivate their rice field and it is usually more than one family member in a farming household who is involved in rice farming. For more on membership and interpretations of membership see Jha (2002b).

Table 4.2: Overview of Pasedahan Yeh Penet subaks

Feeding dam	*Subak*	*Size (ha)*	*Average sub-unit size*	*Members*	*Members per sub-unit*	*Average size per member*
Penarungan	Penarungan	268	54	725	145	0.37
Kapal	Tegan	214	15	598	43	0.36
	Dukuh	132	15	340	38	0.39
	Serobian	64	11	170	28	0.38
	Perang	33	11	115	38	0.29
	Teba	158	14	384	35	0.41
	Aban	150	30	162	32	0.93
	Sad Buwana Tirta	751	16	1,769	36	0.42
Munggu	Munggu	252	21	832	69	0.30
	Cemagi Anyar	120	20	483	81	0.25
	Cemagi Let	360	72	990	198	0.36
	Munggu Tegal Lantang	119	15	227	28	0.53
	Kedunggu	77	11	216	31	0.36
	Panca Tirta Buwana	928	24	2,748	81	0.34

Source: *Subak* heads survey, 2005

Penarungan dam and subaks

Penarungan dam is located 2.5 kilometres upstream of Kapal dam and 15.5 kilometres downstream of Kacagan dam (Table 4.1, Figure 4.2). The permanent dam was built in 1940 at the time of the Dutch occupation and renovated in 1978–79 (DPU Badung 2001b). This dam feeds two subaks: subak Penarungan and subak Babakan. Although there is some coordination between these two subaks, subak Babakan is not part of pasedahan Yeh Penet.

Subak Penarungan is one of the larger subaks in pasedahan Yeh Penet with 268 hectares in total and is divided into 5 sub-units (*munduks*) with an average size of 53.6 hectares (Table 4.2). Each munduk has an average of 145 members who cultivate on average 0.37 hectares of land. Subak Penarungan's territory borders to the south with subaks Aban, Tegan and Serobian.

One of the six subaks that is fed by Kapal dam, subak Aban is substantially dependent on subak Penarungan. In fact, subak Aban receives half of its water share from the off-flow irrigation water from subak Penarungan. Subak Aban therefore follows the cultivation schedule of subak Penarungan, usually beginning its cultivation season a month after subak Penarungan.

Kapal dam and subaks

The six subaks that share Kapal dam are led by five subak heads as two of the subaks, subak Perang and subak Serobian, share a subak head (Figure 4.1).[91] The subaks form together a government motivated federation named *subak-gede* (lit. transl. 'big' subak) *Sad Buwana Tirta* (lit. transl. 'six water worlds') which was founded as a pilot within the IPAIR project in 1996.[92] The IPAIR project (short for *Iuran Pelayanan Irrigasi*, transl. 'Irrigation Service Fee') is a government project which aims at reducing costs in administration and handed over operation and maintenance responsibilities of the dam and primary canal to the federation by introducing an irrigation service fee.[93]

The present main responsibilities of the subak-gede which is managed by the five subak heads are optimal allocation of water amongst the subaks as well as coordination and preparation of inter-subak rituals. The subak heads come together several times per year to discuss how the irrigation water is to be distributed for the following months. Inter-subak rituals at the subak-gede level are carried out at the temple which is closely located next to

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[91] The subak head of the two subaks in question has said that this was always the case. Shared leadership has also been noted by Birkelbach (1973a: 53–5) in his survey, especially in cases with smaller subak territory.

[92] The Balinese word *gede* means 'big'. According to Sutawan et al. (Sutawan et al. 1986: 4–5) subak-gede were known in the period of Dutch occupation though how they came to exist and what their function really was is unknown.

[93] The Indonesian irrigation policies reformation process has led to both confusion as well as frustration in Bali as fee structures to contribute to maintenance are already in place. Subaks in the research site refused to pay the nationally introduced Irrigation Service Fee for they provide their own services and already pay their own fees towards religious and physical irrigation system maintenance (for more details refer to Lorenzen and Lorenzen 2008).

the Kapal dam. There are only a few ceremonies organised annually, which do however demand time and finances to be prepared. According to the five subak heads, the formation of the subak-gede has enabled them to better coordinate and prepare for these large ceremonies and consequently reduce labour input and expenditures. Also, the regular face-to-face interaction among the five subak heads allows greater flexibility in water management during times of water shortage.

The six subaks practice synchronised planting between subaks and crop rotation of two rice crops followed by a fallow period or non-rice crop. Synchronised planting implies that all members transplant their fields within a two-weeks time period determined by their subak head. The six subaks also practice irrigation rotation among each other with one subak (subak Perang) additionally practicing intra-subak irrigation rotation. Rotation of cultivation periods amongst the six subaks allows for optimal allocation of water to all subaks which require higher water demands during the soil preparatory phase and in the first month after transplanting the seedlings.[94] At the time of my research, the water roster foresaw a three-week gap after each subak before the next could start its cultivation season.

The planning of the water roster officially takes place in the *sedahan*'s office, which is on the premises of the Lukluk village administration office (*kantor lurah*).[95] He calls the meeting where the five subak heads of Sad Buwana Tirta meet together with the other subak heads of the subaks of pasedahan Yeh Penet. Although these meetings take an official form, decisions on the water roster seem to have been decided already before the meeting. Apart from these formal meetings many informal negotiations take also place. The subak head of a subak that is in need of water, but has not had its turn will contact the current water user

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[94] In the first month after transplanting, in particular, it is of utmost importance to keep irrigation water levels at sufficient levels (5–10 centimetres) in order to suppress weeds as the seedlings need time to establish their root system before they are able to compete for nutrients, light and water.

[95] See Figure 4.1 for the location of this village.

subak for some additional water. Usually an agreement is made, with the subak in need getting water during the night or for a couple of hours.

Like the Penarungan dam, the Kapal dam was built in 1940, and renovated in 1978–1979 (DPU Badung 1999). The water diverted from Penet river first passes through a 400 metre-long tunnel before entering the primary canal, which extends from dam to the final diversion weir over a distance of 2.3 kilometres. From the primary canal six secondary canals take off at various places to each of the six subaks. These secondary canals are again divided into tertiary canals which convey the water to the munduks, and further into quaternary canals to the individual inlets. Most of the canals' technical set-up is based on continuous flow principle. The primary and secondary canals are cemented while on the tertiary level only parts are cemented and on the quaternary level all canals are mud-lined (Table 4.3). There is one gated diversion weir which divides water from the primary canal into subak Dukuh to the west, subak Aban to the east and a third double gate to the remaining subaks (Figure 4.3). The gates generally stay open but are operated by a Public Works civil servant upon subaks' requests.

Figure 4.3: Gated diversion weirs: subak Aban (left), subak Dukuh (right)

Table 4.3: Irrigation infrastructure subak-gede Sad Buwana Tirta

Infrastructure	*Total Length (kilometres)*	*Percentage concreted*	*Percentage tunnelled*	*Responsibility for operation and maintenance*
Primary canal	2.3km	22	17 (or 400m)	subak-gede
Secondary canals	15.2km	22	0	subak
Tertiary and Quaternary canals	95km	0	0	munduk (tertiary) and farmer (quaternary)

Source: Public Works Department, Regency Badung

Responsibility for the operation and maintenance of the primary canal lies with the subak-gede (Table 4.3). This is because all six subak are fed by this canal. The secondary canals lie in subak territory and thus operation and maintenance is the responsibility of every individual subak. The tertiary canals are operated and maintained by the munduk which receive water from these canals. The quaternary canals lead into the single rice fields and are the responsibility of the individual farmers. Renovations on all canals are organised in communal work on each of the different levels. Maintenance is normally carried out between cultivation cycles. In the case of larger renovations works on the primary and the secondary canals, the subak-gede or the subak can apply for financial support from the government to cover costs for material, and labour if outsourced.

The rice fields of Sad Buwana Tirta with a present total area of 751 hectares are currently cultivated by 1,769 members. Land and membership size varies amongst the subaks (Table 4.2). All subaks are sub-divided into munduks with an average size of 16 hectares, which on average service 36 members who cultivate on average 0.42 hectares (except for subak Aban where fields are more than twice as big on average).[96] Some farming households have fields in several of the six subaks and some also have fields in other subaks adjacent to this

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[96] Why it is that members' average field sizes in subak Aban are so much higher these days compared to those in the other subaks is unclear. One reason for the larger sizes is that the region to the west of subak Aban —that includes all other subaks of Sad Buwana Tirta— was involved in a war between the royal houses of Mengwi and Badung in 1891 (Geertz 1980a: 11–13; Schulte Nordholt 1996: 175–96) . With the war, many villagers fled and new settlers were moving in. The new rulers annexed all the rice fields around Kapal and redistributed the land to their own followers (Schulte Nordholt 1996: 196). Land parcels were subdivided to accommodate the new settlers who received each a rice field of 0.3 to 0.5 hectares (S. Lorenzen 2011, personal communication).

subak-gede. The majority of the 178 farmers interviewed, each representing a farming household, were owners (58 per cent) cultivating a single field in one of the six subaks (Table 4.4). The remaining households were either tenants (28 per cent) or owner-tenants (14 per cent) who cultivate on average larger areas of land and across several munduks or subaks. The usual sharecropping arrangement found in this region is called *ngapit* where the sharecropper pays the landowner a third of his yield and also pays for all the expenditures incurred related to the cultivation such as means of production and hired extra-household labour.[97]

Table 4.4: Owner-tenant ratios of interviewed farmers in the research area

Type	*Share (percentage)*	*Average age*	*Total average field size (hectares)*	*Average number of fields*
Owners only	58	53.3	0.37	1.1
Tenants only	28	56	0.56	1.7
Owner-tenants	14	56.3	0.67	2.4
Total	100	54.5	0.46	1.5

Source: Farmers' survey (2005) [98]

Most of the farming households who cultivate their fields in one or several of the six subak in the main research area live in six surrounding villages with a present population of between 1,895 and 9,957 inhabitants (Figure 4.1, Table 4.5). According to official numbers, less than 20 per cent of the adult inhabitants have their main income in agriculture in all but one village (Darmasaba).[99] Comparing subak membership numbers (1,769) with the total number of households (7,557) indicates that nearly a quarter of the households in

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[97] Other common sharecrop arrangements known in Bali are *nandu* and *nelon*, For a more detailed discussion on sharecrop arrangements, the reader is referred to Birkelbach (1973b), Bundschu (1985), Robinson (1988) and Jha (2002b).

[98] 178 farmers representing 178 farming households were interviewed. They were either household heads (male or female) or grandparents.

[99] It is again unclear why the percentage of inhabitants with their main income in agriculture is so much higher in Darmasaba compared to the other villages. One reason could be related to the fact that farmers who cultivate fields in subak Aban mostly live in Darmasaba. With significantly larger average rice fields compared to farmers in other subaks, they make a better living from rice farming compared to those farmers with smaller fields.

surrounding villages cultivate rice in one of the six *subaks*. There are a further unknown number of households in these villages which cultivate rice fields in other adjacent *subaks*.

Table 4.5: Surrounding villages and percentage of inhabitants' main income in agriculture

Village	*Inhabitants*	*Percentage main income in agriculture*	*Number of households*	*Average members per household*	*Percentage farming households*
Kapal	9,957	18.9	2,090	4.8	
Tangeb*	1,895	n.a.	394	4.8	1769 members of Sad Buwana Tirta
Lukluk	6,069	5.3	1,312	4.6	
Anggungan*	1,894	n.a.	327	5.8	
Penarungan	5,636	19.5	1,501	3.8	
Darmasaba	7,646	71.5	1,933	4.0	
Total (average)	33,097	(28.8)	7,557	(4.6)	23.41

Source: BPS Badan Pusat Statistik Kabupaten Badung, 2004. Kecematan Mengwi dalam Angka, 2003 and Kecematan Abainsemal dalam Angka, 2003, and (*) data collected from Kantor Lurah Lukluk (for Anggungan) and Abianbase (for Tangeb) in 2005.

Subak Tegan

Subak Tegan is the largest of all the *subaks* in Sad Buwana Tirta (Figure 4.1). For this subak and subak Dukuh I gathered the most detailed research data including households who cultivate their fields in either subak Tegan or subak Dukuh or both. At the time of my research, the area given by the subak head for subak Tegan was 213 hectares divided into 14 *munduks* cultivated by 598 members (Table 4.2). This is equivalent to an average area per munduk of 15 hectares with 43 members cultivating on average 0.36 hectares. Member households live in all of the surrounding villages or further away.[100] At the time of my arrival in August 2004 they had just harvested a rice crop. During the following two

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[100] From an evaluation survey on ownership and sharecroppers by the subak head in 2003 I analysed data from five of the total of 14 *munduks* of subak Tegan which showed that of 185 surveyed farming households 153 lived in one of the 16 hamlets of Kapal (83 per cent), 15 lived in Anggungan (8 per cent), two households in Lukluk (1 per cent) and one household in Penarungan (0.5 per cent) with 14 households (7.5 per cent) residing in villages further away.

seasons (September 2004 to February 2005 and May 2005 to August 2005), which were separated by a short fallow period, I participated in sharecropping a field of 0.2 hectares in one of the sub-units of this subak.

All subak representative positions including the board and council were occupied by men. According to the subak heads of the research site, female household members are accepted if there is no male relative available. The few female-only-headed households I met in the field research site were all able to find a male relative as substitute to attend subak meetings and do maintenance work. Women were however usually representing their households for any ritual-related matters.[101]

Meetings on the munduk level usually take place at the end of a planting season when communal work is required to repair damaged canals or diversion weirs. At these meetings the next planting season schedule is announced, recommendations on what kind of varieties of rice are best to be planted are given, fees and taxes are collected and maintenance work carried out if necessary.

In this subak the ploughing is nowadays mainly done with hand-held tractors. Draught cattle are no longer used in this region.[102] The ploughing work is done by hired tractor operators from within or without the subak community. The hiring of the tractor and its operator is organised through the munduk*s* but paid by each individual farming household. In subak Tegan, the tractor operator works his way through the munduk*s* from the topmost field to the bottom-most one and then back up again. Farmers also use hoes for the hoeing of small fields and edges of larger fields that are inaccessible to the tractor.

Two roads transect the territory of subak Tegan: the main route from Denpasar to Surabaya (East Java) in the south of subak Tegan and a new road that was constructed

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[101] In the subak*s* which Jha (2004) studied women were clearly deterred from participating in such meetings and excluded from decision making.

[102] After some thefts occurred in 1990, all cattle previously kept in the rice fields were moved to the compounds in the village. In uphill subak*s*, cattle are still kept in the rice fields.

while I was in the field which connects Anggungan and Kapal (Figure 4.1: 'new road built 2005'). Considerable development along these roads continues to expand into rice fields or is anticipated in the case of the new road.

Subak Dukuh

Subak Dukuh is a smaller subak adjacent to the west of Subak Tegan. At the time of my research the total area was 132 hectares divided into nine munduk*s* with 340 members in total, which is equivalent to an average of 15 hectares and 38 members per munduk and 0.39 hectares cultivated per member (Table 4.2). Most member households live in Kapal and Panglan —a hamlet of Kapal— which are located to the south and north of subak Dukuh territory (Figure 4.1).[103] A road dissects subak Dukuh, connecting Panglan with Kapal and dividing the subak into two parts. The main irrigation canal for this subak passes through residential areas of Panglan and then follows alongside the connecting road. There is considerable development along the road and water stress is common in this subak.

Organisational arrangements in subak Dukuh are similar to those of subak Tegan. All official positions within the subak are held by men only. Meetings and maintenance work take place at the end of a cultivation season, and ploughing is organised munduk by munduk with hired tractor operators.

Both subak Dukuh and subak Tegan have their customary ties with Kapal village.[104] These ties come into play at the time of subak ceremonies with the shared rituals taking place in

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[103] From an evaluation survey on ownership and sharecroppers by the subak head I analysed data from three of the total nine munduk*s* of subak Dukuh which showed that of 159 surveyed farming households all but one lived in one of the 16 hamlets of Kapal.

[104] The other subaks of Sad Buwana Tirta also have customary ties to subak territory neighbouring villages: Subak Teba's customary connections are with Tangeb, a customary village to the south of Kapal. Subak Serobian and Perang have ties with the customary village Anggungan and subak Aban with Tegal, which is part of Darmasaba (for location of villages see Figure 4.1).

the village temple. Also, at certain village ceremonies the attendance of subak members is required for both the festivities and the preparations.

Munggu dam and subaks

Munggu dam is located toward the lower end of Penet river —ten kilometres downstream from Kapal dam— to the south-west of Sad Buwana Tirta. It was built in 1939 and renovated in 1981–82 (DPU Badung 2001a). The five subaks which share Munggu dam had just initiated the process to become a subak-gede called *Panca Tirta Buwana* (lit. transl. 'The five water worlds') under the same government project at the time of my field research. Here, subak and membership sizes also vary, though the average munduk size (24 hectares) is twice as large, and the average members serviced per munduk (81 members) are about twice as many, as in Sad Buwana Tirta (Table 4.2). Presently, the total area of 928 hectares is cultivated by 2,748 farming households whose fields are on average 0.34 hectares, which is slightly smaller than in Sad Buwana Tirta.

At the time of my field research large maintenance work at the primary canal was required. This was organised by the five subak heads with finance from the government. The work was carried out by the subak and munduk heads and their wives over several days.

Two of the subaks' territories (subak Munggu and subak Cemagi Let) stretch to the coast. Here farmers are confronted with the expanding tourism industry. In particular, the expatriate community is interested in buying land for the construction of luxury villas. Several farmers have sold their land, however, according to the subak heads, farmers these days are thinking of leasing their land, rather than selling.

THE SUBAK AS A SOCIAL-ECOLOGICAL SYSTEM

Having introduced the field site subaks, in the final section of this chapter I want to discuss the subak as a social-ecological system. I review literature relevant to the subak of colonial and post-colonial times supplemented with accounts from farmers from the field site to situate the subak in the basin of attraction. I narrow my focus on specific issues in each of the four dimensions that distinguish the subak from other farmer-managed canal-irrigated rice cultivation systems. While I specifically outline the subaks of the time before the Green Revolution, many of their features still exist today.

Physical dimension

Summary of Basin of Attraction – Physical Dimension

The common features of the physical dimension to all farmer-managed canal-irrigated rice production systems is a canal irrigation system with a dam as intake at the river and a bifurcating network of canals that deliver the water to the fields. Before the Green Revolution, these facilities were mainly built from local natural material and accordingly required frequent maintenance. Water is proportionally subdivided, often including a negotiated process depending on the area to be irrigated and with rotational arrangements in peak water demand times.

The landscape is terraced to maximise cultivated area and minimise erosion. The boundaries of a system are defined by the area that is irrigated by the same system and a single dam that feeds the irrigation network usually not shared with other rice farming systems along a river. Average sizes appear to be below 100 hectares with larger systems subdivided into sub-units. These are contiguous and self-contained areas with individual inflows from the primary canal and are assumed to range in size between 35 to 80 hectares.

Bali's unique geographic features have had a significant influence on the type of cultivation and irrigation system found today. With rivers running in deep gorges towards the sea, water had to be taken from the river at a higher altitude than the rice fields, often some considerable distance away.[105] It was common that tunnels needed to be built to facilitate water flow from the river to the fields. In fact, documentation of tunnel builders has been found in inscriptions even before the first citing of subaks (Pitana 2003b: 2; Lansing et al. 2009: 114). Tunnel building was a highly appreciated and important skill. Tunnels were built by simple hand tools and could extend several kilometres. Liefrinck (1969[1927]: 49) remarked on the high standard of skill the Balinese achieved in devising their irrigation systems despite using simple tools only.

In the research site, the dam used to be built from palm trees, boulders, sand and dirt. One farmer can still remember how they had to gather heavy stones to construct the dam, which was located at the same place where the permanent dam is now. According to farmers, the old non-permanent dam was already shared by the six subaks. The dams made from natural material were usually renovated and reconstructed at the beginning of each planting season by all subak members (see for example Ramseyer 1988: 62 for Sidemen, East Bali).

Major construction works to build concrete dams and lined primary canals began with the arrival of the Dutch in South Bali and focused in particular on irrigation systems in Badung regency (Arga and Sudana 1994: 78–9). By 1973, at the beginning of the Green Revolution, around 40 per cent of all irrigation systems in Bali were of a permanent nature while the remaining 60 per cent still had simple irrigation systems made from local material (Booth 1977: 64, 66). In the research site, according to official data, the permanent dam and primary canal were constructed between 1939 and 1940 (DPU Badung 1999). Some farmers, however, remember the dates to be several years later, in 1950–51.

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[105] This geographic situation is distinctively different to the neighbouring island of Java, for example, where plains are much larger and relatively flat and where rivers are also significantly bigger (Christie 1992: 12).

Figure 4.4: Kapal dam

The boundaries of a subak are defined by the collective of paddy fields that are irrigated by the same irrigation infrastructure. Geertz (1964: 20; 1972: 27) in his study of subaks in Eastern Bali observed that a subak includes the territory of all the rice terraces irrigated from a single dam and a primary canal. This principle does not necessarily apply to subaks at the lower reaches of rivers where water flow volumes are much larger, such as in South Bali. Here, dams may serve several subaks, which is also the case in the research site.[106]

The Balinese irrigation system set up is, as discussed in chapter 3, a surface basin irrigation system with bifurcating distributary canals. The continuous splitting into yet smaller canals can result in many separate inlets to the rice terraces, in larger subaks even hundreds of small inlets or rivulets as described by Geertz (1964: 21). Liefrinck (1969[1927]: 50) points out the skills needed to carefully produce the right gradient in canals which cannot be too steep nor too oblique, for the canals would either too quickly erode or clog up with sediments.

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[106] This fact can basically make it difficult to determine whether a subak is a subak or a munduk at first sight. If, however, planting schedules and rituals are analysed the situation becomes clearer as synchronised planting and certain rituals are only carried out on the subak level.

Each inlet defines a separate unit, either munduk or even smaller sub-units. Run-off from rice terraces feed the next lower terraces of the same subak member to eventually discharge in drainage canals. Each subak member has their own supply canal with off-flows being directed back into the main feeding canal instead of into another farmer's fields (Grader 1960[1939]: 270; Pitana 1993: 4).[107] The drainage canals define the natural boundary of a subak territory.

Balinese use gateless, fixed proportional division structures locally called *tembuku* that are based on the principle of continuous flow (as discussed in chapter 3) at every level of the subak (Figure 4.5: a).[108] Each divider has the same crest elevation while the width is primarily defined by the area of the fields to be irrigated and the distance from the preceding diversion weir. These proportional water shares also include other factors such as topography, soil properties or negotiations among members with the aim to ensure equal distribution of the available water to all fields (Wirz 1929: 244–5; Pitana 1993: 10; Horst 1996: 38). Before the Green Revolution diversion weirs were all made from wood. These days those on the farm-field level are still mainly made from wood while those on the munduk and subak level are usually concrete ones as is the case in the research site (Figure 4.5).

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[107] By contrast, in the Philippines, for example, farmers do not have each a separate water inlet to their fields. The water flows from the main canal into field after field without passing through intermediate canals (Siy 1982: 121).

[108] Birkelbach (1973a: 26) terms these tembukus technically as 'notch-type flow gauges'.

Figure 4.5: Tembukus in the research site: a) wooden and b) cemented

Different systems of rotational arrangements for water allocation to stagger peak water demands are used in Bali depending on the general water situation. In Sidemen, half of the subaks cultivate rice in February while the other half plants in August (Ramseyer 1988: 66). Liefrinck (1969[1927]: 61) and Wirz (1929: 246) both describe the case of North Bali where coastal subaks begin the planting season followed in one to three-month intervals by subaks at the upper course of the river. In a region in Klungkung which Geertz (1980b: 81) discusses, subaks at the upper reach plant earlier than the lower ones. Here, subaks also practice intra-subak rotation with two-monthly staggering intervals of cultivating rice followed by a dry land crop (ibid.: 81). These different types of rotation systems are still in place today with variations across regions depending on the availability of water.

Rice terraces nestled seamlessly to the slopes of the volcanic mountains are a key feature of the Balinese landscape. Soil cores taken in a subak in 1997 have shown that this landscape is quite dynamic with some of the terraces being reengineered every decade (Lansing et al. 2006: 343–5). The continuous reforming and rearranging of the landscape is due to frequent volcanic activity and rapid accumulation of sediments in the canals, which necessitates frequent modification of rice terraces and the irrigation system to maintain control of water flows. As Lansing (2006a: 40–2) points out, this modification also allowed farmers to expand the area suitable for terracing.

Subak territory may range from a couple of hectares in the uplands to up to 400 hectares in the lower reaches of a river (Bundschu 1987: 38). Between 1921 and 1971 the number of subaks recorded in Badung regency ranged between 143 to 150 subaks with an average irrigated area of between 120 to 134 hectares (Birkelbach 1973a: 12; 1973b: 154; Bundschu 1985: 18; 1987: 39; Drysdale and Zimmerman 1995: 95). The division into sub-units depends on the size of the subak as well as the topography with those subaks in flat expanses less subdivided (Birkelbach 1973a: 70). Reference to the average munduk size is not detailed in the researched literature for the period before the Green Revolution but Birkelbach's frequency table (ibid.: 70, table 5.4) gives some indication: accordingly, munduk sizes range between 7 to 86 hectares with most munduk sizes averaging around 20 hectares. Subaks surveyed in 1990 in Badung regency ranged in size on average between 70 to 190 hectares with sub-units between 15 to 40 hectares (Table 4.6).

Table 4.6: Average size of *subaks* in Badung Regency, 1990

Administrative irrigation areas (Kepengamatan)	*Surveyed subaks*	*Average size (hectares)*	*Average size of sub-units (hectares)*
Abiansemal	28	78	30
Carangsari	4	101	40
Mambal	38	124	n.a.
Mengwi	15	69	n.a.
Kapal (Pasedahan Yeh Penet)	12	190	34
Denpasar Barat	26	128	16

Source: (Sutawan et al. 1990)

Table 4.7: Subak temple structures

Type of temple structure	*Location*	*Remarks*
Sanggah (pe-)catu / sanggah pangalapan	At the water opening of a holder's fields	Altars of permanent or non-permanent structure
Pura ulun carik	At head end or in the midst of the rice fields	Dedicated to the Rice Goddess Dewi Sri
Pura bedugul / bedugul munduk	At the water inlet on the munduk level	
Pura ulun swi / pengulun subak	At the water inlet on the subak level	Also at the subak-gede level
Pura ulun empelan	Near the dam	Dedicated to Vishnu, the Water God, this temple may be shared by several subaks.
Catu / Pelinggih[109]	In one of the village temples	Altars of permanent structure dedicated to ensure fertile fields
Masceti temple	At the downstream terminus of irrigation systems along the coast	Regional (dedicated to the fighting off of spirits and demons which cause pests and diseases
Ulun danu temple	At the head of the caldera lake	Dedicated to the Goddess of the caldera lake who makes the rivers flow. There are four caldera lakes and thus four such temples.
Ulun danu batur temple	At Batur caldera lake	Largest of the four and considered most sacred of all water temples

Source: (Grader 1960[1939]: 274–6; Geertz 1980a: 75–6; Lansing 1991: 52–5; Pitana 1993: 15; 2005: 8; Stephan Lorenzen 2008: 146)

A subak has joint responsibility for several temple structures integral to the system, which facilitate performance of subak-related rituals dedicated to the worship of the water goddess and various agricultural deities (Table 4.7). Temple structures are generally located at the water inlet into a unit, sub-unit or member's field near or at a diversion weir although the form and existence of these structures vary. The temple buildings on the munduk, subak and inter-subak level are of permanent structure while those on the farm-field level are usually temporarily erected at the time of a ritual and made from wood and other plant material. Where several subaks share a single dam at the river, they also share a temple. The water temples are gathering and worship places to honour the gods and coordinate

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[109] *Pelinggih* or *Palinggih* are sitting-places for visiting deities (see MacRae 2006: 90).

water use amongst those who share water from the diversion weir to which the temple is linked.

Some subaks also have a bale subak which is a covered non-walled meeting place fitted with an altar in the northeast corner. This bale serves as meeting place for the council and as office for the subak head and other board members. The sound of a slit-gong which is set up in the bale notifies subak members that an upcoming subak activity is about to start.

Summary

The subak has a gravity-fed supply driven irrigation system and uses the same principles of proportional water allocation and distribution as other farmer-managed rice farming systems in the same basin of attraction. Unit and sub-units show a similar range of size. There are subaks that are larger than 100 hectares, especially in the lower reaches of river valleys. Sub-unit sizes appear to be on average at the lower range compared to the averages given for the basin of attraction. A unique feature of this system is that the subak and its irrigation infrastructure is interlinked with a temple network which connects subaks along one river.

Ecological Dimension

Summary Basin of Attraction – Ecological Dimension

The common features that farmer-managed canal irrigated rice cultivation systems display in the ecological dimension can be summarised as follows: Rice is cultivated in an artificial swamp reliant on a continuous supply of water which is kept in the fields by bunding and levelling techniques. This semi-aquatic environment is characterised by continuous availability of sufficient plant nutrients through anaerobic soil chemical processes, silt deposits and farming practices which provide for long-term stable yields of rice without eroding the resource base. The rich biodiversity of these semi-aquatic agroecosystems contributes to stable yields and at the same time acts as a supplementary food source for farmers.

The tropical climate of South Bali is similar to that of other tropical countries with a distinct wet season from November to April and a dry season from May to October.[110] The mean annual temperature for Badung regency is 27°C with a maximum of 31°C and a minimum of 24°C, and average annual rainfalls of 1,889 millimetres with monthly rainfalls in the driest months averaging 20 millimetres (Figure 4.6). This climate provides an abundance of water especially in the wet season. Rivers in South Bali are perennial with water flowing all year round. McTaggart (1984: 238) lists approximate irrigation water requirements of 1,372 millimetres for the wet season and 1,628 millimetres for the dry season for rice crops in South West Bali, which correspond to the water needs I have calculated in the previous chapter.

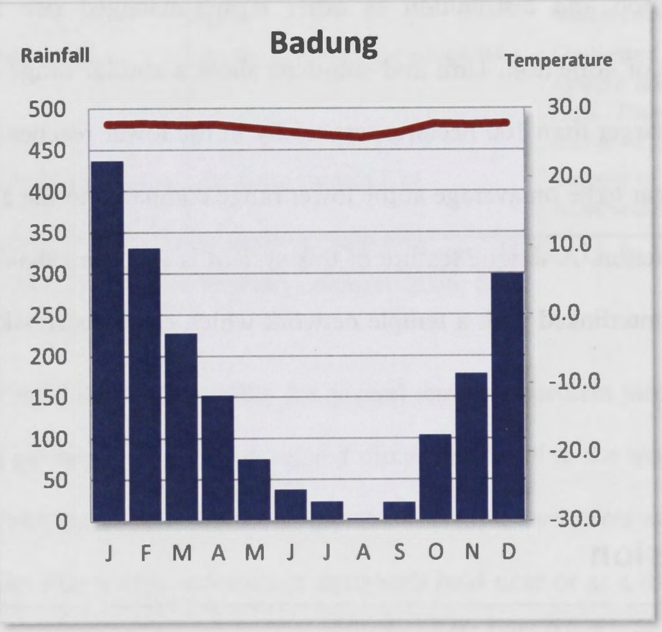

Figure 4.6: Mean monthly rainfall and temperature in Badung Regency 1995–2004 [111]

Source: Badan Pusat Statistik Kabupaten Badung, Badung Dalam Angka 1995–2004

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[110] Based on the Köppen-Geiger climate zone classification system, Badung ecoregion falls in the tropical savannah climate zone (with more pronounced dry months) while the whole of Bali falls in the tropical monsoon climate zone (Kottek et al. 2006: 260).

[111] There are large regional differences in terms of precipitation and temperature. Sutawan et al. (1986: 12), for example, recorded annual rainfall for Tabanan regency between 1978 and 1984, which averaged 2,469 millimetres.

Irrigated rice is cultivated in Bali throughout the year with subaks practicing inter- and sometimes also intra-subak rotation depending on water availability. The usual cropping pattern before the Green Revolution was one season of irrigated rice followed by a dry land crop whereby subaks along a river and sometimes also munduks in one subak plant at different times of the year (not necessarily dependent on wet season rainfall) to stagger peak water demands (Geertz 1964: 23–4; Liefrinck 1969[1927]: 61; Geertz 1980b: 81–2; Ramseyer 1988: 66). Geertz (1972: 31) asserts that without the staggering of planting seasons among subaks 'wet rice cultivation ... could never have attained, and could not maintain, a fraction of its actual extent.' In the field research site, water was available in abundance with the main planting season for rice beginning in March.[112] The rice used to be harvested in August followed by dry land crops and a short-season variety of irrigated rice grown from October to January.

Bali's agroecosystem appears to be very fertile. The soils and silt from volcanic origin are a rich natural source of nutrients (Lansing et al. 2001: 384). The alternating between wet and dry phases also contributes to the fertility of soils, inducing biochemical processes which boost nutrient contents (Lansing 1991: 39). In addition, a variety of methods for fertilising the fields was used in Bali before the Green Revolution such as application of animal manure from cattle and ducks, green manure and other forms of organic matter. Poffenberger and Zurbuchen (1980: 95, 102) noted the practice of applying ash, leaves, manure and straw which contributed to the sustainability of the fertile and productive soils. In Sidemen (East Bali), farmers planted green manure as fertiliser for the rice and also used cow manure, harvest residues, and compost from the compound to work into the soils at the time of soil preparation (Ramseyer 1988: 64–5). Also, local traditional varieties needed considerably less nutrients for a good harvest. In fact, artificial fertilisers applied to local

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[112] The abundance of irrigation water was emphasised by several farmers.

varieties would have a negative effect because the rice plant would grow too high and become prone to lodging.[113]

In the research site, in the northern munduks of subak Tegan, farmers had their cattle stationed in the fields, right next to the water inlet, which would contribute to a continuous supply of nutrients in the irrigation water. They also worked manure from these cattle into the soil at the time of ploughing. Straw was burnt in the dry season and worked fresh into the soil in the wet season. According to a household with fields further to the south in subak Tegan, they did not apply any kind of manure, apart from fresh or burnt harvest residues ploughed under.

Several varieties of local rice were planted and farmers made use of the diversity of plants and fauna around and in the rice fields to supplement their diets. These different rice varieties provided for a diversity of uses including for ceremonial purposes, and varied in terms of taste, gluten content, disease resistance and storage capability. Ramseyer (1988: 66) observed the planting of several local long-duration varieties of '*padi taun*' (or '*padi tahon*') as well as glutinous white and black rice ('*padi ketan*' and '*padi injin*'). Wirz (1929: 14) discusses shorter-duration varieties grown under irrigated conditions: '*padi ampat bulan*', and '*padi tiga bulan*' or '*tjiitje*' with several local cultivars of different size, shape and colour. Traditional rice was transplanted at 35 to 60 days after sowing and grew for another 90 to 140 days until harvested, which adds up to a total duration of between four to six months depending on the variety (Sukawati 1924: 791–2; Ramseyer 1988: 71). Several authors remarked the high yields of local varieties —ranging between 2 to 6 tons per hectare— that were harvested in Bali compared to other places in Indonesia before the Green Revolution

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[113] That is, they grow too tall, with the stem too weak to carry the heavy grains, causing them to fall over damaging the developing grain.

(Poffenberger and Zurbuchen 1980: 94, 104; Booth 1988: 43, 66; Ramseyer 1988: 75; Maurer 1990: 33; Schulte Nordholt 1996: 97).[114]

A feature common to all subaks is the obligation of members within one subak to adhere to a synchronised planting and irrigation schedule and to transplant within a period of one to three weeks from a given date. With the contiguous areas of one subak flooded and drained concurrently rice pests are deprived of their habitat (Lansing 1991: 39–40). This regime combined with the staggering of cultivation seasons across several subaks has proven successful in fighting rice pests and diseases in addition to accommodating peak water demands along a river system.[115] According to Poffenberger and Zurbuchen (1980: 103) damage by pests in Balinese rice production before the Green Revolution ranged between 10 to 30 per cent of the total harvest.[116]

Use of flora and fauna in and around the rice field was commonly practiced in Bali as supplement for farming families' diet as well as a natural pest deterrent. Whitten et al. (1996: 568) mention that weeds were used as food and a variety of different fish were cultured in rice fields. Fish also act as natural fertilisers and pest reducers. In the research area, farmers told me that they used to regularly catch eel and fish as well as snails as a protein addition to their meals as they hardly ever ate meat bought at the market. As natural pest management they would use yarn (or fishing line) which they would pull across the field. The disturbed insects would fly up and birds would then catch and eat

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[114] During the nineteenth century, Bali became the prime rice producer in the region, exporting rice through an extensive inter-island trading network to Java, Singapore and China (Graves and Kaset-Siri 1969; Geertz 1980a: 202; Schulte Nordholt 1996: 99).

[115] Settle et al. (1996: 1978, 1982–4) point out that the size of synchronously planted areas is important: pest control is effective in synchronous planting of 10 to 100 hectares with short fallow periods but rather ineffective where areas are considerably larger —thousands of hectares— and preceded by long fallow periods suggesting that in the latter system natural rice pest enemies build up too late to contain pest populations.

[116] Present day crop loss estimates due to rice pests range between 16 to 40 per cent but have been significantly higher in the early days of the Green Revolution which will be discussed in more detail in chapter 5 (see for example Roger et al. 1991: 120; Savary and Willocquet 2000; Litsinger 2009: 456–7).

them.[117] Ducks were kept in the fields after harvest, which provided fertiliser and control of potential rice pests.

Summary

Subaks, similarly to other rice farming systems, have a favourable agroecosystem at their disposal including fertile soils, abundant water and a rich biodiversity. The referenced approximate irrigation water requirements of 1,372 millimetres for the wet season and 1,628 millimetres for the dry season are at the lower end of the range I proposed as threshold for the basin of attraction in chapter 3. Proof of water being sufficiently available is the fact that subaks also grow rice in the dry season with some subaks growing up to two crops per year. Rice yields are higher compared to other similar rice farming system yields. The high rice yields are also proof that nitrogen is supplied in sufficient amounts to sustain production at high levels. Farmers use various practices to maintain nitrogen input levels but also rely on sediments and the natural fertility of soils. A range of different local varieties is planted and complementary food is gathered in and around the rice fields by farmers. The practice of synchronised planting appears to have a positive effect on the biodiversity of natural enemies to rice pests. Farmers also use other traditional strategies to keep pests at bay.

With respect to the ecological dimension, subaks do not greatly differ from other similar rice farming systems. The main features that distinguish the subak from other such systems are the abundance of water, the higher yields and the practice of synchronised planting as an effective pest deterrent and a means of encouraging natural rice pest enemies' diversity.

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[117] Wirz (1929: 321–2) describes similar pest management strategies used in Bali and other parts of Indonesia.

Technical dimension

Summary Basin of Attraction – Technical Dimension

Irrigation management activities at the system level are coordinated by some form of leadership. While operation requires minimal input, maintenance demands frequent mobilising of labour to attend to repairs. Annual labour input may range between 20 to 80 days. Wet rice cultivation is labour intensive but the degree of intensity varies across regions with between 97 and 200 man-days per hectare and cultivation season. Traditional techniques are labour intensive. Peak labour demand in cultivation is accommodated by a flexible workforce of exchange or hired labour paid in kind. Where farming systems include a ceremonial component, time, finances and labour are required to be invested for worship and preparation, with the level of input depending on rituals' importance in the cultivation and irrigation of rice.

There are numerous rituals carried out at the farm-field level, the munduk level, the subak and inter-subak level, increasing in scale and duration at the higher levels which require a significant input of labour, presence at performances, and financial or material contributions. The rituals are linked to the hierarchic water temple network but vary from region to region. They are essentially undertaken to worship the gods and goddesses of water and rice for sufficient supply of water during the cultivation season and for a good rice harvest.[118]

While at the individual plot level rituals are carried out by the farming household, rituals and ceremonies at the higher level take place at specific temples with assigned priests (*pemangku*) at special times involving specific gods, offerings and prayers, and often require the entire subak membership to be present (Liefrinck 1969[1927]: 30–8; Geertz 1972: 30). The most elaborate rituals involve all subak who are presumed to receive water from the same caldera lake.

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[118] Rituals on the farm-field level are designated to escort the rice plant through the various phases of the cultivation cycle (rites of passage) and to protect it against any evil (pests and diseases) while rituals on the munduk, subak and inter-subak level mainly centre around the sharing of water (see for more details for example Grader 1960[1939]: 276–8; Liefrinck 1969[1927]: 29–38; Ramseyer 1988: 62, 66–73; Lansing 1991: 55–9; Pitana 2005: 9–11).

Rituals demand a great deal of preparatory work and both men and women are required to participate. There is little indication of how much time is invested in ritual preparation and performance in the researched literature. Liefrinck (1969[1927]: 29–30) notes the 'considerable labour' and 'heavy costs' involved as well as the several days' absence from home for the pilgrimages to the caldera lakes. Pitana (1993: 14) alludes to the regularity of these rituals taking place while Geertz (1972: 30) emphasises their elaborateness. Birkelbach (1973a: 101–2) estimates that between 15 to 30 per cent of the total productive time for rice cultivation is spent on religious-related activities.

The amount of water a subak member receives determines the amount of labour that is expected to be committed to the subak for maintenance and subak ritual-related work, irrespective of a member's rank or status (Wirz 1929: 235; Liefrinck 1969[1927]: 17, 27; Pitana 1993: 10–1). Each member is individually responsible to maintain the quaternary canal that diverts water into their field. The maintenance of tertiary canals is organised by the head of each munduk, that of the secondary canals by the subak head and that of the primary is the responsibility of all the subaks that share this canal together. Basically, those members who receive water from a particular structure are responsible for its maintenance. Payments (water levy, Balin. *pengoot*) can be made to substitute for labour, except for major repair and construction works in which everyone has to participate (Birkelbach 1973b: 166).[119] In larger subaks, the subak head may organise working groups with those exempt from work having to pay the water levy. These working groups undertake maintenance work and monitor irrigation facilities for water thefts or damage to infrastructure (Liefrinck 1969[1927]: 17–8, 21–2; Birkelbach 1973b: 164; Geertz 1980b: 80–1).[120]

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[119] According to Liefrinck (1969[1927]: 25) water levy payments vary according to the type of work and the degree of prosperity of a subak. For major investments the subak may raise special levies to cover the costs of the material used (Birkelbach 1973b: 166). In the research site, such payments were made in rice sheaves.

[120] Water thefts occur in the form of modification to the diversion weirs to increase or stop the flow of water.

Reference to time invested into maintenance work in scholarly literature is scarce. Liefrinck (1969[1927]: 21) records that repairs to the dam can require up to a month's work and that subak members 'have their hands full with work' during the entire cultivation season to clean and mend the canal network. Working groups which monitor the canal network may have to patrol daily (but are relieved regularly) where water supply is limited (Liefrinck 1969[1927]: 22; Geertz 1980b: 81). Geertz (1964: 23) observes that in the subaks he studied all subak members gathered once every two weeks 'for some piece of heavier work.' Sutawan et al. (1986: 72) found that farmers had to join communal work 20 to 40 times in one cultivation season to repair non-permanent dams, particularly during the rainy season because of higher water volumes in the river.[121] Meetings require the attendance of all subak members and are another time investment. Liefrinck (1969[1927]: 62) and Wirz (1929: 232), for example, mention monthly meetings. According to farmers in the research site, before the construction of the permanent main irrigation facilities (dam and primary canal) the dam as well as the primary canal had to be repaired regularly during the rainy season for heavy rainfalls would cause erosion. Communal work requirements significantly decreased after the permanent structures were put in place, as farmers still vividly remember. Working groups were used to mend eroded canals during the rice cultivation season.

Balinese rice cultivation is intensive, as in other farmer-managed canal-irrigated rice cultivation systems. The seedlings are transplanted and finger knives are used at harvest time. There are no detailed surveys of how much labour is invested in particular in Bali. Presumably, however, labour invested into the cultivation of rice is comparably intensive to that in Java or even higher, for population density is similarly high but yields are higher.[122]

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[121] Apparently, invested time was less where the dam was located away from roads as people would otherwise arrive and take away larger stones (parts of the dam) for their own use, damaging the weir and disturbing water flow into the subak.

[122] Booth (1988: 113–4) describes how it is the yields that primarily determine labour input mainly through their impact on harvest labour requirements and customary obligations as well as cropping ratio (how many crops are grown in one year on the same field). In Bali, yields are significantly higher than in Java (as discussed in the

Farmers in the research site stressed that soil preparation was more laborious and stretched over a longer period of time before the Green Revolution. In addition, the draught cattle used for the ploughing and harrowing needed feeding, tending and training. Nevertheless, several farmers in the research site mentioned that in the low labour demand periods between transplanting and harvesting, they would wander off to the uplands to work as farm labourers on richer farmers' fields or on coffee plantations for additional income, usually paid in sheaves of rice. The practice of working off-farm indicates that in Bali also, rice cultivation had its peak and low labour demand times.

In Bali, labour mobilisation to attend to peak labour demands in the cultivation of rice is organised in working groups either by the village or by the individual household. These planting and harvesting associations are independent from the subak structure. They either consist of family, neighbours and other members of the same hamlet, relatives, or acquaintances (Poffenberger and Zurbuchen 1980: 96; Ramseyer 1988: 72). Payment of wages is in cash and food, or at harvest, also in-kind (Wirz 1929: 269, 308; Grader 1960[1939]: 283–4; Liefrinck 1969[1927]: 71–2). In Sidemen, a sixth of the harvest is in-kind payment (Ramseyer 1988: 72). In one of the villages in the research site, all hamlet members were obliged to join the harvesting of the rice terraces of fellow hamlet members. Women would bring food to the field but not work. As an in-kind payment, every participant received a share of the harvested rice. The hamlet received a share, too, which it would redistribute in times of food shortages, or sell and use the money it earned for collective activities or repairs of hamlet facilities. For other work in the rice fields, working groups of around ten people were formed. They would be paid in sheaves of rice. In other villages, working groups for work in the rice fields were only organised by the hamlet to finance forthcoming rituals or for maintenance work.

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physical dimension of this chapter), while customary obligations and cropping intensity are similar, thus, labour requirements must be similar or higher.

Before the Green Revolution many of the tasks involved in irrigation and crop management were gender segregated: Labour relating to the maintenance of irrigation infrastructure was male work on the household, munduk and subak level. Ploughing, sowing of seed, removal of seedlings and transplanting was carried out by men, while weeding was done by both, men and women (Sukawati 1924: 791; Wirz 1929: 269, 307; Ramseyer 1988: 63, 67). Harvesting was usually done by both using the finger knife only. Men bundled harvested rice into sheaves which women then carry to the village. Rituals on the farm-field level were almost exclusively carried out by women, as was the purchase and preparation of offerings (Liefrinck 1969[1927]: 18; Ramseyer 1988: 67). According to farmers in the research site, women participated in harvesting rice, otherwise the cultivation and irrigation of rice was chiefly men's business.

Summary

The most distinct features of subaks with reference to the technical dimension are the elaborate and plentiful rituals, as well as the ways labour is mobilised for irrigation system maintenance (including temple facilities) and for peak labour demand in crop management. Subaks involve a great deal of extra labour for preparation and worship in rituals that are an inherent part of Balinese irrigated rice cultivation. Irrigation maintenance was intensive before the Green Revolution but decreased where subak irrigation facilities were upgraded to permanent structures. There are no detailed indications of the extent of this intensive working input into maintenance. Mobilisation of labour for maintenance work appears to have been working, given the high yields and the efficiency of their irrigation system.

Balinese farmers use intensive cultivation techniques and presumably their labour input is as high if not higher than that of Java, with on average 200 person-days per hectare. Labour on the farm-field level for cultivation is mobilised with exchange and hired labour paid in-kind and it is most often organised in traditional social working groups, which are also used for irrigation maintenance.

The main differences between the subak and other similar rice farming systems are the higher labour input due to an important ritual component and the mobilisation of labour by traditional forms of working groups.

Institutional dimension

Summary Basin of Attraction – Institutional Dimension

The common features of the institutional dimension of the basin of attraction for such rice farming systems are characterised by a framework of informal and formal rules that regulate the use and maintenance of the irrigation system and set out an organisational structure to attend to activities at different levels of the system. The guiding principles of equality, egalitarianism and transparency are reflected in rules and regulations which define each member's share of rights and obligations to receive water. Both elected leaders and members are locals from nearby villages familiar with local customs and culture. Rituals which in symbolic performance unify members in their collective action can be part of these rice farming systems and can involve additional work commitments. External governmental control is limited yet the extent of intervention varies.

Every subak has a set of laws in written or oral form (*awig-awig*) that sets out the rules and regulations of the subak, and which all members have to adhere to. The awig-awig contains information about the boundaries and assets of the subak including temple structures, and the size and names of sub-units. It sets out the rights and religious and profane duties of the members and the board, the amount of levies for receiving water and fines that are to be paid in case of infractions such as stealing of water, crops or cattle, and non-observance of planting schedules or damaging of infrastructure and crops. The penalties laid out depend on the type of violation incurred and increase if not paid promptly. If there is insufficient evidence of violation of the rules, the accused is required to take an oath of purification in one of the subak temples. Many of the penalties, however, are hardly ever enforced as reprimand by another subak member or by the subak leaders usually suffices. In the research site all but two of the six subak have a written rule book with one dating back to the 1960s. That subak rules can exist in oral form only is indicative of these rules being negotiable, that is, they can be adapted to changing circumstances subject to agreement by all members.

Subak membership follows automatically from owning or sharecropping rice fields in that subak.[123] A farming household might be member of several subaks including the rights and duties to these subaks, depending on where the fields they cultivate are located (see for example Ramseyer 1988: 62). Members are all equal and village authorities do not hold separate special status or have a right to leadership roles in subaks. Each subak member has one vote regardless of status in society, ownership of land or size of land cultivated (Geertz 1972: 29; Birkelbach 1973b: 169). Members have to adhere to synchronised planting schedules predetermined by the subak head and are not permitted to manipulate any of the tembukus to increase flow into their fields. This is strictly monitored by other members and the subak head.

A member's right to water is defined by *tenah* or *tektek* (depending on the region), which is the final unit of water arriving at the individual farm-field level after being diverted through the irrigation system. The term tenah represents an equal share to all individual plots of a subak's total water supply at any given time, that is, including fluctuations in the flow (Geertz 1972: 28; 1980a: 72). The tenah relates to water as well as to land, rice, seedlings

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[123] Land in subak territories tends to be individually owned by farmers without claims from villagers or the sovereign (Geertz 1980a: 66, 127; Hobart et al. 1996: 53; Christie 2004: 51; Lansing 2006a: 59; Henley 2008: 276). Robinson (1988: 27) estimates that in 1950 about 85 per cent of land was privately owned. Sharecropping of rice fields is common in Bali but varies from region to region. Sharecropping contracts exist according to Liefrinck (1969[1927]: 68) 'virtually in every subak' when holdings are too large to be managed by a single household or when the owner has no time to cultivate. In Geertz's (1980b: 85) surveyed subaks, for example, the percentage of tenant-worked land ranges between 17 and 89 per cent. Sharecroppers are required to pay the landlord a share of the harvest. There are different sharecropping arrangements co-existing in Bali, depending on the region (Liefrinck 1969[1927]: 68–9; Birkelbach 1973a: 74–5; Geertz 1980b: 84–5). In Sidemen, for instance, a sharecropper can only keep a third of his harvest, while in other regions the share is half/half (Ramseyer 1988: 73).

planted and harvested yield: a tenah of water irrigates a tenah of land, needing a tenah of seedlings to harvest a tenah of un-threshed rice (Birkelbach 1973b: 155; Geertz 1980b: 79–80). The tenah also defines the extent to which members have to contribute finances and labour to communal maintenance works and ritual activities. The tenah reflects the guiding principles of equity, egalitarianism and transparency in that equal water shares irrigate equally sized rice fields that demand equal amounts of labour to attend to subak work.

The tenah's size varies from subak to subak depending on the area and history of a subak, and general water availability. Lansing et al. (2009: 116), for example, found that the tenah highly corresponds with actual water flow into a subak. The measurement is the result of a trial and error process including consensus-based negotiations and renegotiations (Sutawan 2004: 4). The tenah ranges between 0.25-0.6 ha of rice fields for one planting season (Suadnya 1990: 16; Pitana 1993: 11; Windia 2006: 18). In the case of the subaks which Geertz (1980b: 79) surveyed, a tenah was 0.45 hectares in one subak and 0.30 hectares in the other.[124] In the research site one tenah supplies sufficient water for fields of up to 0.5 hectares and accordingly subak members have to supply one person for obligatory subak labour (S. Lorenzen 2008: 63).

The beginning of the main rice cultivation season which had to be followed by all members was determined by sighting a particular star combined with the Balinese calendar.[125] In subak Penarungan, for instance, up to the present day, the main rice cultivation season

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[124] This range corresponds very roughly to the average size of irrigated land cultivated per subak member. In my research area, for example, these average 0.41 hectares in 2005 and 0.39 hectares in 1990, while in Eastern Bali they average 0.36 hectares (Anonymous 2005). Landholding sizes pre-Green Revolution ranged between 0.32 and 0.61 hectares (Birkelbach 1973b: 156; Geertz 1980b: 79–80; Robinson 1992: 78). One could be tempted to conclude that most likely at the time a subak was newly formed each member received one tenah of land that was watered by one tenah of irrigation water.

[125] The Balinese calendar system is a complex overlay of several calendars based on solar, lunar, ritual and agronomic cycles which combined together determine auspicious days for specific activities related to life in general but also to the cultivation of rice and animal husbandry (Fred B. Eiseman 1990: 172–92; Lansing 1991: 67–70). This calendar system matches the cultivation cycle of traditional rice varieties consisting of six periods of thirty-five days to form 'one year' of 210 days equalling the time from sowing to harvesting of traditional long-duration rice.

begins after particular star has appeared on the night sky. Both Wirz (1929: 250–2) and Liefrinck (1969[1927]: 63) mention similar practices in North-Bali.

According to farmers in the research site there was some coordination amongst the six subaks off the Kapal dam facilitated by the sedahan to arrange the beginning of planting seasons and to organise annual rituals at the water temple near the dam. While subak members have to follow the scheduled dates for transplanting, other decisions in regard to the cultivation of rice and intercrops are left to the farmers. Soil preparation, planting, crop management, harvesting and marketing of the rice crop is organised and managed independently at the farm household level with no interference from the subak (Geertz 1972: 28–9; Ramseyer 1988: 62).[126]

To be elected subak leader a subak member has to fulfil a number of requirements. First of all, he has to own land in the particular subak, which is an indication that leaders are from nearby villages. A subak leader's beliefs, experience in subak affairs and initiative seem to be important (Birkelbach 1973b: 156; Ramseyer 1988: 62). In addition to the usual tasks — such as control and monitoring of irrigation facilities, mobilising of members for maintenance work and leading meetings— subak leaders are required to interrelate with leaders of other subaks that are located further upstream and downstream along a river, especially when these subaks share a common weir. The subak leader has to determine the planting schedules by arrangements with other subaks. He is also required to coordinate and perform appropriate rituals on the subak and inter-subak level that are needed at different stages of the cultivation season. Maybe most importantly, subak leaders are 'weak

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[126] Geertz (1972: 28–9) emphasises that 'on his own land (which he can sell, rent, tenant, or whatever, as he wishes), within the regulations set by the subak, the individual peasant is his own master working in his own way, consuming (or selling) his own produce. The subak never engages in the actual process of cultivation as such, nor, as I say, of marketing; it regulates irrigation, and that's all that it does...the actual process of cultivation within those constraints has always been a matter specifically...beyond both its competence and its interest. The subak is a technically specialized, cooperatively owned public utility, not a collective farm.'

managers', as Birkelbach (1973b: 161–2) points out; that is, he executes what has been decided by all members at the regularly held meetings.[127]

The ritual system which is attached to the temple network regulates the order of planting amongst different subaks. According to Lansing (1991) the hierarchically linked water temple network with the summit at one of the two caldera lakes purports to control irrigation water distribution on each level of a subak and on the inter-subak level within one water catchment. Each temple symbolically links the social unit of subak members with their physical environment: those who obtain water from the irrigation structure controlled by the linked temple congregate in that temple to decide the rotational synchronised planting schedules and the timing of relevant ceremonies (Geertz 1972: 30; Lansing 1991: 53, 128). The ritual ties that exist between the nested water temples facilitate coordination on the inter-subak level. These religious dependencies require regular exchange of delegates of subordinate temples in fulfilment of their ritual obligations, which allows for coordination of water distribution at the system and super-system level (Lansing 1991: 55–72).

During these coordinated temple ceremonies water is blessed. From the summit, the most upper temple at the caldera lake, the blessed water is carried to water temples through the hierarchical structure.[128] Every temple creates its own unique holy water, symbolising in the joining of sacred waters the hierarchical relatedness of the temples and their congregations, adding the blessings of local deities along the way (Lansing 1991: 57–8, 128; Lansing 2006a: 4). This movement and joining of blessed waters with prayer and incantation proceeds down to the subak, munduk and individual farm-field level, where subak leaders and farmers fetch the holy water to pour it into the topmost water inlet to their respective

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[127] See also chapter 1 where I mention that the subak head has no formal authority.

[128] The caldera lake Batur, the most sacred of all four caldera lakes, is seen as the ultimate source of water for all the rivers and springs of Bali with its temple consequently the most sacred and most important of all the water temples (Lansing 1991: 73–7). Grader (1960[1939]: 166, 186) also mentions the importance of honouring the temples of the caldera lakes for the blessing of irrigation water.

units. In the research site the present-day coordination of water distribution linked to rituals in water temples takes place on the local inter-subak level but is more detached on the watershed level. Here, subak heads of the subaks of the entire regency meet once a year at the relevant temples (*masceti* and *ulun danu* temple) (Table 4.7). The rituals and exchange between delegates becomes more formalised and is only loosely linked to everyday practical irrigation and crop management (S. Lorenzen 2008: 136).

Traditional social working groups that Balinese form to attend to work in the rice fields and on irrigation infrastructure are an inherent part of Balinese culture. There are several forms of social groupings that exist besides the subak and harvesting and planting associations, such as the hamlet, customary village and other working groups. These groups are all based on the *sekaha* principle (lit. transl. 'to be as one') (Geertz and Geertz 1975). They are voluntarily formed and autonomous, implying equality of members and consensual decision making. Memberships of sekahas are overlapping but almost never congruently. Taking the example of one single farmer, this implies that he or she is not only a member of a particular subak, but also a particular hamlet, a kinship group, a customary village, and possibly other particular working groups. While this farmer's neighbour is equally a member of the same subak, he or she will not necessarily belong to the same hamlet, nor the same village and most likely not to the same kinship group and so on. For instance, in some of the munduks of subak Tegan, as many as 13 hamlets and 4 different villages are represented by its members. The complex social network that accordingly emerges spans the whole society and ultimately functions as social monitoring tool, controlling the way in which people cooperate and comply (Lorenzen et al. 2005). This social cohesion is one of the fundamental institutional features of the subak, reflected in the willingness of subak members to comply with the rules and regulations stipulated by the awig-awig and to cooperate in sharing the common-pool resource water (S.Lorenzen 2008: 6).

Summary

A distinct features of the subak in comparison to other similar rice farming systems is a specific rules book devised by the subak members which can exist in written or oral form and which consists of negotiable rules. Membership is based on who cultivates rice fields in a particular subak and not on ownership of land and includes rights and responsibilities to receive water similar to other such farming systems. What is different is that members have to adhere to a synchronised planting schedule and that they are involved in a large ritual component that interlinks subaks on different levels with each other where they share a diversion structure. The interlinked temple network involves additional responsibilities for subak leaders, allowing for the coordination of water sharing among several subaks along a river. As with other similar rice farming systems, the way rights and duties to water shares are specified mirrors the guiding principles of equity, egalitarianism and transparency. The sekaha principle —expressed in the ways in which Balinese are grouped together and collaborate— interlinks each farmer in different ways, creating a complex social network that functions as means of social cohesion and increasing rule compliance.

CONCLUSION

In this chapter I have discussed the subak as a social-ecological system using the four dimensions of the basin of attraction. Although there are variations across Bali in how subaks operate, there are nevertheless common principles that underlie all subaks in Bali. I have also highlighted the distinct features that distinguish the subak from other similar rice farming systems (Table 4.8).

Bali has a favourable climate to support irrigated rice cultivation, characterised by fertile soils and an abundance of water. The rugged terrain, on the other hand, necessitated the construction of a sophisticated irrigation system to secure water supply to each field.

Although water is generally available in abundance, in order for subaks to extend the planting of rice across the whole year, a temple network has developed which facilitates water sharing coordination among subaks along one river. Balinese farmers are successful in producing high yields of rice with intensive labour input, both for irrigation system maintenance and cultivation. One of the keys to that success is that each farmer is part of a social network consisting of multiple interlinked social groups to which they have recourse to mobilise labour for work in the fields. This complex social network in turn serves as a social control system in order for farmers to collaborate in sharing water.

Table 4.8: Key features of the subak as social-ecological system

Dimension	*Key features*
Physical	Some subaks are larger than 100 hectares, especially in the lower reaches of river valleys Sub-unit sizes are at the lower range, on average 20 hectares Subaks in one water catchment are interlinked with a temple network
Ecological	Abundance of water, allowing subaks to grow rice also in the dry season Approximate irrigation requirements between 1,372 and 1,628 millimetres High rice yields, between 2–6 tons per hectare due to fertile soils and sediments, and organic fertilising practices Practice of synchronised planting has a positive effect on biodiversity of natural rice pest enemies
Technical	Elaborative and plentiful rituals adding to labour intensity Labour input averaging around 200 person-days per hectare Mobilising of labour by means of social working groups
Institutional	Specific rules book with negotiable rules Membership based on who cultivates rice in a particular subak and not on ownership of land Ritual component links farmers and subaks to water temple network which coordinates planting schedules Sekaha principle links farmers, creating a complex social network as means of social cohesion and increasing rule compliance

The subak's efficiency in maintaining the irrigation system, their skills in managing irrigation and cultivation and the resulting high yields of rice have been remarked upon by several authors. Now that I have introduced the subak and located it in the basin of attraction, it is time to examine how the Green Revolution impacted on the subak, whether any of the thresholds outlined in chapter 3 have been —temporarily— crossed and how the subak managed to be resilient and survive.

CHAPTER 5

GREEN REVOLUTION AND THE SUBAK

INTRODUCTION

In the previous chapters I introduced the basin of attraction for farmer-managed canal-irrigated rice cultivation systems and proposed key thresholds in each of the four dimensions (physical, ecological, technical and institutional) which delineate the boundaries of this specific basin of attraction (chapter 3). I described the distinct features of the subak as a social-ecological system in that basin of attraction which distinguishes the subak from other farmer-managed canal-irrigated rice cultivation systems (chapter 4). As per definition of the resilience concept, a social-ecological system can move closer to the boundaries of a specific basin of attraction if thresholds are approached or crossed following a disturbance (chapter 2). Crossing of one threshold can have a cascading effect in that other thresholds are crossed that may lead the system to move beyond the boundaries of a specific basin of attraction —losing its resilience— or recover and adapt to the changes imposed and remain resilient.

This chapter seeks to demonstrate that the subak as a social-ecological system was exposed to a disturbance in the past, namely the Green Revolution, but was able to recover and adapt to the changes imposed. The Green Revolution modernised agricultural production across the developing world with the aim of reducing the looming food crisis amid a fast growing population and stagnating yields. The subak as the organisation that manages irrigated rice production on Bali became therefore automatically involved. The newly introduced technologies considerably altered the ways in which rice was produced, which affected each of the four dimensions that define the basin of attraction in which the subak as a social-ecological system resides. As a consequence of these changes thresholds were approached or even crossed, yet the subak managed to remain resilient and adapt, which redefined some of the thresholds at new levels.

Before I discuss how this disturbance impacted on the subak as a social-ecological system and how the subak as a social-ecological system responded and remained resilient, I begin with a brief overview of the events and achievements of the Green Revolution.

THE GREEN REVOLUTION IN ASIA

The Green Revolution had its beginning in the 1960s. A rapidly growing world population was demanding new solutions to guarantee a sufficient and continuous supply of staple crops, particularly in the developing world. Traditional agricultural methods became increasingly inadequate in meeting these demands. Local varieties, for example, did not respond well to increased chemical nitrogen application —which is the most crucial nutrient to increase rice yields— causing them to grow too tall and fall over (lodge), damaging the developing grain (Grist 1975: 246; Cassman et al. 1998: 8; Kirk 2004: 8). In response to this dilemma, four international agricultural research centres were established across the developing world supported by the Rockefeller Foundation, the Ford Foundations, the World Bank and other international donor agencies that focused on increasing the productivity of major staple crops.[129] In Asia, the International Rice Research Centre (IRRI) in the Philippines developed an intensification program that was

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[129] The four research centres were the International Rice Research Institute (IRRI) in the Philippines, established in 1960, the International Maize and Wheat Improvement Centre (CIMMYT) in Mexico in 1966, the International Centre for Tropical Agriculture in Colombia (CIAT) in 1967, and the International Institute of Tropical Agriculture (IITA) in Nigeria in 1967. In 1971, the four research centres joined a newly formed umbrella organisation, the Consultative Group on International Agricultural Research (CGIAR), which expanded the Green Revolution program by establishing further centres to integrate intensification of other major food crops such as sorghum or cassava and other agro-ecological zones such as semi-arid and dryland regions. For a detailed history of the CGIAR, see http://www.cgiar.org/who/history/origins.html and Evenson and Gollin (2003: 758).

specifically targeted at lowland rice agriculture with a focus on plant breeding and irrigation infrastructure improvements (Conway and Barbier 1990: 19; Pingali and Rosegrant 1994: 4; Evenson and Gollin 2003: 758).[130] This two-pronged intensification strategy which was supported by national research programs in a number of Asian countries resulted in the development of a modern cultivation technology package and upgrades to and extensions of irrigation facilities.

The cultivation technology package included newly bred high-yielding varieties (HYV),[131] chemical fertilisers and pesticides, hand-held tractors,[132] and threshers. The new high-yielding varieties produced up to double the yield of local varieties and matured in a shorter period of time (Scholz 1998: 532).[133] Yet to achieve optimal yields these modern varieties required a balanced input of concentrated chemical fertilisers and pesticides and a continuous supply of irrigation water. In particular, the first breeds were more sensitive to irregularities in water and nitrogen supply, water levels in the field, and unusual changes in weather conditions (Poffenberger and Zurbuchen 1980: 7; Foley 1987: 150–2; Ramseyer 1988: 79). The shortening of the cultivation period facilitated the increase in cropping intensity, that is, rice could be grown now up to three times a year. Farm machinery was introduced to support the intensification. Hand-held tractors shortened land preparation time and threshers reduced post-harvest handling time.[134]

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[130] Lowlands are defined as areas at or below 500 metres (Fox 1991: 123).

[131] Also known as modern varieties (MV).

[132] Also known as two-wheel tractors or power cultivators.

[133] Traditional varieties grow for 150–210 days from sowing to maturation, while the new varieties can be harvested after 90–130 days.

[134] The new rice was directly threshed in the rice fields; the grains were filled into bags and sold to the mills for cash. The traditional varieties, in contrast, would be carried home in sheaves for storage and hand-pounded at the time of consuming the rice. Before the Green Revolution, only a small proportion of the harvested rice entered the market in Indonesia (Nehen 1989: 90).

The first variety introduced widely in Indonesia and elsewhere in Southeast Asia in the 1960s was a cross between an Indonesian[135] and a Chinese dwarf species characterised by shorter and stronger stems that with the application of nitrogen were able to carry the heavier grains and not lodge easily (Fox 1991: 65; Whitten et al. 1996: 572; Peng and Khush 2003). More varieties were to follow in the succeeding decades bred with a focus on more resistance to pests and diseases, a shortening of the cultivation period, and better grain and cooking quality (Fox 1991: 66–74; Peng and Khush 2003: 159–61). In Bali, new high-yielding varieties were first cultivated in the early 1970s (Poffenberger and Zurbuchen 1980: 94; Bundschu 1987: 28; Foley 1987: 87–8; Lansing 1991: 112).[136]

In-country agricultural policy strategies in adopting the new technologies differed greatly among different Southeast Asian countries, resulting in different outcomes. In the Philippines and Indonesia, for example, the adoption rate of modern varieties the was most rapid, whereas in Thailand traditional varieties were only partially and slowly replaced (Herdt and Capule 1983: 5–17).[137] Scholz (1998: 533–4) suggests that while in Indonesia the major focus was on rice self-sufficiency, Thailand and Malaysia concentrated on cash crop export and greatly diversified agricultural production. Nevertheless, rice areas planted with modern varieties more than doubled between 1970 and 1990 from 30 to 70 per cent all over Asia (Hazell 2002: 2). In Indonesia, by 1982, more than 87 per cent of irrigated rice fields were cultivated with modern varieties while in Bali this percentage was reached a few years earlier (Bundschu 1987: 28; Nehen 1989: 100; Fox 1993: 129).

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[135] The variety *Cina,* which probably came from Vietnam and was extensively used in the Dutch rice breeding program, shattered easily when harvested, which was one of the reasons for changing harvesting and storage practices in the Green Revolution (Fox 2010, personal communication).

[136] Most well-known HYV in Indonesia are IR 5 and IR 8, IR36, IR51 and IR64 which succeeded one another between 1965 and 1985. IR indicates that these varieties originate from IRRI. IR 5 and IR8 are also known as PB, short for *Peta Baru* —'new' *Peta*— which were a cross between a tall Indonesian (*Peta*) variety and a semi-dwarf variety developed at the International Rice Research Centre (IRRI) in the Philippines (Fox 1991: 65).The first varieties, IR5 and IR8 matured in 130 days while later varieties such as IR36, IR51 and IR64 mature in 110 days (Greenland 1997: 207). Fox (1991) offers a detailed description of the genealogy of all the modern rice varieties that were cultivated in Indonesia.

[137] Thailand has a large export market for high quality rice which the new varieties lacked (Herdt and Capule 1983: 17). Accordingly, apart from low adoption rates yields increased only marginally from 1.8 to 2.1 tonnes per hectare between the 1960s and the beginning of the 1990s (Scholz 1998: 533–4).

With the overall aim to achieve national rice self-sufficiency, the Indonesian government developed four major intensification programs (Table 5.1). These programs were characterised by an increasing level of sophistication in production management, increasing amounts of agrochemicals for application to the crop and demands for better quality irrigation (Drysdale and Zimmerman 1995: 97). According to Whitten et al. (1996: 572), they were one of the most impressive achievements of the Indonesian government at that time. Indonesia, which was the largest rice importing nation in the late 1960s and 1970s, achieved self-sufficiency in rice production in 1984 (Fox 1991: 71; Simatupang and Timmer 2008: 67).

Table 5.1: The four Indonesian intensification programs

Program	*Time Period*	*Details*
BIMAS *Bimbingan Massal* or mass guidance	1969-70	Included five components: (1) new varieties, (2) chemical fertilisers, (3) chemical pesticides, (4) better water management and (5) modern cultivation techniques
INMAS *Intensifikasi Massal* or mass intensification	1972	Introduced a new credit system for farmers and agricultural extension services
INSUS *Intensifikasi Khusus* or special intensification	1981	Accelerated the adoption of the new technology
SupraINSUS *Supra-Intensifikasi Khusus* or super-special intensification	1986	Included 10 elements: (1) the use of new varieties, (2) cropping pattern planning, (3) balanced use of fertilisers, (4) increased plant density per hectare, (5) use of better harvest and post-harvest methods, (6) better soil preparation methods, (7) use of chemical growth stimulants, (8) application of integrated pest and disease management, (9) better water management techniques and (10) planting of different varieties throughout the season

Source: (Drysdale and Zimmerman 1995: 97; S. Lorenzen 2008: 217–8)

The rice intensification programs included the creation of new institutions and facilities to allow for the production of chemical fertilisers, transport and storage of chemicals and seeds as well as research and extension services. Localised purchase of seeds and agrochemicals, and the processing and marketing of rice was facilitated. In addition, agricultural extension services were set up to support farmers in using the new technologies. A new banking system was introduced which provided farmers with the necessary cash to purchase the new cultivation technology packages (Fox 1991: 62).[138]

Across Asia, increases in food production more than kept pace with increases in population. Rice production grew by 2.9 per cent per annum during 1965–1980 compared to an annual population growth rate of 2.1 per cent in the same period (Cassman and Pingali 1995: 300; Huber-Lee and Kemp-Benedict 2003: 39). A number of studies have discussed the factors that contributed to production growth such as yield growth, area expansion, new varieties, cultivation technologies, improved irrigation and increase in cropping intensity —that is, rice crops grown per year (Herdt and Capule 1983: 22; Nehen 1989: 95; Rosegrant and Svendsen 1993: 13–4). In Bali, both yield increase (by 35 per cent) and harvested area (by 36 per cent) were equally responsible for production growth which increased by 84 per cent between 1968 and 1980 (Figure 5.1) (BPS Bali 1976: 16; BPS Bali 1980: 125).[139] The actual irrigated area, however, rose only marginally from 98,680 hectares to 99,219 hectares in the same time period, which indicates that in Bali harvested area expansion was mainly achieved by increasing cropping intensity (BPS Bali 1970: 33; Bater 1995: 15).

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[138] BRI (Bank Rakyat Indonesia) *Unit Desa* or Village Bank system started off as a government subsidised rural financial institution lending money to rice farmers with low interest rates as part of the BIMAS intensification program. It later became a fully independent market-oriented micro-finance bank and is seen as a success story. For more details, visit Asian Development Bank (ADB) website at http://www.adb.org/documents/policies/microfinance/.

[139] I rely here on data published by the Bali provincial statistics office (Badan Pusat Statistik Bali, formerly known as Kantor Statistik Propinsi) which are higher than those referred to in the literature, for example by Fox (1993: 123) and in the IRRI online World Rice Statistics database (http://beta.irri.org/index.php/Social-Sciences-Division/SSD-Database/ accessed on 17/11/2010).

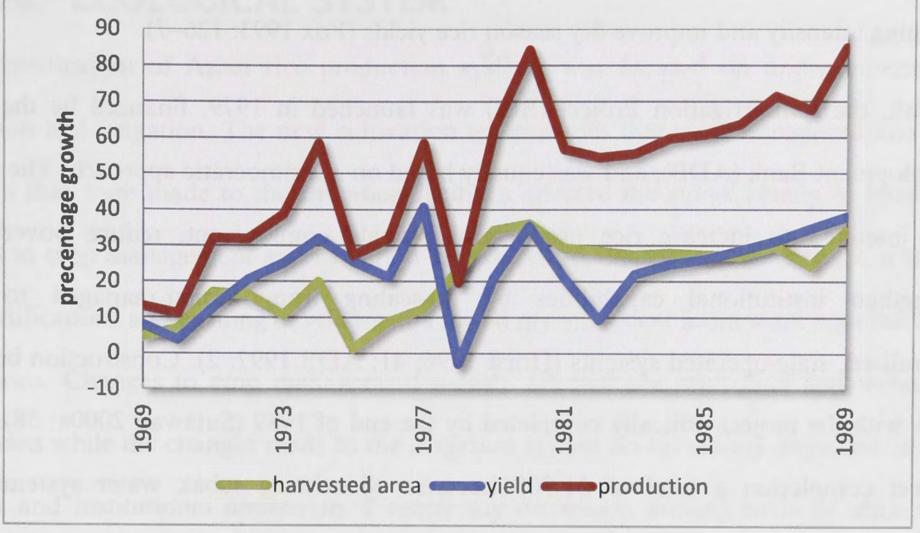

Figure 5.1: Annual growth rates of harvested area, yield and production of irrigated rice, Bali, 1969–1989 (base year 1968)

Source: (BPS Bali1976: 16; BPS Bali1980: 125; Kantor Statistik Propinsi Bali 1983: 101; 1986: 115; Foley 1987: 35 (Appendix); Kantor Statistik Propinsi Bali 1988: 112; 1991: 112)

Investment into the upgrade and expansion of irrigation facilities mainly focused on large-scale irrigation systems which were state-operated with highly centralised administration (Barker et al. 1985: 105). In Indonesia, major rehabilitation and expansion projects were undertaken by the government between 1969 and 1979 with substantial technical and financial assistance from the World Bank (Booth 1977: 51–5; Thorburn 2007: 8). Irrigation system upgrades involved repair and extension of permanent structures initially constructed by the colonial government, such as permanent primary and secondary canal networks and appending structures (Booth 1977: 51–3).

As a result of these investments, Southeast Asia's irrigated areas increased annually by 3 per cent on average between 1962 and 1985 with the construction phase reaching its peak in the mid-1970s (Rosegrant and Svendsen 1993: 17; Barker and Molle 2004a: 13). According to Nehen (1989: 94), a total of more than 3 million hectares of irrigation infrastructure was built in Indonesia between 1969 and 1984 which included rehabilitation

(65 per cent), expansion of existing systems (6 per cent) and construction of new irrigation networks (29 per cent). In East Java irrigation improvements allowed farmers to increase cropping intensity and improve dry season rice yields (Fox 1993: 126–7).

In Bali, the Bali Irrigation Project (BIP) was launched in 1979, financed by the Asian Development Bank (ADB), and was equally based on a technocratic approach. The project was intended to increase rice production, provide employment, reduce poverty and strengthen institutional capabilities by up-scaling from farmer-managed to more centralised, state-operated systems (Horst 1996: 41; ADB 1997: 2). Construction began in 1981 with the project officially completed by the end of 1989 (Sutawan 2000a: 58). Upon project completion a total of 31,900 hectares of existing subak water systems were improved and an additional 1,850 hectares of new irrigation schemes had been built (ADB 1997).

While improvement projects had been underway since independence the Bali Irrigation Project had the largest impact and covered the greatest areas. Especially in lowland areas, the physical integration of smaller subaks into larger systems that began during the Dutch colonial era was continued with several subaks now sharing a common permanent dam (Sutawan 2000c: 317). Maintenance and operation of the shared structures, which include the dam at the river, the primary canal and a diversion weir to the different subaks, became the responsibility of the public works department. Many of the traditional fixed proportional diversion structures were replaced by hydraulic regulatory gates, which regulate and measure flows according to crop water requirements (Horst 1996: 35; S. Lorenzen 2008: 178). Many observers considered the Bali Irrigation Project's interference into subak autonomy as the most momentous in history (Planck and Sutawan 1983: 290–91).

GREEN REVOLUTION IMPACTS ON THE SUBAK AS A SOCIAL-ECOLOGICAL SYSTEM

The intensification of Asian rice production systems was focused on improvements in cultivation and irrigation. The new cultivation technologies that were introduced and the upgrades that were made to the irrigation facilities affected the subak chiefly in terms of changes to crop management and irrigation system set-up. To identify the impact of these two modifications and ensuing developments I used my analytical framework with the four dimensions. Changes to crop management mainly affected the ecological and technical dimensions while the changes made to the irrigation system set-up mainly impacted on the physical and institutional dimension. I centre my discussion around basin of attraction thresholds that were (potentially) crossed as well as cross-dimensional interactions. Considering the changes in the four dimensions, I focus on four issues that have had the greatest impact on thresholds as a consequence of the Green Revolution: (1) biodiversity, (2) nitrogen supply, (3) cultivation techniques and labour coordination, and (4) physical set-up of irrigation infrastructure.

Biodiversity

In the late 1970s and early 1980s Bali experienced massive outbreaks of pests and diseases. Lansing (1991: 115) lists several reports in his book on these outbreaks of pests such as brown planthopper, green leafhopper including tungro virus, brown leaf spot and rice blast with farmers struggling to keep ahead by planting the latest resistant variety of the new breeds of rice. Ramseyer (1988: 79) also reports a massive outbreak of green leafhopper on IR36 in 1981. Neither intensified pesticide use nor new varieties brought any relief, with signs of the brown plant hopper in particular showing resistance to pesticides and damaging supposedly resistant varieties (Foley 1987; Fox 1991:68–9; Lansing 1991: 113; Whitten et al. 1996: 573). The statistics on yearly production and yield of irrigated rice reflect these reports with three troughs where production fell by 15–25 per cent and yields by 8-31 per cent between 1975 and 1982 of an otherwise increasing production (Figure 5.2, Figure 5.3).

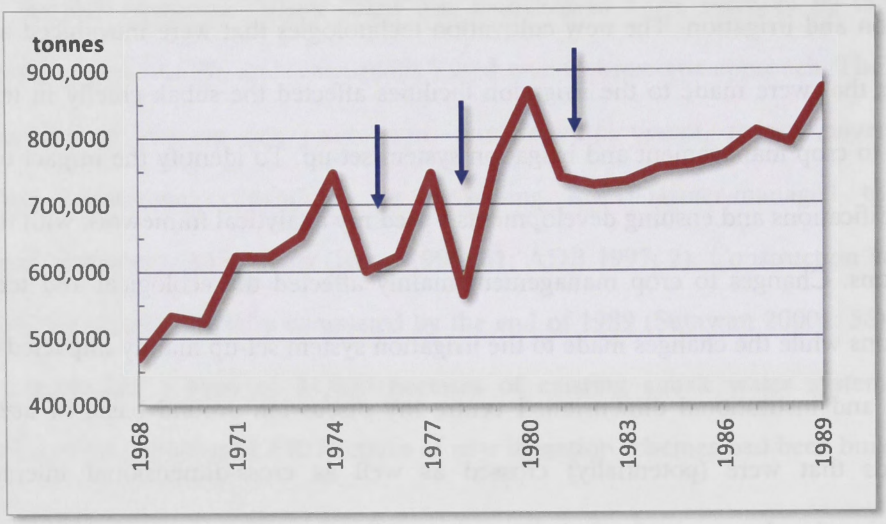

Figure 5.2: Green Revolution rice production throughs (tonnes), Bali, 1968–1989

Source: (BPS Bali 1976; Kantor Statistik Propinsi Bali 1983; 1986; Foley 1987: Appx, 35; Kantor Statistik Propinsi Bali 1988; 1991)

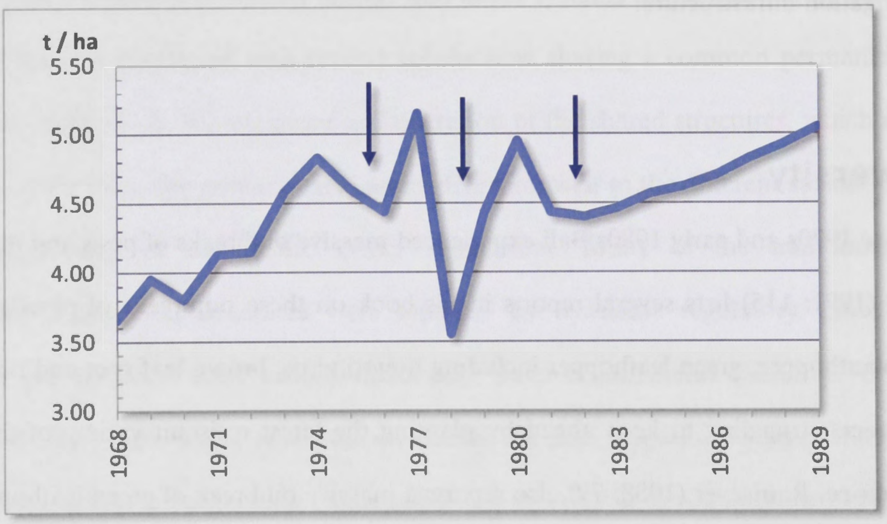

Figure 5.3: Green Revolution rice yield throughs (tonnes per hectare), Bali, 1968–1989

Source: (BPS Bali 1976; Kantor Statistik Propinsi Bali 1983; 1986; Foley 1987: Appx, 35; Kantor Statistik Propinsi Bali 1988; 1991)

What had happened? The unprecedented outbreaks can mainly be explained by the altered ecology of the rice field: a reduction in biodiversity of planted rice varieties and associated flora and fauna species with the use of pesticides, uncoordinated planting of rice and the disappearance of non-rice crops planted in the rice fields with rice crop intensification.

By the rapid replacement of a varied range of locally adapted varieties with one single or only a few new varieties of rice the genetic variation which includes multiple resistances to various pests and diseases was drastically narrowed. It is estimated that in the course of the Green Revolution between 1,000–1,500 varieties disappeared from rice fields in Indonesia (WRI et al. 1992: 9; Jhamtani 2008). In addition, the few new varieties that were planted were all interrelated —originating from the same parental material— further narrowing the variation(Fox 1991: 66–7; Whitten et al. 1996: 573). In Bali, not all of the traditional varieties disappeared because they are required for ceremonial purposes and even today, farmers dedicate a small percentage of the fields to the cultivation of these varieties.

An additional strain on the rice field ecology was the use of broad-spectrum pesticides which are non-selective in that they destroy pests as well as beneficial natural predators of pests. When applied in sub-lethal doses or used too extensively they can alter insect behaviour, cause resistance in pests and even damage the very crop they ought to protect (Pimentel 1996: S89–91; Whitten et al. 1996: 575). In the early phases of the Green Revolution, pesticide was applied based on the assumption that yields are limited by insect pests and that pesticides could control these pests (Settle et al. 1996: 1977; Thorburn 2007: 9). The heavy subsidies by the Indonesian government and an extensive distribution network also encouraged farmers to use pesticides on a large scale. In the case of outbreaks across broader areas aerial spraying was also used (Barker et al. 1985: 251; McClelland 2002: 191; Lansing 2006a: 9). In Bali, aerial spraying was carried out in the 1981–1982 season following a particularly strong build-up of the green rice leafhopper (Oka 1991: 163). Farmers in the research site can still remember when aeroplanes flew over their rice fields spraying pesticides and how they were told to keep inside on the day of spraying.

The massive pesticide application also impacted on health and environment. Improper handling impacted farmers' health and led to increased pesticide concentration in the soil and water bodies (Pimentel 1996; Resosudarmo 2000). An environmental assessment undertaken in Bali in the mid-1980s reported that rice field soils as well as surface waters were considerably contaminated with organo-chloride pesticides and that the aquatic ecology had been seriously and persistently impaired (Machbub et al. 1988: 12).[140] Farmers in the field research site noted a considerable decline in the rice field fauna which had previously served as alternative protein sources in local diets (as discussed in chapter 4, ecological dimension).

Intensification of rice production was also achieved by increasing rice cropping intensity. The traditional pattern of one main rice crop followed by a dry crop or prolonged fallow period was discontinued in favour of two or three consecutive rice crops per year on the same land. The Bali government instructed farmers to abandon local varieties and the subak organised cropping schedules in favour of planting the new rice whenever they wanted and as often as possible (Lansing 1991: 113; Sutawan 2000c). In the beginning, however, farmers were reluctant to grow the new varieties for fear of crop failure and because of the poor taste when cooked compared to the traditional varieties (Poffenberger and Zurbuchen 1980: 101–4). In the field research site, farmers remember that because initially, they refused to plant the new rice, the subak head had brought along an imposter disguised as military officer to the meetings to reinforce the growing of the new rice. They also vividly recall the governor of Bali eating the new rice in a public appearance in order to increase farmers' acceptance.

A renewed outbreak of brown planthopper across Java in 1986 led the then Indonesian president Suharto to immediately ban several broad-spectrum pesticides following the suggestions of Kenmore and other FAO scientists (Kenmore 1991: 6, 15; Thorburn 2007:

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[140] The environmental impact assessment was part of the feasibility study for the Bali Irrigation Project.

10–11). Indonesian policy shifted from a singular approach depending on pesticides only to Integrated Pest Management (IPM) which seeks to include protection of natural enemies of pests using field observation techniques, controlled and limited use of pesticides, crop rotation and synchronous planting (Oka 1991: 163–4; Settle et al. 1996: 1977–8, 1986; Resosudarmo 2001: 2; McClelland 2002: 191). In farmer field schools (FFS), farmers across Indonesia learnt to adjust and target the use of pesticides based on knowledge of the life cycles of pests and their natural enemies (Oka 1991; Way and van Emden 2000: 84; McClelland 2002). They were also encouraged to plant a non-rice crop (*palawija*) after every two crops of rice (Thorburn 2007: 16).

In Bali, farmer field schools were less instrumental in controlling pest outbreaks. Farmers in the field hardly remember any field school training by extension services.[141] With the imminent threat of toxic contamination from pesticides and gradual loss of soil fertility, however, the Balinese government finally came to strongly support the subak's role in organising synchronised planting and crop rotations (as discussed in chapter 4, ecological dimension) (Lansing 1991: 41; 2006a: 9). The staggered re-introduction of non-rice crops into the cultivation schedule allowed for a better allocation of water amongst subaks along a river (Sutawan et al. 1986: 65). Yet, farmers generally prefer to grow rice continuously except to break pest cycles, or to restore land fertility by fallowing (Heytens 1991: 43). While I was in the field, the subaks of the field research site did not plant a palawija but had their fields lay fallow.

In short, biodiversity of the rice field ecology was diminished in three ways: (1) with a small number of new varieties with a narrow genetic base replacing multiple local varieties; (2) with pesticides impacting on associated flora, fauna and the environment; and (3) with a tendency to monocrop rice year after year without prolonged fallow periods and synchronised cropping patterns. A locally adapted and diverse cropping system was turned

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[141] Although farmer field schools proved to be successful where adopted, they only reached one million of 19 million farming households in Indonesia (Way and van Emden 2000: 84).

into an intensive and continued rice monoculture system —with a narrow genetic base to uphold resistance— cultivated over vast areas in a short period of time. The application of pesticides further reduced biodiversity, leading to substantial production losses. Yet with the return to the subak's control over planting schedules and the ban on broad-spectrum pesticides rice production recovered. No further drastic temporary declines occurred and rice productivity began, although modestly, to increase again.

The reduction in biodiversity of rice varieties in the rice field has been somewhat compensated by extensive conservation programs such as, for example, the International Rice Research Institute's collection of more than 80,000 rice cultivars as well as conservation efforts by community-based non-governmental organisations (Vaughan and Chang 1992; Greenland 1997: 98; Carpenter 2005). In Bali, as discussed, farmers still cultivate a diversity of local varieties. One farmer in the field research site is actively breeding high yielding rice varieties, selecting the best strains in his and his fellow farmers' fields. He then sells his own locally adapted modern varieties to his fellow farmers for a better price.

Summary

The introduction of a few modern varieties with a narrow genetic base greatly reduced in-field biodiversity of rice varieties. The continued practice of Balinese farmers planting local varieties albeit on smaller areas, has somewhat compensated for that reduction. The abundance and species-richness of natural enemies has been partially restored with the return to traditional methods of synchronised planting. While the use of broad-spectrum pesticides has been banned, other pesticides are still in use. Whether their long-term use has any negative effect on natural enemy populations will require further investigations. The practice of collecting complementary fauna in and around rice fields, on the other hand, has been abandoned, given that they have been greatly reduced by the application of pesticides.[142]

With respect to my conceptual model of the subak as a social-ecological system, I suggest that the biodiversity threshold has clearly been approached and maybe temporarily even crossed, given the drastic outbreaks of brown planthopper. With the return to traditional cropping patterns the subak was able to recover. Yet the biodiversity threshold has changed, with biodiversity being reduced due to reduced variety in-field of rice planted and associated flora and fauna.

The rice yield development, I argue, reflects the resilient behaviour of the subak as a social-ecological system. With the new rice, yields began to increase. This initial yield growth stability was momentarily replaced by great instability with the massive pest outbreaks and resistance development in brown planthoppers (Figure 5.1). Eventually yield growth increased again. The subak had to reorganise and adapt, which it managed, albeit with reduced biodiversity levels. The use of pesticides continues to impact on the ecological dimension of the subak, which in the long run decreases the subak's resilience.

Nitrogen supply

The new breeds of rice responded in a positive way to high fertiliser application. Or, in other words, to achieve the high yields they were bred for, these varieties were dependent on the sufficient and timely application of fertilisers as well as adequate water supply. Under suboptimal conditions the new varieties produced far less than traditional varieties (Poffenberger and Zurbuchen 1980: 98–100). More importantly, local sources of organic fertiliser (such as discussed in chapter 3, ecological dimension) were generally insufficient

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[142] Other reasons mentioned by farmers in the field site were the fear of toxicity of fauna collected in the fields, caused by the applied pesticides, and the possibility to buy protein food, such as meat and soy products at the market due to an improved cash economy of rice farming households. The substantial increases in rice production enabled farmers to sell part of their yields.

in providing the quantities of nitrogen required because they contain lower nutrient concentrations. One tonne of animal manure, for example, contains approximately 6 to 16 kilograms of nitrogen which is equivalent to 0.6 to 1.6 per cent of the total mass while urea —a commonly applied inorganic fertiliser— has a concentration of 46 per cent nitrogen content (Greenland 1997: 126; FIFA Website 2010).[143]

With such a large disparity in bulk and value, it comes as no surprise that inorganic fertilisers have greatly replaced organic forms such as manure and compost because much smaller quantities have to be applied, and they produce better results. In addition, organic sources of nitrogen, once worked into the soil, are not immediately available for the plant; they have to be broken down by microbes first. Chemical nitrogen, on the other hand, is directly available for the plant and responses can be seen as early as two to three days following application (Dobermann and Fairhurst 2000: 45). Yet although the response time of chemical fertiliser is quick, the efficiency of application is low. Studies suggest that nitrogen loss in irrigated rice systems ranges between 10 to 65 per cent with an average nitrogen fertiliser uptake efficiency of 40 per cent (Roche 1994: 69; Cassman et al. 1998: 8; Dobermann and Fairhurst 2000: 30; Cassman et al. 2002: 133). This poor efficiency of chemical fertilisers requires application in excess of the amounts consumed by the crop. Nevertheless, even including an uptake efficiency of 40 per cent, urea's nitrogen content still outperforms that of organic manure between 11 to 30-fold.[144]

The minimum amount of nitrogen that is required to harvest one tonne of new rice is estimated to be between 16 to 20 kilograms (Kyuma 1995: 12; Kirk 2004: 206). Thus, for a yield of four tonnes per hectare an estimated 64 to 80 kilograms are required. Greenland (1997: 130–31) calculated a total of 335 kilograms nitrogen are added per year and hectare

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[143] Ammonium sulphate (AS), another commonly used nitrogen fertiliser in Indonesia contains 21 per cent nitrogen (FAO 2005: 17).

[144] Considering an efficiency rate of 0.4, urea's nitrogen content that reaches the plants is 184 grams per kilogram while 1 kilogram of organic manure contains 6–16 grams of nitrogen.

for a typical modern rice cultivation system that includes two crops of rice yielding four tonnes per hectare and a legume yielding one tonne per hectare. Application quantities tend to vary across regions, contingent on farming intensity and also farm size. Decisions on the quantities of fertiliser applied further depend on farmers' own experiences and financial means (FAO 2005: 14). In the field research site, for instance, farmers consciously apply more fertiliser than recommended. They do this as a means to assure even distribution of the manually applied amounts on their small fields, which average 0.37 hectares (S. Lorenzen 2008: 231–2). This tendency for smaller holdings —using on average more fertiliser— has also been noted by Booth (1988: 166), who records nearly double the amount applied in holdings smaller than 0.5 hectares compared to those holdings of 1 hectare.

Fertiliser use has markedly increased since the beginning of the Green Revolution. Between 1961 and 1988 total nitrogen consumption across Indonesia —including non-rice crops— grew more than twelve-fold (Figure 5.4). The rise in consumption has been encouraged by heavy input subsidies, a well-functioning distribution network and protective agricultural policies (Roche 1994: 60; FAO 2005: 9–10). Between 1970 and 1980, Indonesia had the most favourable urea/rice price ratio —in Bali, the farmgate urea/rice price ratio at the time was 0.66— which is the reasons farmers were able to apply increasing amounts of nitrogen (Booth 1988: 151; Thorburn 2007: 8).[145] In Bali, fertilisers were distributed to each subak from where farmers would then buy it.

Rapid growth of chemical fertiliser use was the key to Indonesian rice production increases during the Green Revolution decades (Roche 1994: 59). Accordingly, between 1972 and 1989 total rice production increased by 5.1 per cent annually on average —two-thirds (or 3.4 per cent) of which was due to yield growth— while fertiliser use grew by 9.8 per cent (ibid. 1994: 60) (Table 5.2). In Bali, yield growth was not that substantial in that period

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[145] This development can also be seen in the graph of Figure 5.4. Nitrogen consumption grew most rapidly between 1975 and 1980.

because of the pest outbreaks, increasing annually by 2.1 per cent only. While Bali's yields in the late 1960s were nearly twice as high as those across Indonesia, the margin became smaller and levelled out at around 20 per cent above the Indonesian average from 1982 (Figure 5.5).

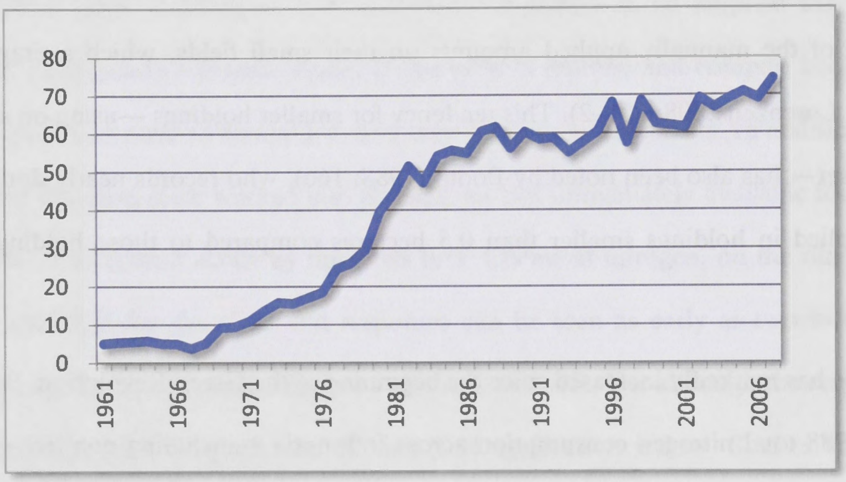

Figure 5.4: Total nitrogen consumption per harvested area of crops (kilogram per hectare), Indonesia, 1961–2007

Source: (IFADATA 2010a; FAOSTAT 2011)

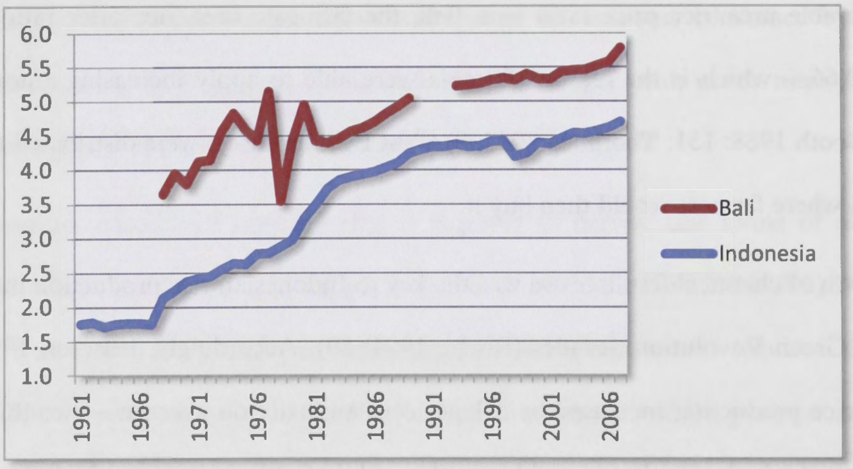

Figure 5.5: Rice yields (tonnes per hectares), Bali and Indonesia, 1961–2007

Source: (For Bali: BPS Bali1976: 16; BPS Bali1980: 125; Kantor Statistik Propinsi Bali 1983: 101; 1986: 115; Foley 1987: 35 (Appendix); Kantor Statistik Propinsi Bali 1988: 112; 1991: 112; BPS Indonesia 2010b; for Indonesia: FAOSTAT 2011)

Table 5.2: Rice yields (kilograms per hectare) and average annual growth rates (percentage), Bali and Indonesia, 1972–1989

	Bali		*Indonesia*	
	Rice yield (kilograms per hectare)	*Average annual growth rate (percentage)*	*Rice yield (kilograms per hectare)*	*Average annual growth rate (percentage)*
1972	4.1	0.5	2.5	1.2
1973	4.6	10.4	2.6	4.1
1974	4.8	5.5	2.6	3.3
1975	4.6	-4.9	2.6	-0.4
1976	4.4	-3.5	2.8	5.9
1977	5.2	16.1	2.8	0.3
1978	3.6	-31.0	2.9	3.3
1979	4.4	24.7	3.0	3.4
1980	5.0	11.8	3.3	10.3
1981	4.4	-10.5	3.5	6.1
1982	4.4	-0.8	3.7	7.0
1983	4.5	1.4	3.9	3.1
1984	4.6	2.4	3.9	1.4
1985	4.6	1.1	3.9	0.9
1986	4.7	1.9	4.0	0.9
1987	4.8	2.6	4.0	1.6
1988	4.9	2.1	4.1	1.8
1989	5.0	2.4	4.2	3.3
Average	**4.75**	**2.1**	**3.35**	**3.3**

Source: (For Bali: BPS Bali1976: 16; BPS Bali1980: 125; Kantor Statistik Propinsi Bali 1983: 101; 1986: 115; Foley 1987: 35 (Appendix); Kantor Statistik Propinsi Bali 1988: 112; 1991: 112; for Indonesia: FAOSTAT 2011)

Indigenous N sources such as rainfall, sediments, and irrigation water remained more or less the same. Where water is stored before delivery to the field, sediments may be trapped and nutrients contained in sediments no longer reach the rice field (Kirk 2004: 205). Drainage water, on the other hand, which irrigates fields further downstream, now contains higher amounts of nitrogen due to the higher solubility of inorganic nitrogen fertiliser and insufficient uptake by the crop. BNF is suppressed by the application of inorganic fertiliser, though the reduction appears to be small (Marten and Vityakon 1986; Greenland 1997: 130; Cassman et al. 1998: 16). Greenland (1997: 130–31) estimates these indigenous sources of nitrogen to be at 135 kilograms per hectare annually.

Increased application of the more convenient chemical fertilisers has, however, significantly reduced the amount of organic manures applied to rice fields. Farmers no longer have to invest time and labour to prepare and apply organic manure. Especially in countries with rapid economic development, the rising costs of land and labour are the main reasons for reduced application of organic manures (Cassman et al. 1998: 24). The amount of organic matter applied to the fields these days is basically limited to harvest residues incorporated at the time of soil preparation. The applied amount is reduced if farmers burn or sell the straw.[146]

The reduction of organic matter input has in turn led to decreased soil organic matter content. In Indonesia, as many as 66 per cent of all rice fields suffer from low organic content (Simatupang and Timmer 2008: 74–5). In the field research site, farmers have noted a change in the colour of the soil from yellow to a greyish-blackish tint since applying inorganic fertiliser. One possible indirect explanation could be due to their farming practices such as no application of manures and an intensified cropping cycle with only short aerated fallow periods. As a consequence, soil organic matter content has been reduced and with it compartmentalised oxygen contained in organic matter. In anaerobic soils iron oxide is reduced, changing the soil colour from red and yellow to a bluish-grey tint (Kirk 2004: 68). With less compartmentalised oxygen contained in submerged soils and less fallow periods of aerobic soil conditions, all available iron oxide is reduced, leaving no more traces of red and yellow in the soil.

There has been a long-term trend in declining productivity growth (decreasing yield growth) in double- and triple-cropped irrigated rice fields across Southeast Asia though the reasons for this are debated (Pingali and Rosegrant 1994: 5, 10–11). Whether changes to the soil's organic matter content leads to reduced productivity of monocropped rice soils in the long run is subject to further investigations (Pingali 2005: 422). Several studies showed

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[146] Also, the traditional rice varieties are harvested with the fist knife, leaving a greater part of the stalk back in the field, while the new rice is harvested with sickles and cut closer to the ground.

that there was no correlation between soil organic matter content and yield increases unless organic manures are used in conjunction with inorganic fertilisers (Cassman et al. 1998: 24; Witt et al. 2005: 144). Others, however, have indicated that the chemistry of organic matter in continuously submerged soils is being altered thereby inhibiting nitrogen uptake by plants (that is, reduced soil nitrogen-supplying capacity), which is now being discussed as a possible reason for declining yields (Cassman and Pingali 1995: 302; Kirk 2004: 76; Olk et al. 2005: 375). Declining yields and yield growth rates have been noted in Indonesia by Simatupang and Timmer (2008: 74–5), who attribute this trend to imbalanced and excessive use of fertilisers, high land use intensity which depletes the soil of nutrients, increased production costs and decreased competitiveness of farmers. In Bali, yields have so far continued to increase though with a declining growth rate (Figure 5.6).

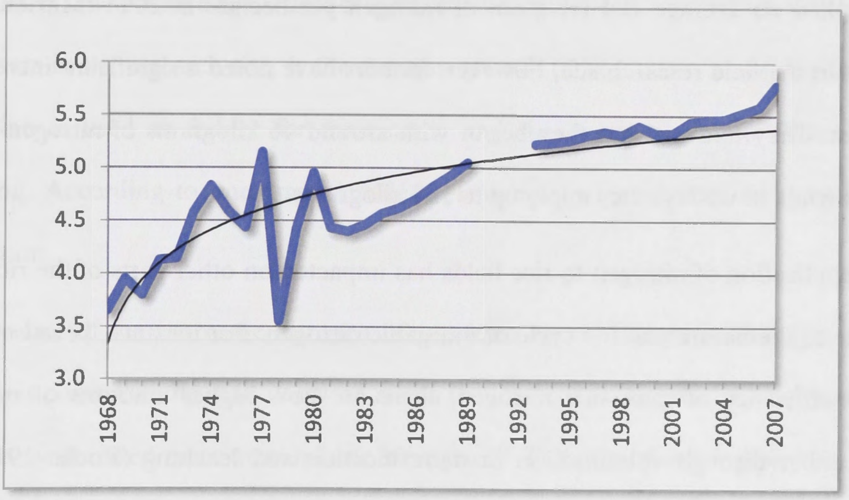

Figure 5.6: Declining trend of rice yield growth (logarithmic, tonnes per hectare), Bali, 1968–2007

Source: (For Bali: BPS Bali1976: 16; BPS Bali1980: 125; Kantor Statistik Propinsi Bali 1983: 101; 1986: 115; Foley 1987: 35 (Appendix); Kantor Statistik Propinsi Bali 1988: 112; 1991: 112; BPS Indonesia 2010b; for Indonesia: FAOSTAT 2011)

Imbalanced fertiliser application of the three major nutrients (N, P, K) is partly the result of price differentials, and partly the lack of knowledge among farmers about the need for balanced fertilizer application (Anonymous 1995; Kyuma 1995: 11; Rosegrant and

Meinzen-Dick 1996: 38). In Bali, the subak institutional framework has little influence in the application of fertilisers (as discussed in chapter 4, institutional dimension). In the field research site, for example, farmers take a fairly rational approach to fertiliser application which is less focused on a scientific approach of a balanced nutrient input. They consider the costs and benefits of production as well as local knowledge about the status of the crop (S. Lorenzen 2008: 233).

The declined productivity growth is mirrored in a trend across Indonesia to increased fertiliser use per hectare. The average nitrogen use in rice increased between 1989 and 2004 from 99 to 127 kilograms per hectare with regional variations of between 24 to 184 kilograms per hectare (Roche 1994:68; FAO 2005: 29). In Bali, there appears to be no clear trend. Foley (1987: 159) recorded nitrogen fertiliser use of 119–159 kilograms per hectare in 1982/1983, while Roche (1994: 68) lists 107 kilograms per hectare in 1989. In Tabanan farmers applied on average 104 kilogram of nitrogen per hectare in 2004 (Marion et al. 2005: 939). In the field research site, however, farmers have noted a significant increase in applied urea. They told me that they began with around 46 kilograms of nitrogen in the early 1970s while nowadays they apply up to 184 kilograms.

Increased application of nitrogen to rice fields has impacted on other parts of the rice field ecology due to the nature and life cycle of inorganic nitrogen. For instance, because of the low uptake-efficiency of inorganic nitrogen, there are now higher amounts of nitrogen being lost either through volatilisation or denitrification and leaching (Roche 1994: 69; Pimentel 1996: S94). Volatilisation and denitrification are processes in which soluble nitrogen is converted to gaseous form —mainly nitrous oxide (NO_2) and nitrogen gas (N_2)— and become unavailable for the plant, while leaching removes soluble nitrogen with irrigation water. These losses accumulate in other places: nitrous oxide, a greenhouse gas, and nitrogen gas are returned into the atmosphere while leached soluble nitrogen may be used in fields further downstream, percolate into groundwater or wash out into the ocean.

Nitrogen-fluxes into the environment have clearly increased, but what it means for the environment in the long term is unclear as of yet (IFA 2007; UNEP 2007: 11–16).

A study undertaken on corals off the coast of Java showed that bio-erosion of corals —a process limiting growth and possibly contributing to reef death— was significantly higher in sites subjected to eutrophication due to the influx of agricultural, aquaculture and domestic sewage runoff (Holmes et al. 2000).[147] In Bali, increased use of inorganic nitrogen since the 1970s has contributed to the degradation of coral reefs off the coast of Bali (Marion et al. 2005: 941; Lansing 2006a: 9). High levels of nitrogen, phosphorus and potassium measured in spring and river water in Tabanan in 2001 to 2002 led to recommendations to adapt applied fertiliser quantities so as to reuse nutrients in irrigation water in an effort to minimise groundwater pollution, eutrophication of water bodies and coral reef degradation (Lansing et al. 2001: 388–9; Arthawiguna 2002: 184–91; Lansing 2006a: 9).[148] One positive side-effect of applying inorganic fertilisers, which was highlighted by farmers in the research site, is the stronger growth of vegetation along the bunds. This vegetation is used as fodder for their cattle and the stronger growth allows for faster gathering. According to one farmer, fodder yield has increased twofold since the Green Revolution.

Another fact of the inorganic nitrogen life cycle to be considered is its origin. Inorganic nitrogen is commercially manufactured *ex-situ* (beyond the farm gates) whereby ammonium (NH_3) is synthesised from atmospheric nitrogen.[149] The manufacturing process is energy-

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[147] A eutrophic water body is a sink of excessive nutrient input usually from farming activities —mainly nitrogen and phosphorus— which impacts on the water body's ecological functionalities, promoting the excessive growth of algae and other plants. The decomposition process of this increased growth uses up all the dissolved oxygen in the water, which leads to living creatures dependent on oxygen in such water bodies becoming extinct (R.P. Lorenzen 2001).

[148] Lansing et al (2001) demonstrated that phosphorus and potassium concentrations in Balinese irrigation water and soils are high due to the island's volcanic origin, with rice crops not really requiring additional top-ups by chemical fertilisers.

[149] The production of ammonium from atmospheric nitrogen was made possible in the first part of the twentieth century by the development of the Haber-Bosch process which was recognized by two Nobel prizes for chemistry, awarded to Fritz Haber in 1918 and Carl Bosch in 1931 (IFA 2010b).

intensive and depends on natural gas, which is a non-renewable resource (Gellings and Parmenter 2004). There are also wastes and emissions from the manufacturing process that impact on the environment. The energy used is mainly indirectly consumed during production, packaging and transportation (ibid.).[150]

Summary

Rice productivity increased substantially over the period of the Green Revolution and also beyond. In Bali, yields increased from an average 3.7 tonnes per hectare in 1968 to 5.8 tonnes per hectare in 2007 (BPS Bali 1976; BPS Indonesia 2010b). This was due to the new varieties and the application of inorganic fertiliser. Greenland (1997: 130–31) suggests that with the new rice a total of 335 kilograms of nitrogen are added per year and hectare where two rice crops with one legume crop are grown. In Bali, however, most farmers grow five crops of rice over two years without any non-rice crops, thus nitrogen input must be higher.

To calculate the input of nitrogen into the rice field with Green Revolution crop management (new varieties and inorganic fertiliser application) I use an approximation averaging referenced nitrogen inputs over the last 40 years, which would be at 120 kilograms per hectare.[151] Annual nitrogen input into the rice field —considering 2.5 crops of rice per year— would therefore be at 300 kilograms per hectare.[152] In addition to inorganic nitrogen fertiliser, indigenous sources of nitrogen have to also be taken into account — averaging 135 kilograms per hectare and year (Greenland 1997: 130–31)— which would sum up to a total nitrogen supply of 435 kilograms per hectare and year.

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[150] Application, on the other hand, requires considerable less energy compared to organic manure.

[151] For an average yield of 4.75 tonnes per hectare (over the forty years) the minimum amounts of nitrogen required would be around 76–95 kilograms per hectare.

[152] This amount could range to up to 460 kilograms per hectare considering current application volumes of farmers in the field research site.

Considering the basin of attraction for the subak and similar rice production systems, the nitrogen threshold, I suggest, has therefore been changed from 130 to 435 kilograms per hectare and year. It appears that there have been no imminent impacts other than a significant increase in rice production of more than 50 per cent in total between 1968 and 2007. There are, however, a number of corollaries to the increased nitrogen supply. Due to inorganic nitrogen's low efficiency this fertiliser has reached other parts of the environment with positive and also damaging effects which will need careful monitoring in the long run. For instance, the in-field biodiversity of natural enemies could be compromised given that organic matter is now no longer applied, or only applied in limited amounts. Production increases have also been possible because the energy-rich production of nitrogen has been moved out of the system, its production impacting on the environment elsewhere. Considering the long-term declining trend in yield growth, nutrient input practices as well as soil nutrient status require careful monitoring on a continuing basis.

Intensive cultivation techniques and farm labour mobilisation

The shorter and faster-maturing new varieties and their need for adequate application of agrochemicals and ample water supply brought considerable changes to the way rice was cultivated, irrigated and celebrated. Mechanisation shortened the soil preparation process, herbicides reduced weeding frequency, and commercialisation of production changed the organisation of harvesting and post-harvest handling of rice, while upgrades to irrigation facilities —which I will discuss in the next section— reduced frequency of maintenance work. These changes clearly supported intensification of rice production, enabling the cultivation of more rice crops per year with less input of labour per crop. In short, the Green Revolution had an impact on techniques, organisational arrangements and labour productivity.

Hand-held tractors were introduced in Bali in the early 1970s. They made draught cattle basically redundant. Soil preparation was made easier and also faster. Previously, farmers would plough and harrow the fields in several rounds with long resting periods in between. With hand-held tractors farmers soon abandoned this two-step process and would use only the harrow, although tractors are equipped with both plough and harrow. Across Indonesia, mechanisation was slow however. In 1984, around 15 per cent of all the irrigated rice fields were ploughed with a tractor (Nehen 1989: 92). Booth (1988: 181) attributes the slow penetration of mechanisation to small land holdings to the very low marginal costs of family and hired labour compared to the cost of imported farm machinery.

Although there are no specific numbers for Bali, I assume replacement of draught animals with tractors was much faster because of Bali's advantageous economic situation with plenty of off-farm employment available. According to farmers' accounts in the field site, in the beginning only rich farmers could afford to buy a tractor and work the land. Later on, being a tractor operator became a new trade and an attractive side business for those who could afford to own one. These tractor operators would then travel from subak to subak to offer their services. Several subaks received tractors from the government as part of the Indonesian intensification programs to be used by the subak members for free. Yet, according to the accounts of farmers and subak heads in the field site, these tractors were of poor quality and hard to manoeuvre, or in some cases, subak heads would use these government tractors for their own benefit, renting them out to operators instead. In subak Tegan, these days, the subak head sources the tractor operators who bring their own tractor. The subak head negotiates the price per 0.01 hectare they get paid by farmers. The tractor operators commit to plough a certain amount of hectares in a certain amount of time. The tractor operators then get paid directly by the farmers at the time their fields are ploughed.

Compared to the traditional varieties of rice which would reach shoulder height, the new varieties were much shorter. The new plants were also sturdier and had significantly more tillers. Harvesting with the fist knife became impractical and so this technique quickly disappeared where new varieties were grown. With the new techniques, labour input into harvesting was drastically reduced. The number of harvesters declined to almost half from the former 184 labourers per hectare to 80 workers with the sickle (Palmer 1977: 150; Stoler 1977: 683; Booth 1988: 183). By 1982/1983 the majority of farm households cultivating irrigated rice in Bali used the sickle to harvest and only 15 per cent still used the traditional method (Booth 1988: 184).

The old rice, once harvested, was carried home in bundles of stalks (sheaves). The new rice, on the contrary, is directly threshed in the field. Only a small part of the harvest is brought home in bags while the surplus is sold to the mills. Portable threshers are used instead of the traditional hand-threshing. In Bali, although portable threshers are now mainly used, hand-threshing is still used.[153] According to one of my informants, women prefer to hand-thresh because the portable threshers are too heavy to carry from field to field across the bunds and irrigation canals. Hand-threshing is also used by farmers for the rice that is brought home for their own consumption.

With the new rice, a higher proportion of the harvested rice entered the market. A new marketing system, the *tebasan*, found its way into rice production and soon became the standard. In the tebasan system, which was known and widely used for other non-rice crops, rice is sold shortly before the harvest while the crop is still standing in the field (White 2001: 83). The middlemen, who buy the rice, bring their own harvesting teams for the harvesting. Nowadays, the tebasan system is still widely in use in Bali. Many of the harvesting teams hired by the Balinese traders are Javanese male or mixed-gender day

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[153] In the Philippines portable threshers completely replaced hand-threshing (Hayami and Kikuchi 2000: 119).

labourers. To a lesser extent, harvesting and hand threshing is also done by local women harvesters who are paid in piece-rate according to the area harvested.

The changes to cash crop production impacted on labour mobilisation for peak demand times. The traditional working groups (sekaha) were now progressively replaced by day wage labour groups. In one of the research site villages, I was told that after the women of the hamlets saw that other women's groups from hamlets further south offered their services to work in the rice fields of their men they decided to form their own group. It took them a little while to learn the techniques of transplanting seedlings. Once the women groups were established local farmers preferred to engage the women from the village rather than people from outside to work in fields. The harvesting working groups organised by the village or the hamlet have entirely disappeared as has the village-based rice storage facilities. One of the farmers explained that the new rice cannot be stored that long and that also these days, rice can easily be bought at the markets. But the main reason, he argued, was that these days, it was difficult to mobilise labour on the village-level for communal agricultural work.

In the field site, mobilisation of work on the subak-level has changed as well. At the time of my field research larger maintenance work at the main canal of subak Tegan was required. The majority of maintenance work was carried out by paid workers from outside as according to the subak head it was too difficult to mobilise labour for longer periods of time from within the subak. In subak-gede Panca Tirta Buwana, on the contrary, the five subak heads did not outsource the work but together with all munduk heads and all their wives carried out the work together. They were all paid a normal day labourer's wage. They argued, that even though they spent several days working on the project, they preferred to do it by themselves to ensure good quality work.

Gender division of labour shifted with the changes in technology and labour arrangements. The traditional varieties were harvested by women or mixed-gender groups. With the new rice, male harvesters with their sickles became common (Stoler 1977: 691; White 2001: 87).

Both in Bali as well as in Java, women in particular became displaced by the new harvesting system which raised concerns about their ability to earn an extra income (Poffenberger and Zurbuchen 1980: 100; White 2001).[154] Ramseyer (1988: 86), too, observed that in Sidemen possibilities to join harvesting work were reduced with the arrival of the new varieties. Yet especially in the case of Bali, the diversification of the rural economy allowed for new opportunities in non-agricultural employment. Also, the gender division of labour in agriculture became more relaxed. These days, women undertake all of the cultivation activities that men do (Jha 2004: 554). In the field site, at the time of my research, the only activities exclusively done by men were the application of pesticides, and the operating of the hand-held tractor, while the rituals remained women's responsibility. With respect to subak activities, the gender disparity remained unchanged: women did generally not participate in any subak-related activities such as attending subak communal work and meetings except for ritual preparatory work and attending of ceremonies.

Irrigated rice cultivation in Bali has transformed from mainly subsistence agriculture to cash-crop production. The new cultivation technologies, such as tractors, herbicides and sickles, and commercial forms of harvesting have considerably shortened the rice production process and reduced labour input, which increased labour productivity.[155] Per-hectare labour use in rice cultivation has decreased though available data is limited. Barker et al. (1985: 126) report a decrease of 10 per cent in the first decade of the Green Revolution, while van der Eng (2004: 355) records a 40 per cent decrease between 1955 and 1992.[156] Nevertheless, with intensification of rice cultivation, annual labour input increased because they grow up to five crops of rice over a two-year period.

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[154] The displacement of particularly poor women has also been discussed by others for other Southeast Asian regions (Huvio 1998; Rigg 1998: 508–9).

[155] An additional time saver in using tractors was that training cattle to become draught animals which used to require considerable time and effort became redundant.

[156] A detailed discussion of current labour use in the field research site is the subject of chapter 6.

Summary

Green Revolution practices reduced labour input requirements by replacing human labour with farm machinery and simplified labour techniques. Although overall labour increased with farmers now growing two to three rice crops annually, in-field labour time per cultivation cycle was reduced, giving farmers more flexibility in pursuing other income-generating activities. The diversification of the Balinese economy has increased off-farm employment opportunities that enable farmers as well as agricultural labourers to find work off-farm.[157]

The commercialisation of rice production changed organisational arrangements, replacing in-kind labour with wage labour. It is debatable whether social ties amongst members of the subak have weakened with the abandoning of traditional communal harvesting such as argued by Planck and Sutawan (1983: 291). In the field research site, as discussed in chapter 4, labour mobilisation for cultivation was organised by the household or the village disconnected from any subak structures. There is however a trend to the outsourcing of larger subak-related maintenance work as mobilisation of labour within the subak membership for work that takes longer than one day has become difficult.[158]

With respect to the subak as social-ecological system, I suggest that the labour techniques threshold changed to a lower intensity level. The labour mobilisation threshold with respect to cultivation changed qualitatively with exchange labour being replaced by paid labour. The labour mobilisation threshold with respect to irrigation requires further observation to confirm the trend to outsourcing of maintenance work and the consequences of this shift on the quality of the irrigation facilities.

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[157] This will be discussed in more detail in the next chapter.

[158] See also chapter 6 for a discussion of subak-related labour input.

Changes to the physical infrastructure

The renovation and improvement works undertaken as part of the Bali Irrigation Project (BIP) confronted subaks and farmers with a new irrigation system and technology which, as it turned out, disregarded the basic principles of proportional water divisions and continuous water supply inherent to the subak system, ignored the coordinating roles of the water temples, and left the subak community in doubt about maintenance and operation responsibilities. The technocratic top-down approach had failed to comprehend and integrate the logic of the existing irrigation system into the rehabilitation works, believing that its upgrades would result in a more efficient system with higher yields and less work for the subak community (S. Lorenzen 2008: 181). Farmer involvement in the construction of the new system had been minimal or often non-existent (Horst 1996: 48). As a result, conflict emerged over joint water management rights and duties within subaks and on the inter-subak level where subaks were merged to share a dam (S. Lorenzen 2008: 179). Although operational performance had improved and labour input into maintenance was reduced, with the upgrade to more permanent structures 'a complex and uncertain situation had emerged' (ADB 1997: iii, 12).

One of the main Bali Irrigation Project design failures was the replacement of the traditional proportional dividers with regulatory gates that required flow measurements. The new technology was based on crop water requirements and hydraulic efficiencies, which were assumed to be controlled and monitored by trained public service staff (Horst 1996: 35; ADB 1997: 3). A system based on adjusting the cultivation cycles to the availability of water was turned into a system where water flows are adjusted to crop needs, which requires frequent gathering of large amounts of data, constant readjusting of water flows at the gates and trained personnel for the operation of the gates (S. Lorenzen 2008: 178–9).

These gates became frequently blocked by debris and overflowed, causing damage to canals and embankments because they were not suited to manage the variable flows and the large amounts of sediments that are characteristic of Balinese rivers. With gates overflowing visual monitoring of water shares became impossible (ADB 1997: 3). Soon, many of the new structures were modified, restructured or simply neglected because they failed to distribute water equally, disadvantaged farmers near the water in-let and required high maintenance during the peak water season (Sutawan 2000a: 58– 60).[159]

A further result of the Bali Irrigation Project was that the water temples almost completely lost their control over cropping cycles and water allocation (Lansing 1991; Horst 1996: 44). Irrigation schedules were now to be determined pursuant to hydro-meteorological data by external irrigation experts who were oblivious of the institutionalised intra- and inter-subak religious ties that previously helped negotiate water for each individual subak and farmer field (Horst 1996: 51; S. Lorenzen 2008: 181–3). Eventually, in 1988, Bali Irrigation Project officials recognised the importance of the water temple system and the water temples regained informal control of cropping patterns in most of Bali (Lansing 1991: 125). This re-institution, however, only occurred after Lansing and his team of computer modellers could prove that the water temple system played a key role in deciding the timing of water allocation and planting schedules.[160]

With the physical integration of several subaks to share a single dam and primary canal, subaks were left in limbo with regards to who would take over responsibility for the maintenance and operation of the new set-up. This reorganisation demanded a different way of collaboration amongst the subaks that was previously not envisaged. The newly integrated systems also mainly benefited upstream subaks because the integration did not take into account existing water dependencies between up and downstream subaks. As a consequence, downstream subaks resorted to using their old dams for sufficient irrigation

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[159] According to Sutawan (2000a: 58–60), farmers near the in-let were getting less water because of the narrow openings of the upgraded structures which would easily clog up.

[160] See also chapter 2 where I discuss the self-organisation ability of subaks along a river for coordination of cropping patterns.

water (Sutawan 2000c: 317). Questions also arose about the responsibilities for religious duties and maintenance of the water temple at the dam (Sutawan 2000a: 60).[161]

To this end, the local university in collaboration with the Public Works department developed a participatory approach motivating newly integrated subaks to form subak federations for a better performance of the system. During the process, which involved several meetings with farmers and subak officials, it was agreed that maintenance and operation responsibilities were to be handed back to the subaks coordinated through the agency of the newly formed federations (Sutawan 2000a; c: 321–7). The formation of the coordination bodies proved to be successful, particularly because subak communities were involved from the beginning.

In the research site, Penarungan dam, Kapal dam and Munggu dam were rehabilitated between 1978 and 1982 according to official documents. I assume that rehabilitation of primary and secondary canal and irrigation infrastructure were renovated in or around the same period. A former subak head of one of the subaks in the research site still remembers the changes that occurred and the impact on the performance of the irrigation system. With the introduction of the new technology, farmers and subak heads were disempowered, unable to informally negotiate water shares as they used to do. Eventually, the gated structures on the munduk and subak level were destroyed while on the inter-subak level, subak heads started informal negotiations for additional irrigation water with the public servant responsible as the gate keeper. Official restoration of proportional dividers with continuous flow occurred in the mid-1980s when the Bali Irrigation Project finally complied to the requirements of subak principles (Horst 1996: 45–6; S: Lorenzen 2008: 183).

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[161] This uncertainty also links into the issue of water temple coordination, for coordination cannot take place if the religious dependencies are not reorganised and clarified.

These days, there are still a few leftovers of the failed Bali Irrigation Project technology. In the field research site, the primary division structure which divides water among the six subaks is equipped with gates that can be opened and closed (Figure 5.7). These gates, however, usually remain open. If subak Dukuh, which has their inlet to the west, or subak Aban, with their inlet to the east, require an extra share of water they make a request to the other subaks to close one of the two gates to the south to create an increased water flow into their respective secondary canals.

Figure 5.7 Gated primary division structure (a) and detail of a gate (b)

The gated primary division structure together with a number of other dividers further along the primary canal also lack the typical crest elevations and the parallel water flows in the bifurcating canals pivotal to equal water distribution, which results in reduced water flow into the offsetting canals (Figure 5.8). The subak heads of the respective subaks have mentioned water stress but prefer to informally negotiate their water shares with the other subaks rather than requesting renovation works by the Public Works Department, for they fear the outcome might be worse.[162]

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[162] For a more detailed discussion of the Bali Irrigation Project changes and impacts on the subaks of the field research site, see S. Lorenzen (2008: 181–90).

Figure 5.8 Example of non-parallel water flow bifurcation

Summary

The modification of the irrigation structures undermined the guiding principles of water division, altering the way water was delivered to each individual field. The introduction of water schedules devised by external irrigation experts led to the abandoning of rotational synchronised planting set by the coordinating water temples. The amalgamation of subaks, which neglected existing water dependencies, resulted in conflicts over water and confusion about the maintenance and operation responsibilities of the irrigation infrastructure on the inter-subak level. The complexity of the newly introduced irrigation technology which required frequent monitoring and measuring of water flows, and the shortage of public service staff to attend to operation and maintenance eventually led subaks to take back irrigation management. The return was possible and successful due to the combined effort of independent academics and government officials with the inclusive participation of the subak community. Traditional dividers were rebuilt, the water temple coordination restored and inter-subak collaboration improved.

Although the traditional water allocation and distribution system was restored, the permanent nature of the new irrigation structures greatly reduced the frequency and intensity of maintenance labour. The reduced input into maintenance work further contributed to the newly gained flexibility of farmers to work off-farm as a result of reduced labour input into the cultivation and irrigation of rice.

With respect to my conceptual model of the subak as a social-ecological system located in a specific basin of attraction for farmer-managed canal-irrigated rice cultivation systems, I argue that the order of events with the changes to the physical infrastructure show how the subak was resilient. I suggest that that several thresholds have been momentarily crossed or approached. The proportional principle threshold as well as the gravity-fed supply-driven threshold was crossed (physical dimension). Water supply was negatively affected with the introduction of the gated structures affecting the water supply threshold (ecological dimension). The labour input into maintenance was increased because the new gates needed frequent maintenance, which affected the labour input threshold (technical dimension). Conflict over water allocation and distribution, and confusion over maintenance responsibilities emerged which impacted on the guiding principles threshold and the relative autonomy threshold (institutional dimension). Once traditional principles were restored, however, the subak reorganised and recovered, finally benefiting from the new permanent structures. Thresholds were restored with the labour input threshold permanently changed to a lower input.

CONCLUSION

The events of the Green Revolution and the Bali Irrigation Project have invoked major modification to irrigation set-up and cultivation techniques. Overall, the productivity of rice as well as the efficiency of the irrigation systems has been greatly increased. Yet momentarily the changes brought havoc to the subak and rice production in Bali. Variable yields, unprecedented outbreaks of pests and diseases, water shortages, and inter-subak conflicts marked the first years of the Green Revolution in Bali. Rice production recovered eventually and conflicts over water were settled. Other changes became permanent such as the transition from a rice-based economy to one dependent on cash and a capital-intensive market.

With the Bali Irrigation Project the government's attention has been turned more closely to the subak as a key organisation in producing rice in Bali. As the population continues to grow, further increase in rice production will be required and state intervention will certainly continue to ensure production meets the needs of its people. Projections of possible futures will be discussed in more detail in chapter 7 with one scenario contemplating the trend towards an agency-managed system.

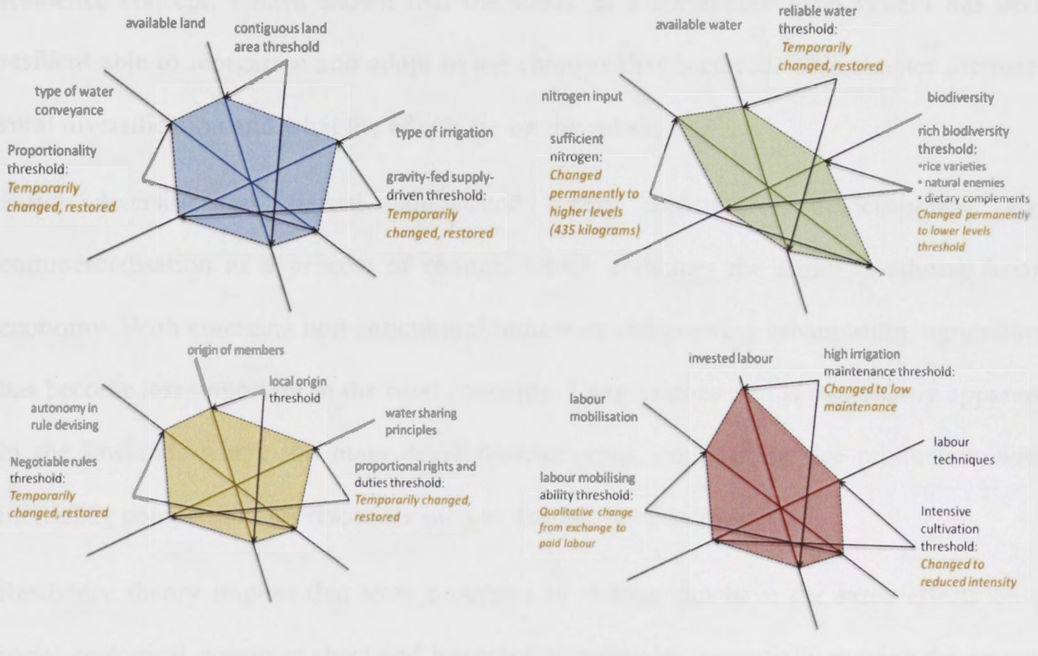

Figure 5.9: Green Revolution impact on thresholds in the four dimensions

Applying the concept of resilience to the subak, I argue that the subak as a social-ecological system was resilient to the Green Revolution disturbance. The temporary near-break down of rice production and efficiency of the irrigation system show that some thresholds of the basin of attraction were momentarily crossed (Figure 5.9). With the restoration of biodiversity levels and the basic principles that guide water allocation and distribution, the system was able to recover and reorganise. This reorganisation resulted in some of the thresholds being permanently changed. Yet the subak has retained its primary function and structures: it has returned to its identity as a highly productive and efficient rice production system. Nevertheless, with the permanent changes, the subak's positioning in the basin of attraction has moved. The use of pesticides continues to impact on the biodiversity threshold as does the trend for outsourcing maintenance work on the labour mobilisation threshold which will have to be carefully evaluated in any future studies of the subak's resilience.

CHAPTER 6

RURAL DIVERSIFICATION AND THE SUBAK

INTRODUCTION

The previous chapter discussed the major modifications to the irrigation and cultivation of rice in subaks that occurred as a result of the Green Revolution. With respect to the resilience concept, I have shown that the subak as a social-ecological system has been resilient able to reorganise and adapt to the changes that occurred. This chapter discusses rural diversification and what the effects are on the subak.

Rural diversification started concurrently with agricultural modernisation and commercialisation as a process of change, which embraces the entire Southeast Asian economy. With emerging non-agricultural industries and growing urbanisation, agriculture has become less important in the rural economy. Deagrarianisation is particularly apparent in the lowlands where the main developments occur, confronting rice production with increasing competition for resources such as, labour, land and water.

Resilience theory implies that slow processes of change can have the same effects on a social-ecological system as short and intensive disturbances, potentially moving the system out of the basin of attraction. The growing competition for resources relevant to the subak in conjunction with rural diversification is a less pronounced and much slower process of change compared to the modifications that took place as part of the Green Revolution. It is my intention in this chapter to illustrate that the subak as social-ecological system so far has remained resilient, and that thresholds are being approached but have not yet been crossed.

I begin with an introduction to rural diversification and deagrarianisation in Southeast Asia and its impact on agriculture and rice farming. In the second part, I examine the key challenges to the subak, namely the withdrawal of labour, water and land, using the field research subaks as case study. Considering my conceptual model of the subak as social-ecological system I assess the status quo of the thresholds that are affected by the resources withdrawal to locate the subak in the basin of attraction.

RURAL DIVERSIFICATION

In the past, agriculture constituted the main share of the rural economy, the principal source of rural income, employment and output. Other industries existed but were not as important or dominant. The term 'rural' used to be a synonym for agriculture in the context of Southeast Asia (Rigg 2003: 193–4). Rural diversification began in the 1960s concomitant to the Green Revolution as a process of change away from agriculture, substantially altering the structure of the rural economy and landscape in Southeast Asia (Booth 2002: 179; Dawe 2005b).[163] While the Green Revolution can be assigned to a specific period beginning in the 1960s and ending in the 1980s, rural diversification is ongoing.

The beginning of rural diversification was marked by the rapid growth of Southeast Asian economies, which saw the emergence of other industry sectors, encouraged by a more thorough integration into the world market. In Indonesia, growth was particularly strong in the mining, manufacturing and construction industries (Hill 1994: 61–5; Hayashi 2005: 41–3). The mining sector, for instance, was booming mostly because of a rapid expansion in oil production combined with high oil prices between 1973 and 1981 (Hayashi 2005: 41). The growth in the manufacturing and construction industry was also partly due to the new

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[163] Other terms used in this context are 'rural transformation', 'agrarian change' and 'agricultural transition'. 'Agrarian change' and 'agricultural transition' focus more narrowly on the processes that have evolved in the agricultural sector.

Green Revolution technologies, such as modern varieties seeds, agrochemicals, and farm machinery, which necessitated the establishment of a new industry for production, storage and transport. The agricultural sector likewise grew, though less rapid than other sectors (Hill 1994: 57; Dawe 2005b). Overall, while agriculture's share in Indonesia's GDP growth was still as strong as the service sector in the first years of the Green Revolution, its contribution to GDP growth shrank in the succeeding decades, with the industry and service sectors taking up the main share (Figure 6.1).

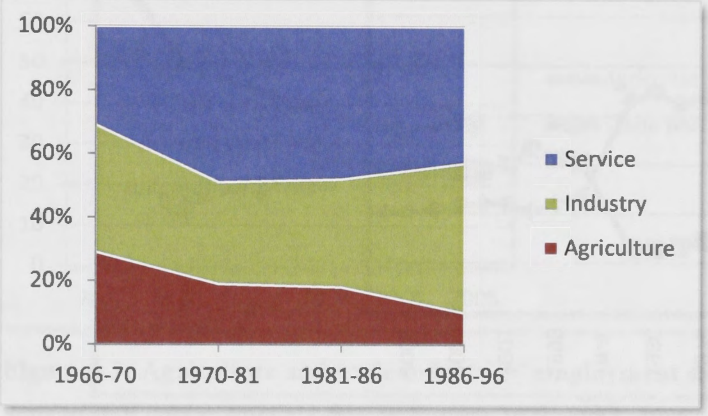

Figure 6.1: Sectoral contribution to GDP growth (weighted by respective sectoral shares), Indonesia, 1966-1996

Source: (Hayashi 2005: 42, table II)

In Bali, the diversification of the rural economy was encouraged by the arrival of mass tourism. Agriculture, until a few decades ago, the mainstay of the economy both in terms of GRDP (gross regional domestic product) and employment became less important. Between 1970 and 2006 agriculture's GDRP share declined from 66 to 20 per cent, while the workforce decreased from 61 to 36 per cent between 1976 and 2008 (Bendesa and Sukarsa 1980: 32–3; BPS Bali 2010b; BPS Bali 2010d) (Figure 6.2, Figure 6.3).[164] The trade

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[164] The Balinese statistics on GRDP differentiates nine economic sectors, which are 1) agriculture, livestock, forestry and fishery, 2) mining, 3) manufacturing, 4) electricity, gas and water supply, 5) construction, 6) trade, hotel and restaurant industry, 7) transportation and communication, 8) finance and business services, and 9) services. There are no aggregate data available with respect to the Balinese economy.

industry, on the other hand, which includes the largest segment of the tourism industry, has become the most important part of the provincial economy: its GRDP share rose from 7 to 29 per cent and its workforce from 12 to 23 per cent in the same period (Bendesa and Sukarsa 1980: 32–3; BPS Bali 2010b; BPS Bali 2010d).[165] Nevertheless, agriculture is presently still the second largest sector of the economy in terms of GDP and the biggest employer of the island.

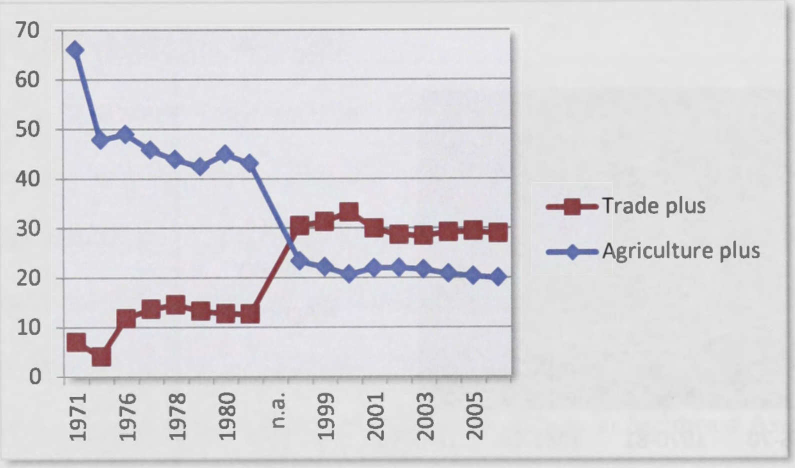

Figure 6.2 Agriculture and trade industries' GRDP share, Bali, 1971–2006
Source: Bali dalam Angka / Bali in Figures 1982, 2001, 2005, 2006, 2009 (online) (Bendesa and Sukarsa 1980: 33)

With agricultural modernisation and commercialisation, farmers shifted their focus from subsistence-oriented production towards a more specialised cash-crop production depending on the market. Agriculture became more diversified, although the degree of diversification as well as the focus on crops cultivated varies amongst Southeast Asian countries. In Indonesia agricultural diversification was less substantial compared to other countries, except for palm oil and cocoa, with food crops still dominated by rice (ibid. Hill

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[165] The GDP and employment numbers only partly reveal the real proportions of the tourism industry. The trade industry does, for example, not include businesses involved in tourism transport such as travel agencies or car rentals as well as many other tourist-related businesses (Pitana 2003a). A Balinese economist has estimated that, in 1998, in summary 51 per cent of people's income and 38 per cent of Bali's employment opportunities were directly linked with the tourist industry (Pitana 2003a: 1; Pringle 2004: 195).

1994: 72, 75). Nonetheless, the harvested area of non-rice crops has increased more rapidly than the harvested rice area and the share of rice in gross value production has been declining since the early 1980s (Figure 6.4, Figure 6.5). In Bali, rice is still by far the most important crop in terms of volume produced (production values are not available), especially in the lowland area (BPS 2005).

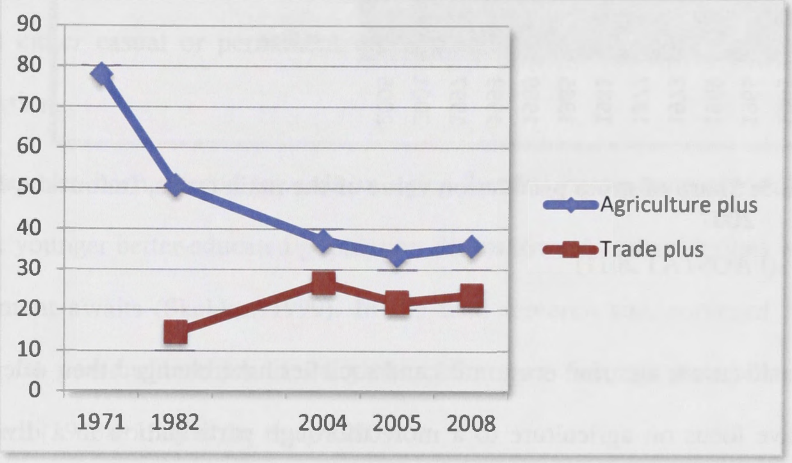

Figure 6.3: Agriculture and trade industries' employment share, Bali, 1971–2008
Source: Bali dalam Angka / Bali in Figures 1971, 1982, 2005, 2009 (online) (Bendesa and Sukarsa 1980: 32)

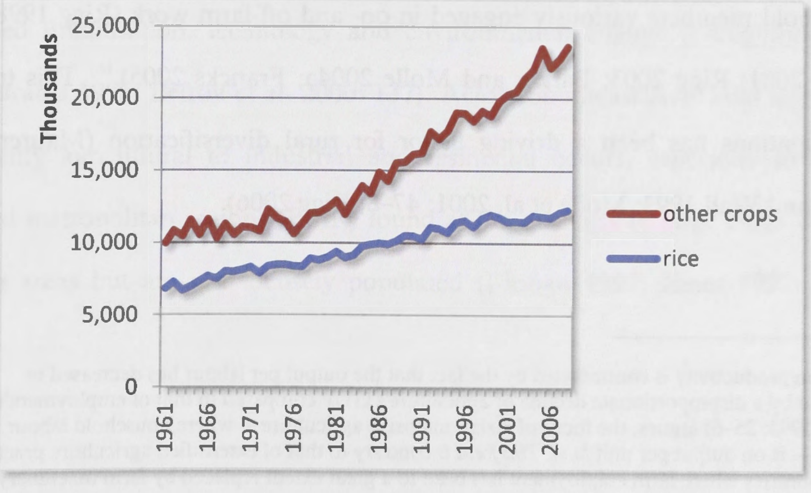

Figure 6.4: Harvested area development of rice compared to other crops, Indonesia, 1961–2007
Source: (FAOSTAT 2011)

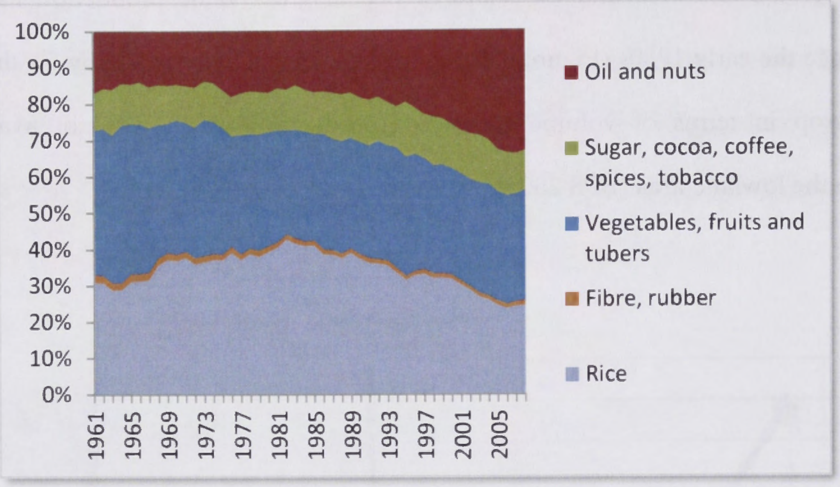

Figure 6.5: Share of gross production value of the main crops, Indonesia, 1961–2007

Source: : (FAOSTAT 2011)

With rural diversification, agrarian economies and societies have changed their orientation from an exclusive focus on agriculture to a more thorough participation in a diversified economy (Harriss 1982: 37; Elson 1997: 238). Intensive small-scale farms with high labour demand have, however, persisted and increased their land productivity (Harriss 1982: 37; Bray 1994: 1–8).[166] Increasingly, these small-scale farms operate on a part-time basis with several household members variously engaged in on- and off-farm work (Rigg 1998; Eder 1999; OECD 2001; Rigg 2003; Barker and Molle 2004a; Francks 2005).[167] This trend to multiple occupations has been a driving factor for rural diversification (Maurer 1991; Cukier-Snow and Wall 1993; Molle et al. 2001: 47–8; Rigg 2006).

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[166] This increase in productivity is contradicted by the fact that the output per labour has decreased in agriculture caused by a disproportionate decline of agriculture's GDP compared to that of employment's share. Yet, as Netting (1993: 25–6) argues, the focus of Asian intensive agriculture —where household labour is readily available— is on output per unit *land. This focus is* contrary to that of extensified agriculture practiced in many western countries where farm employment has been to a great extent replaced by farm machinery with the focus on output per unit *labour.*

[167] Part-time farming is possible because peak demands for agricultural labour are short-term and seasonal. This will be discussed more in detail in Chapter 6.

The official statistics on labour force in Bali say little about part-time farming.[168] However, an increased prosperity linked to the tourism industry has created a growing demand for tourist infrastructure construction, such as, for example, hotels, roads and shops, as well as local infrastructure which created plentiful off-farm labour opportunities for small-scale farmers. Although rice cultivation has never been abandoned, people's time and effort shifted from a single focus on agriculture to off-farm work in other sectors of the economy. In the field research site, a survey I undertook with 178 farmers showed that 42 per cent pursued either casual or permanent off-farm work, 46 per cent of which was work in construction.

There has also been a trend towards an aging farming community across Southeast Asia with the younger better-educated population drawn towards urban regions where well-paid employment awaits (Skeldon 1999). In the field research site, surveyed farmers are on average 54 years old which is 24 years older than farmers surveyed across Bali by Birkelbach (1973b: 156) in the early 1970s.

The process of deagrarianisation not only draws labour away from agriculture but also competes for land and water. The conversion of agricultural land to other uses is a global phenomenon linked to economic development, population growth, industrialisation, continued urbanisation, technology and environmental change (Houghthon 1994: 305; Alexandratos 1995; Lefroy et al. 2000: 137). Across Southeast Asia land use change from dominantly agricultural to industrial and residental occurs, especially in the so-called extended metropolitan regions (EMR) found at the outskirts of large cities which are rice growing areas but are also densely populated (Firman 1997; Jones 1997: 240; Firman 2000).

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[168] To gather workforce data, the Bali statistics office records what activities people have engaged in during the week previous to the census, which does not consider the fact that many Balinese are pursuing multiple jobs in different parts of the economy.

The conversion to non-agricultural land use is accelerated as it impacts on the remaining agricultural sector creating further incentives to sell farm land with farming becoming less profitable and land rents more attractive (Firman 1997: 1027–8). Although Indonesia's irrigated rice field area was still increasing until 1993, land conversion to industrial and urban development had already begun in the 1980s (Agus and Mulyani 2005). Much of the conversion occurred in Java with a total decline in irrigated rice field area of 8 per cent across Indonesia between 1993 and 2005 (Agus and Mulyani 2005).

In Bali, the heavily urbanised tourist areas and the growing cities such as Denpasar, Mengwi, and Tabanan have led to a increased loss of irrigated rice fields. All over Bali, the rapid urbanisation process has seen as much as 1,000 hectares of rice fields disappear per year and up to 3,000 hectares in 2003 (MacRae 2005b: 212).[169] Badung regency, the most economically active region in Bali, has lost 1,361 hectares (12 per cent) of irrigated rice fields in the last eight years (BPS Badung 2004; BPS Bali 2010a).

Another notable impact on land conversion is the rising land prices which create attractive alternative possibilities to working in the mud. In the five-year period from 1990 to 1995 per hectare land prices in coastal areas in south Bali rose from Rp500 million to Rp5,000–7,000 million (Rieländer 1998: 62).[170] Those who have rice fields adjacent to roads and in coastal regions especially have been tempted or opted to sell.

Competition for water has increased with rural diversification. Growing demands from non-agricultural entities such as potable water supply to urban areas and water for industries, in particular the tourism industry, are the main reasons for the increased competition. A recent revision report of the Bali 15-year spatial plan states that of 17 regional river basin units in Bali in which rice is planted, 12 experience water stress in the dry season and three suffer constant water stress (Anonymous 2002) (Figure 6.6).

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[169] Pitana 2004, personal communication.

[170] On 31 December 1995, 1 Australian Dollar was equal to Rp1,693 (Oanda, 2011. 'Historical Exchange Rates'. Viewed on 2/3/2011 at http://www.oanda.com/currency/historical-rates/).

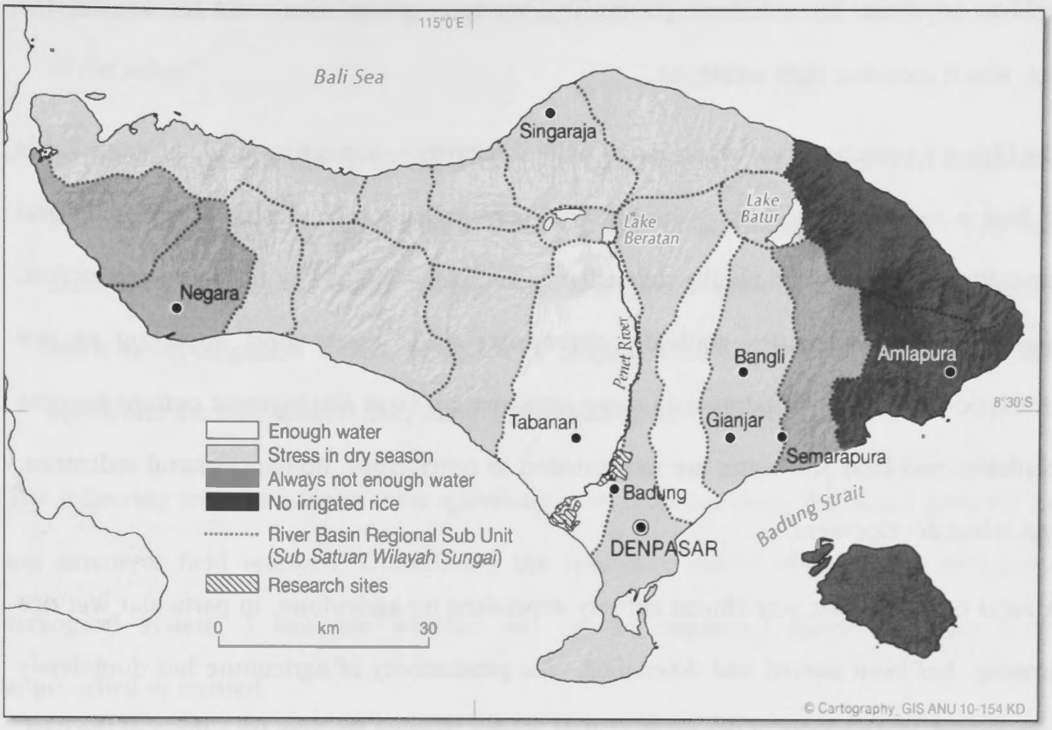

Figure 6.6: Regional river basin units and water situation for agriculture
Source: Bali Provincial Spatial Plan Revision (Anonymous 2002)

In addition to a decline in general availability of water there is also the obstruction and damage to irrigation canals that impairs water supply (Putu Suasta 2001: 44) as well as domestic, industrial and agricultural waste pollution.[171] Reports of water shortages and pollution have become more frequent.[172] One of the many issues raised is the consequence of excessive groundwater extraction, which has led to saltwater intrusion in groundwater in the densely populated coastal areas. A recent study on Bali's water balance concluded that with current demands the balance has nearly reached a critical stage (Purnama 2009).

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[171] Waste management is almost non-existent in Bali. Until a few decades ago, waste was of mainly organic nature disposed of in the natural environment. These days, a large percentage is inorganic waste. Although there are meanwhile many local initiatives underway for a more environmentally friendly waste disposal, the majority of people in Bali still discard their waste by either burning it or dumping it at places around the village, often on a slope near a river. Villagers in the field research site practiced both burning and dumping for there are no alternatives.

[172] See Introduction chapter.

Subak heads in one of my discussions mentioned the issue of waste and acknowledged the problem of plastic. There is more plastic clogging up irrigation canals and also littering the soil, which increases their workload.

The Green Revolution focused on issues of food security —increasing yields of staple foods to feed a rapidly growing population. With non-agricultural industries developing and agricultural production gradually diversifying, the focus shifts away from rice production. Non-agricultural industries gradually appropriate those assets most important to rice production: labour is withdrawn as more attractive off-farm employment options become available, and land and water are redistributed to other crops, non-agricultural industries, and urban development.

A rural economy that was almost entirely dependent on agriculture, in particular wet rice farming, has been altered and diversified. The productivity of agriculture has doubtlessly been raised, in particular in the south of Bali, where starving farmers are a thing of the past. Yet the trend to a declining focus on agriculture may result in less research and development in this sector. This reduced investment combined with the diminishing resources trend ultimately impinges on agriculture's productivity and a region's capacity to produce enough food. What are the implications for the subak given the current developments? There are three major issues that require further attention:

- With the diversification of the economy, new employment opportunities have arisen for farming households to take up. An emergent trend in Southeast Asia is part-time farming where households earn a living in both on- and off-farm work. How does this partial move out of agriculture affect labour mobilisation and the coordination of irrigation maintenance in the subak? And how does the farming household manage cultivation and irrigation of rice under these new circumstances?
- An increasing area of land is converted to urban and industrial infrastructure and prime agricultural land is irrevocably lost as the population and the rural economy expand.

Conversion of agricultural land usually occurs along roads cutting into subak land. Does this reduction and fragmentation of fertile rice fields affect any of the dimensions of the subak?

- Water shortages are due to be experienced as new stakeholders emerge who demand a share of water, be it for industrial or domestic use. Water is the lifeblood for wet rice farming; how does the subak manage with less water? With increasing urbanisation, often along irrigation canals, pollution of irrigation canals increases. How does the subak and the individual farmer manage this additional work load?

The following sections address these questions in more detail using the data I gathered in my extensive field research. Considering the resilience model of the subak as social-ecological system, I examine whether any of the suggested thresholds have been approached or crossed.

LABOUR

A diversified Balinese economy offers a range of off-farm and non-agricultural employment opportunities that are generally better paid. Salaries earned off the farm are up to four times the income earned with rice cultivation (Table 6.1). Particularly the younger generations are attracted to non-agricultural work which allows detaching themselves from the stigma of being a farmer, for farmers are seen as low-skilled and their work is considered dirty. They are usually better educated than their parents are and consequently have a better chance to get a regular job. Most jobs off-farm are, however, of a casual nature.

Table 6.1: Daily average rice farm returns and common wages in Badung, 2004–2005[173]

Type of work	*Rupiah*
Net return rice farming, landowner	19,250
Net return rice farming, sharecropper	12,850
Day labourer in agriculture	25,000-30,000
Day labourer, non-agriculture	35,000-40,000
Permanent off-farm	25,000-50,000

Source: Data collected in collaboration with S. Lorenzen

Table 6.2: Interviewed farmers – key statistics

Farmer survey	*n=178*
Average age	55
Rice production	
Average size of land cultivated	0.46 hectares
Average number of fields cultivated	1,5
Percentage of one-field-cultivators	65 per cent
Average size cultivated by one-field-cultivators	0.34 hectares
Percentage of two-fields-cultivators	22 per cent
Average size cultivated by two-fields-cultivators	0.61 hectares
Percentage of three-fields-cultivators	13 per cent
Average size cultivated by three-fields-cultivators	0.85 hectares
Off-farm work	
Percentage working off-farm	42 per cent
Average days off-farm per week	5.6
Average salary per day, in Rupiah	Rp36,340
Percentage of off-farm work in construction	46 per cent

Source: Data collected in collaboration with S. Lorenzen

The key statistics of farmers interviewed in the field research site show signs of rural diversification (Table 6.2). Forty-two per cent of the interviewed farmers work off-farm and on average 5.6 days a week, which is an indication that rice cultivation can be organised around other work off-farm and that part-time farming is common. That nearly half of the

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[173] On 31 December 2005, 1 Australian Dollar was equal to Rp7,172 (Oanda, 2011. 'Historical Exchange Rates'. Viewed on 2/3/2011 at http://www.oanda.com/currency/historical-rates/).

farmers we met in the fields are grandparents is an indication that their sons may be pursuing off-farm work while the grandparents look after the rice.[174]

To find out how farmers nowadays organise peak labour demands in rice farming and coordinate labour for irrigation system maintenance, I discuss three case study households, which are representative of the majority of the interviewed farmers in the field: they cultivate between one and two fields, which vary in size; and household members are to a varying degree engaged in rice production and off-farm work. The data for the two case studies is provided from a detailed time use survey over the course of one cultivation season with two different farming households.[175] My own recordings of labour invested into the cultivation of a rice field for two consecutive cultivation seasons (which I sharecropped together with my husband) serve as basis for the third case study. Participant observation and interviews with key stakeholders in irrigation complement the data.

- Case study A: Farming household A consists of three people involved in rice farming: a couple, aged in their mid-30s, and the husband's father, aged 60. They cultivate two fields (0.13 and 0.45 hectares) in two different subaks which are within walking distance from their home. In addition to rice farming, they also have cattle and pigs for which they gather fodder on the edges of the rice fields. The couple both work off-farm, he in a more permanent arrangement with a weekly average of 40 hours and she works, when work is available, in construction, on average 14 hours a week. Their children (aged eight and 13), and the husband's mother (aged 60) are not participating in any farm nor off-farm work.

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[174] Balinese households typically consist of a nuclear family, often including unmarried siblings and aged parents, who participate in household-income generating activities on- and off-farm. For more details on Balinese household structure, the reader is referred to other Balinese academic literature (S. Geertz 1959; Warren 1993; Hobart 1995; Jha 2004; Lorenzen 2008: 86–7).

[175] I have recorded and analysed time use data for a cultivation period of 126 days or 18 weeks altogether, including soil preparation.

- Case study B: Farming household B consists of a couple and the husband's parents. Both, husband and wife, aged in their early 30s, work off-farm on a casual but regular basis and do not engage in rice farming. The husband's parents who are in their mid-50s cultivate their two rice fields (0.15 and 0.52 hectares) in two different subaks. Both their fields are within walking distance from the village. They do not work off-farm. They do have cattle and pigs and need to gather fodder.

- Case study C: the rice field of 0.2 hectares in one subak that we cultivated represents a farming household where only one person is engaged in rice production yet also engages in casual off-farm work in the first three months of the cultivation season. The rest of the family pursues permanent off-farm work. Peak labour demands such as transplanting and weeding are organised with hired extra-household farm labour and the entire crop is sold before the harvest.

Labour input in to rice farming and irrigation

In chapter three I looked at the ata of labour invested into cultivation of rice across the Southeast Asian region. As discussed, this labour data is often fragmental due to a number of issues such as recording accuracy, conversion errors of measurement units, and unaccounted externalities.[176] In chapter four where I discussed labour in Bali, I suggested that labour investment is as intensive as in Java, ranging between 158 and 360 person-days per hectare before the Green Revolution. Green Revolution technologies have reduced this labour input by between 10 and 40 per cent (between 95 and 324 person-days), as discussed in chapter five. This data, however, does not always include or only partially covers management of irrigation on the farm-field level.

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[176] See chapter 3, Table 3.5.

A complicating factor in comparing labour input data in Bali is that farm households may cultivate more than one field. These fields are located in different munduks or subaks, are of varying size, and have different planting schedules. In the research site, interviewed farmers cultivated up to three fields, owned or sharecropped, with the average cultivating 1.5 fields and the majority (65 per cent) cultivating one field only (Table 6.2). The farm households of case studies A and B, for example, cultivate two fields, a smaller field which they own, and a larger field which they sharecrop. The two fields are located in two different subaks (subak Tegan and subak Dukuh) and the beginning of the planting season differs for the two fields in both cases by three weeks.

Given that the majority of farmers (65 per cent) cultivate one field only (Table 6.2: 'one-field-cultivators'), I disentangled the data of the two case studies A and B to make use of their labour input into both the cultivation of one field in one subak as well as labour into two fields in two subaks. The comprehensive (two fields) as well as the disentangled (one field) data from case studies A and B combined with the data of case study C (one field) allow for some further variation to illustrate a more representative picture of labour input into rice cultivation in Bali given the limited data set. The only other detailed example of labour input into rice cultivation I found was that from Java 25 years ago, which I have added for comparative reasons (Table 6.3: last column). To be able to compare the Bali and Java data sets, other labour, such as travel, supervision of labour and sales and purchase activities as well as communal subak labour, were separated (Table 6.3: sub-total labour).

The results of the analysis show that actual per-hectare labour input ranges between 100 and 250 person-days depending on field size and number of fields cultivated (Table 6.3: total labour). In three of the five cases, rice cultivation in the field research site is less intensive than in the Javanese case. Labour use is most intense for the smallest field (case study B, one field). This inverse relationship between holding size and labour input has been noted by other authors, too. They mainly relate to a much higher per hectare availability of family members on smaller holdings (Booth 1988: 116–7). This does not hold true for the case studies, for case study B operates with less people (two persons) than case study A (three persons) and C (one person plus hired labour). As I briefly discussed in chapter three, one of the reasons for the discrepancies are extrapolation errors: the smaller the fields, the less accurate the conversion to hectare units becomes.[177]

Table 6.3: Per-hectare person-day labour input into irrigated rice cultivation over one cultivation season, field research site, 2005 and Java, 1977-1980[178]

Activity (unit = person-days)	*1 field (0.15 ha) Case study B*	*1 field (0.2 ha) Case study C*	*1 field (0.45 ha) Case study A*	*2 fields (0.58 ha) Case study A*	*2 fields (0.67 ha) Case study B*	*Java, 1977-80*
Soil preparation and sowing	33.3	15.9	15.3	10.2	10.3	23
Transplanting	12.5	14.1	12.2	14.2	14.9	26
Crop management (CM)	113.3	100.5	49.7	37.9	40.3	52
Irrigation O&M field level	15.0	10.0	12.0	17.8	11.2	(part of CM)
Rice Rituals	16.7	11.3	7.4	3.4	3.7	n.a.
Harvest	6.7	0.0	9.2	3.4	1.5	43
Sub-total labour	***197.5***	***151.7***	***105.8***	***87.1***	***81.9***	***144***
Other	46.7	21.7	29.4	20.9	16.4	n.a.
Communal subak labour	3.3	2.8	6.6	5.1	0.8	n.a.
Total labour	**247.5**	**176.2**	**141.8**	**112.8**	**99.1**	**144**
thereof hired	**0.0**	**48.1**	**10.4**	**10.5**	**4.3**	**n.a.**

Source for Java example: (Barker et al. 1985: 126)

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[177] We also have to bear in mind that this data was collected over one cultivation season only, thus, variability in labour input across the samples is unavoidable. There is also the issue of accuracy of data recorded. Nevertheless, the Javanese case shows that overall the data recorded is in a similar range.

[178] The results presented here are derived from the time-use survey for case studies A and B for a dry season cultivation for 126 days or 18 weeks in 2005. Half-hour records were converted into eight-hour person-days. Case study C results represent the average of labour we invested in two cultivation seasons (wet and dry) between October 2004 and August 2005. 'Crop management' refers to fertiliser and pesticide application, weeding, and scaring of birds away the month before harvest to protect the rice grains on the panicles. 'Irrigation O&M' includes watering and drying the fields as well as repair and maintenance of irrigation canals, including clearing of weeds along the dykes on the farm-field level. 'Other' includes sales and purchase activities, supervision of hired labour, as well as travelling to and from the field. 'Rice rituals' involves preparation of offerings and performance of the ritual.

Other factors that influence labour input and cause variations in labour are: local climate and soil and irrigation infrastructure conditions, local crop management issues and water availability, the age of those working in the field, the field distance from home, time available to attend to a crop, harvesting arrangements, as well as whether a farmer holds an official subak position. In farm household A, for example, the grandfather spent most of his time in the rice field because he did not work off-farm. He also works slower than younger farmers do. He combined daily routine irrigation maintenance work with gathering of fodder along the dykes for his cattle.[179] Case study B spent more time for soil preparation (hoeing instead of using a tractor) and crop management (mainly weeding and chasing birds); and had to travel further to get to the field.[180] Also, in subak Dukuh water supply was short, which resulted in farmers spending more time in their fields to monitor water levels. Case study B, for example, invested significantly more time into irrigation management for their small field located in subak Dukuh (15 days). The grandfather in farm household A held an official subak position as a munduk head at the time of my research, which is the reason for a greater time investment into communal subak labour.

Overall, farmers spent most of their time in crop management: between a third to more than half of total labour input. Case study C (0.2 ha field) has used hired labour for ploughing, transplanting and weeding, while case study B has outsourced some of the transplanting and both case studies A and B have outsourced the ploughing of the fields. Between 3 to 8 per cent of the total labour (or between 4 and 9 per cent of sub-total labour) is used for ritual preparation and performance, which is significantly lower than the 15 to 30 per cent which Birkelbach (1973a: 101–2) estimated. With respect to irrigation

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[179] In fact, he fills one bag of grass in twice the amount of time a younger farmer usually requires.

[180] In smaller fields, hoeing by hand which is more labour-intensive often replaces the tractor for convenience reasons. Some farm households also choose to hoe larger fields. Choosing to hoe the field rather than let it be ploughed by a hired tractor operator is the preferred option in households where intra-household farm labour is readily available to save financial expenditure.

maintenance and operation, farmers in the field research site spent on average 10 per cent with a variation of 6–18 days.

Labour input into communal activities on the subak level, on the contrary, take up a small part of farmers' time, between one and five per cent or one to seven days respectively in one cultivation season. Communal workdays for the subak or munduk usually fall on a Sunday, which is when farmers are most likely not working off-farm. Time invested is in general related to field size —the bigger the field the more labour is required— which is measured in tenah or tektek (see chapter 4). A tenah services on average 0.5 hectares of rice field with water and requires one person to attend to communal work. Compared to the communal labour averages I have found in the literature (see chapter 3), which range between 20 and 80 person-days a year, communal subak labour for irrigation infrastructure maintenance and attendance of meetings and ceremonies is remarkably low. Given that a maximum of 2.5 crops are cultivated in one year, per hectare labour input into communal labour does not exceed 18 days a year (with an average of 9 person-days per hectare). This small workload is an indication that irrigation infrastructure is intact and functional.

Balinese farmers expended significantly less labour for harvesting compared to the Javanese sample. The reason is that in Bali, as discussed in the Green Revolution chapter, the tebasan system is standard for harvest and post-harvest handling of rice. Usually a small part of the crop is harvested by the farm household and brought home for their own consumption, and the rest is sold to the trader before the harvest. Accordingly, harvest labour is significantly reduced. Variations in harvest labour input depend on how much of the rice a household brings home and how much it sells. In some cases, the farm household sells the entire crop to the trader, such as the example provided with case study C. In the Javanese case the harvesting of the crop was presumably not outsourced, although there is no further explanation as to the details of the data.

The practice of selling the crop before the harvest is an economic decision for farmers. It saves them labour and money. Firstly, they do not have to invest labour into harvesting the crop, carrying the bags home and drying the rice for two days before selling it to the mill.[181] Secondly, the price they receive from the trader in the field is better than the price they would get at the mill (Table 6.4). Prices paid to farmers in the field depend on the trader's judgement of the quality of the standing crop, and the negotiation skills of the farmer as well as the field's distance from the road. Prices paid to farmers at the time of my field research ranged between Rp6–10 million per hectare. Even for fields that received the lowest price with a lower yield (Table 6.4: last two columns), farmers still got a good price, given that they did not have to invest any further labour. The disinclination of farmers to invest extra time for a marginally better price is presumably also a sign of rural diversification and the opportunities of off-farm casual and permanent work, which make it attractive to farmers to minimise their time spent in the rice field.

Table 6.4: Post-harvest farm economics

Price paid per hectare (in Rp1,000)	*10,000*	*8,000*	*6,000*	*6,000*	*5,000*
yield fresh (kg)	7,500	6,000	5,000	4,000	4,000
yield dried (kg) (85%)[182]	6,375	5,100	4,250	3,400	3,400
Price per kg dried rice	**Rp1,569**	**Rp1,412**	**Rp1,765**	**Rp1,471**	**Rp1,569**
Price range for dried rice at the mill, 2004–2005	Rp1,200–1,500				

The comparison of labour input into rice cultivation shows that Balinese rice cultivation is on average more labour-intense compared to cultivation elsewhere in Southeast Asia. Yet conclusions cannot be final as the data from the literature which I have listed in chapter 3 is

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[181] The drying at home entails further labour for spreading the grains in the sun, monitoring the moisture content and, in the evening, raking the grain together and repacking it into the bags.

[182] See also Fox (1993: 155) for more on conversion rates from freshly harvested rice to milled rice.

unclear about the degree of detail that has been included or omitted. If labour input into travel and irrigation management is deducted from the Balinese case studies, labour input is similar to that of other countries. With the use of the tebasan system for the marketing of the rice a substantial labour investment at harvesting time has obviously been eliminated.

Off-farm work and rice cultivation

The question remains however, whether rice cultivation can be organised in a way that household members can pursue off-farm work concurrently to growing rice. Transplanting, weeding and harvesting are the most labour-intensive tasks in rice cultivation and need to be undertaken within a short time frame at specific times in the cultivation cycle.[183] For instance, farmers usually weed their fields shortly before transplanting the seedlings, and before fertiliser is applied (which is done twice) in order to prevent weeds from profiting from the fertiliser.

To find out how rice cultivation is organised over one cultivation season I examined labour input per household member and weekly labour input into the cultivation of rice. Of the total labour invested into rice cultivation, household members of each of the three case studies contribute on average between 26 and 32 days of total labour over a 126-day cultivation cycle (Table 6.5). This average labour input per household member already shows that rice cultivation, with weekly labour input ranging on average between 1.4 to 4.2 days, does not require daily full-time attention.

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[183] Hand-held tractors have considerably reduced time into soil preparation. Where land is hoed by hand, which is more time-intensive, it is usually a smaller field, at the edges of fields or where labour is plentiful but there is less cash at hand to pay the tractor operator.

Table 6.5: Average weekly farm labour input into rice cultivation, case studies, 2004–2005

Case study	*Size (hectares)*	*Total labour input (person-days)*	*(outsourced)*	*Farm Labourers*	*Average labour input / person*	*Average weekly labour input*	*Average weekly labour input / person*
A	0.58	77	8	3	26	4.2	1.4
B	0.67	64	2.5	2	32	3.6	1.8
C	0.2	26	10	1	26	1.4	1.4

Each farm household organises their labour allocation to rice cultivation over the 18 weeks differently (Figure 6.7, Figure 6.8, Figure 6.9). In both case studies A and B, one farm labourer invests most of his time while other farm household members join in for tasks that are more specific. Daily attending to the crop usually requires less physical labour while specific tasks often involve heavier labour, such as hoeing, transplanting, weeding, carrying bags of fertiliser to the field and harvesting. Activities that require presence but are less physically straining are not outsourced to hired labour and are often undertaken by older household members, which is being practiced by case study A. The only gender-segregated activities in the rice field are pesticide application (by men only) and rice rituals (by women only).[184]

Peak labour demands were identified using weekly averages and standard deviations combined with and verified by participant observation in the field. Accordingly, a common peak labour demand period is the time of transplanting (case study A: weeks 3 and 5, case study B: weeks 4 and 6, case study C: week 6) and harvesting for case study A and B.[185] Case studies C and B used hired labour for peak demands while case study A used household labour. Case study A only used hired labour for the ploughing of one of their fields.

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[184] Of course, there are exceptions to the norm.

[185] Peak labour demands were identified visually and using weekly averages and standard deviation (all weeks above the sum of the weekly average and the standard deviation) combined with and verified by participant observation in the field.

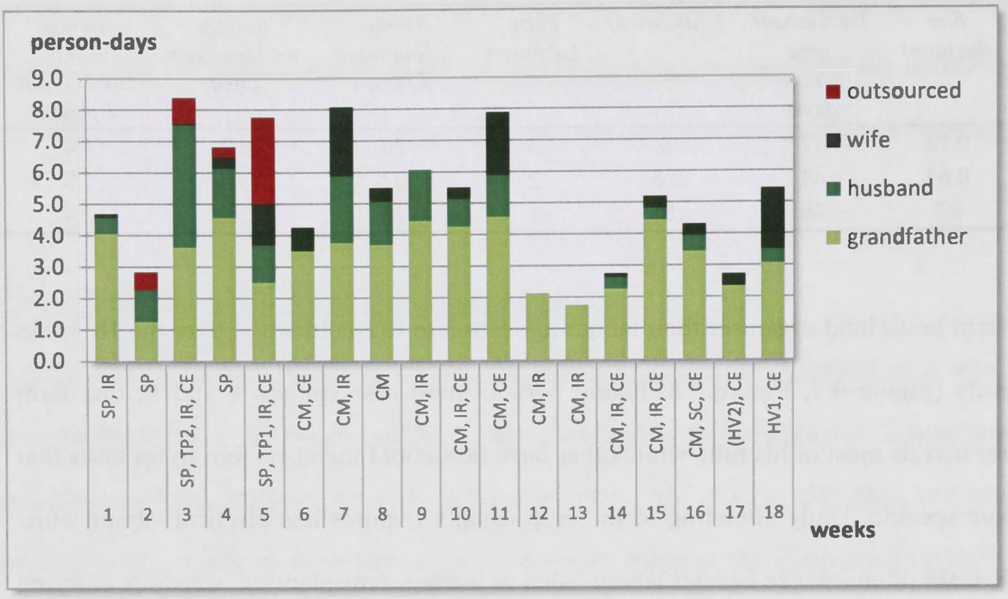

Figure 6.7: Weekly labour input, case study A (2 fields, 0.58 hectares), dry season 2005[186]

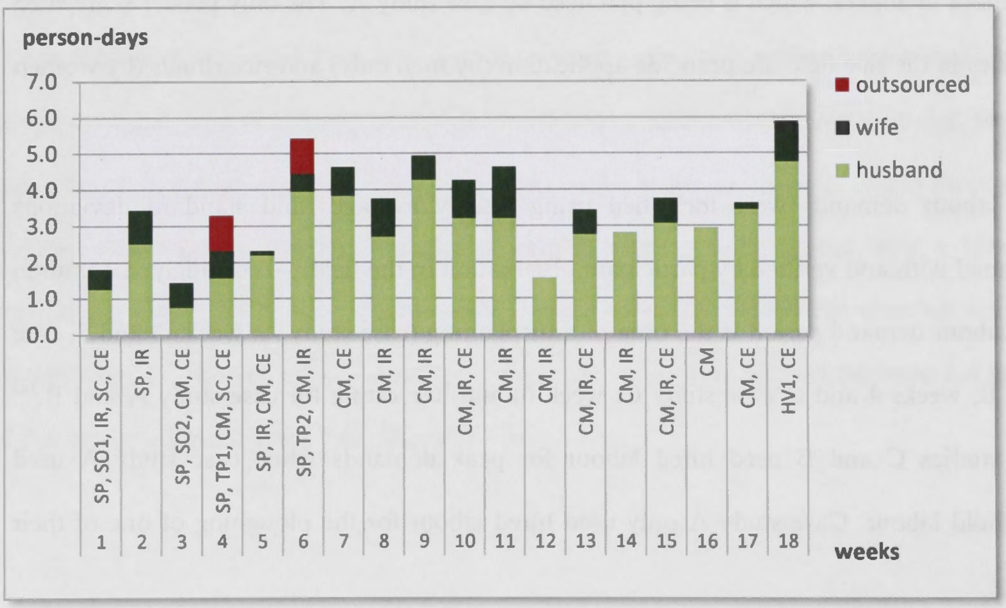

Figure 6.8: Weekly labour input, case study B (2 fields, 0.67 hectares), dry season 2005[187]

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[186] SP: soil preparation, IR: irrigation management on the farm-level, TP2: transplanting of secondary field, CE: rice ritual, TP1: transplanting of main field, CM: crop management, SC: subak communal labour, (HV2): outsourced harvesting of secondary field, HV1: harvesting of main field.

In the field research site, the ploughing is undertaken by male tractor operators, either from within the subak or travelling from other areas. Other extra-household labour requirements are organised by hiring agricultural wage labourers. These wage labourers are usually women from the same village of poorer households or those who cannot find non-agricultural work off-farm. Women are the preferred labourers for transplanting and weeding because they charge less than men. At the time of my field research, the average daily wage for men was Rp35,000 while women cost only Rp25,000 a day. Harvesting is organised through the tebasan system. These teams, organised by the trader who bought the crop, consist often of male and mixed-gendered migratory labourers mainly from Java. To some extent, there are also local women groups that harvest fields, paid in piecework (instead of a daily wage, they are paid per kilogram rice harvested).

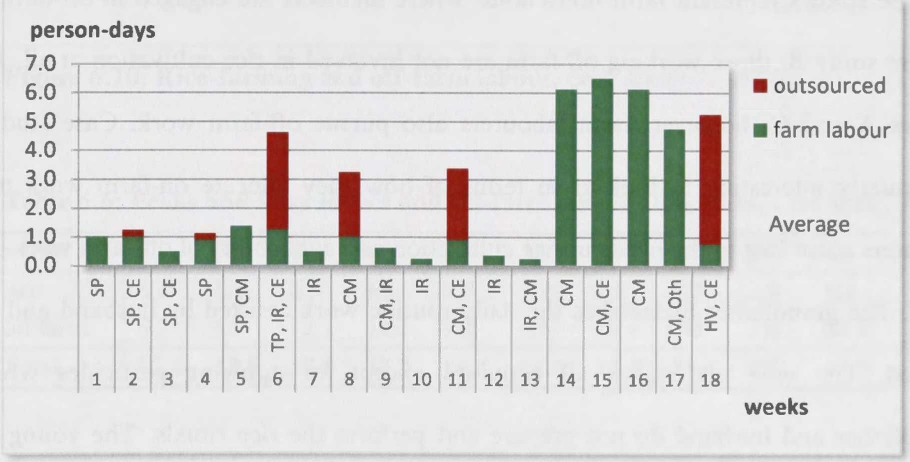

Figure 6.9: Weekly labour input, case study C (1 field, 0.20 hectares), wet season 2004–5[188]

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[187] SP: soil preparation, SO1: Sowing of main field, IR: irrigation management on the farm-level, SC: subak communal labour, CE: rice ritual, SO2: sowing of secondary field, CM: crop management, TP1: transplanting of main field, TP2: transplanting of secondary field, HV1: harvesting of main field.

[188] SP: soil preparation, CE: rice ritual, CM: crop management, TP: transplanting, IR: irrigation management on the farm-level.

Both case studies A and B have one household member doing the larger share of work in the rice field; and in both cases, they are older and are not engaged in off-farm work. They undertake the daily routine work, such as weeding, monitoring of water levels and quaternary canal maintenance. This routine work is often combined with other activities, such as attending to dry land crops and gathering fodder for cattle or pigs. Case study C spends less time on daily routine work, for the rice cultivator in the household pursues casual off-farm work in the first three months of the cultivation season, which explains the lower average weekly input. Case study C's labour investment increased in the last month before the harvest. The reason for this sharp increase is that once the rice is ripening on the fields, birds need to be scared away for they otherwise start eating the grains. This labour-intense time requires less physical work but more importantly presence, and is usually combined with other activities in the field.

All case studies represent farm households where members are engaged in off-farm work. In case study B, those working off-farm are not involved in rice cultivation at all. In case studies A and C, however, farm labourers also pursue off-farm work. Case study A is particularly interesting to look at in terms of how they allocate on-farm work to farm labourers according to the needs in rice cultivation and availability of off-farm work (Figure 6.10). The grandfather undertakes the daily routine work assisted by husband and wife if needed. The wife undertakes all activities except for applying pesticides while the grandfather and husband do not prepare and perform the rice rituals. The young couple organise their workload on- and off-farm depending on upcoming tasks on-farm and available work off-farm. The husband works in the rice field when heavy physical work needs to be done, such as transplanting or weeding. Towards the end of the season, he almost no longer participates, as all the work is less physically demanding and there is less work to do. The wife spends the least amount of time in the field. In the first few weeks of the cultivation cycle she was also busy with ceremonial work so she did not work on- nor off-farm. She increased her off-farm work at a time in the second last month of the rice cultivation season, when work on the rice field is mainly routine work.

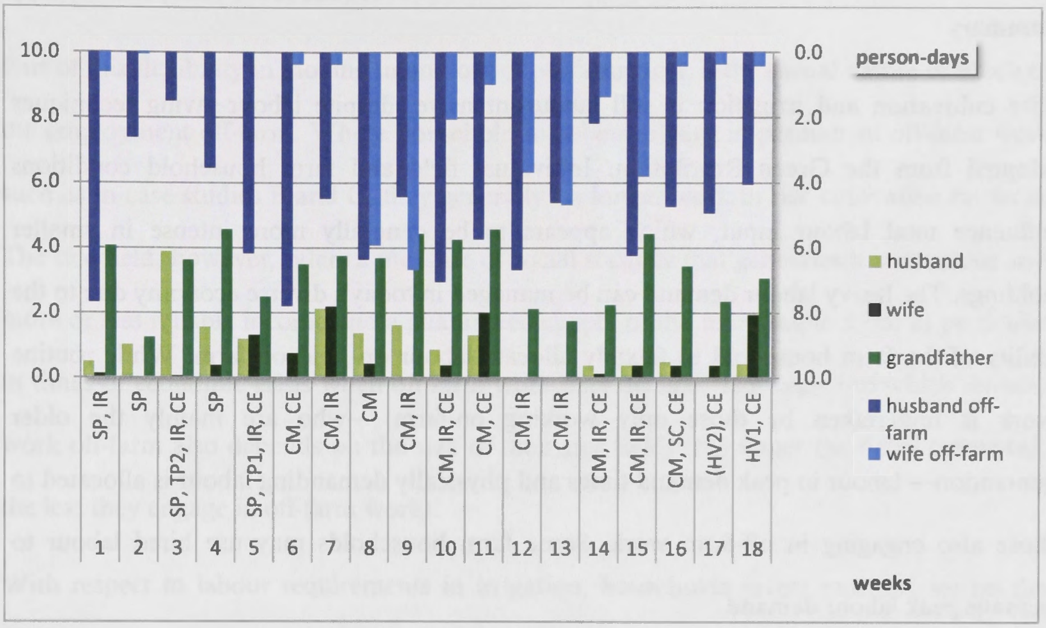

Figure 6.10: Rice-farming and off-farm labour, case study A, 2005

Table 6.6: Peaks and lows in rice and off-farm labour allocation, case study A

weeks	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*
rice	4.3	8.1	5.5	6.1	5.5	7.9	2.1	1.8	2.8	5.2
off-farm	8.2	4.9	12.3	11.1	9.1	6.8	10.4	9.3	3.6	10.1
Total	**12.4**	**12.9**	**17.8**	**17.2**	**14.6**	**14.6**	**12.5**	**11.1**	**6.3**	**15.3**

The couple's off-farm work is particularly adjusted in weeks six to fifteen (Table 6.6). In weeks three, four, seven, nine and eleven, labour demand in rice cultivation is increased to 7.2 person-days on average. Off-farm work is accordingly lower with on average 4.2 person-days off-farm. In weeks eight to ten and twelve to fifteen, labour demand in rice cultivation is lower (4.1 person-days), therefore off-farm work is increased to 9.4 person-days on average. In weeks eight to ten, twelve, thirteen and fifteen, both husband and wife engage in more off-farm work at the time when less physically strenuous labour is needed in the rice field.

Summary

Rice cultivation and irrigation is still labour-intensive, despite labour-saving techniques adopted from the Green Revolution. Individual field and farm household conditions influence total labour input, which appears to be generally more intense in smaller holdings. The heavy labour demand can be managed in today's diverse economy due to the ability of the farm household to flexibly allocate labour on- and off-farm. While routine work is undertaken by those only working on-farm —who are mainly the older generation— labour in peak demand times and physically demanding labour is allocated to those also engaging in off-farm work. Some farm households may use hired labour to manage peak labour demand.

The comparison of the three case studies shows that there are variations in how labour is allocated to household members. For instance, the extent to which farmers do daily routine work depends on crop-related conditions in the field as well as varying time constraints due to other activities that are not related to rice farming, and personal preferences. These variations give an indication of individual preferences and the availability of time. This capability of coordination and flexibility in allocation of labour is characteristic of smallholder households, which has been emphasised by several authors (Netting 1989; Wilk 1991; Eder 1993; Netting 1993; Bray 1994; Eder 1999). Netting (1989: 229), for instance, points out that household members of a smallholder farm are not only readily available and highly skilled but also work better and more effectively than wage labour because of their direct attachment to the household and direct dependence on the farm's performance. Everyone is able to perform every task within the constraints of time and availability. Part-time farming persists not only because of new technologies reducing labour input on-farm but also because of the competitive advantage of the flexible organisational structure of the farming household, which allows for a continuation of crop cultivation as a side business alongside the household's participation in several off-farm opportunities (Eder 1993: 665; 1999: 7–9).

Part of this flexibility in moving in and out of off-farm work is the casual nature of much of the employment off-farm. Where household members engage in permanent off-farm work such as in case studies B and C, they generally no longer work in rice cultivation on-farm. The rice field, however, offers a measure of social security that generates a continuous and more or less reliable income and a guaranteed supply of the main staple food, in particular in times of economic crisis when off-farm work may decline. The degree to which farmers work off-farm also depends on the size of their rice fields (the larger the fields cultivated, the less they engage in off-farm work).

With respect to labour requirements in irrigation, households invest most labour on the farm-field level while only little labour is invested on the subak and munduk level. Labour commitments on the subak level are given and cannot be influenced by the individual farm household. Labour input on the farm-field level, on the contrary, depends solely on the farm household's decisions in the allocation of labour. Water supply to the fields is one of the crucial aspects in determining the yield. The less time is invested, the more the farm household risks a decrease in yield. Consequently, those who can afford that extra time do invest it. The minimal labour required for subak duties shows that the subak merely provides a supportive framework to allow farmers to manage rice production as smoothly as possible, assuring continuous access to irrigation water, crop protection by setting cropping schedules and performance of rituals, and a functioning irrigation system through joint maintenance and operation responsibilities.

Concerning my model of the subak as social-ecological system, there are no indications that any of the technical thresholds are being approached. Although average labour input into rice cultivation is still high —128 person-days per hectare or 154 if other labour is included— labour coordination on the farm-field level is flexible and allows pursuing off-farm work. Labour input into subak work is low, averaging 3.7 person-days per hectare and cultivation season or 2 per cent of total labour invested.

WATER

To investigate the current water situation in the field research site, I analysed crop irrigation water needs and data for water supply to the subaks. I looked at farmers' and subak heads' perception of the water situation and current water sharing practices. In chapter 3 I discussed gross rice irrigation water needs —which include return flows and irrigation scheme efficiency— to range between 1,688 and 2,313 millimetres and net rice irrigation needs at 1,250–1,598 millimetres per cultivation season using references from the literature (table 3.2). For the field research site, I recalculated net and gross rice irrigation water needs for a dry season cultivation of 122 days (when water supply is less abundant), considering local climate data such as wind, rainfall and mean temperature as well as crop growth stage, to estimate average seasonal, daily and monthly net irrigation water needs.[189] The net irrigation water needs (IN_{net}) in the field research are lower than the referenced ones (Table 6.7: average).[190] One reason being, that those from the literature include a variety of environments and climates whereas the calculations made here are location-specific to south-central Bali.

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[189] I mainly used FAO Irrigation manuals No. 3, 4 and 6 as a basis for the calculations (Brouwer and Heibloem 1986; Brouwer et al. 1989; Brouwer et al. 1992). The calculations for rice crop evapotranspiration consider annual daytime hours, mean temperatures, effective rainfall, and the rice crop factor for a humid climate with little wind. A standard rice crop grown in the dry season has a cultivation season of four months which includes one month of soil preparation and three months from transplanting to harvesting. I assumed 200 millimetres to obtain soil saturation and 100 millimetres to maintain standing water levels. I used a rate of 5 millimetres per day for water loss through soil percolation.

[190] The irrigation water needs include water required to saturate the soil for the ploughing and for the establishment of a standing water table in the rice field which I have assumed at a total of 300 millimetres.

Table 6.7: Average dry season net irrigation water needs, field research site, April to September

Dry season IN_{net} (mm)	*season*	*monthly*	*daily*
Average	968	238	7.9
Subak Tegan, April to September 2005, soil preparation: 24/4 – 22/5/2005, harvesting: 25/8 – 22/9/2005	1,159	283	9.4
Subak Dukuh, April to September 2005, soil preparation: 31/3 – 14/4/2005, harvesting: 1/8 – 15/8/2005	952	236	7.9
Estimated average (chapter 3)	1,424	356	11.7

The rice crop irrigation needs do not yet include the staggering of the planting season which is often practiced in subaks. The data for the dry season cultivation in subak Tegan and Dukuh in 2005 considers the staggering (Table 6.7: subak Tegan and subak Dukuh). In subak Tegan those near the top-end plant two weeks ahead of those in the middle while those at the lower end plant four weeks later than the top-enders. In subak Dukuh the transplanting spans a two-week period. Demand in subak Tegan is higher, presumably, because the staggering stretches over a longer period and so do requirements for soil saturation and maintenance of standing water levels.

To find out whether water supply in the field research site is sufficient, I examined water flows in the irrigation network. I used data measured by the Public Works Department at the three dams Penarungan dam, Kapal dam and Munggug dam of the (Figure 4.2: wider context and main research site). I also took my own water flow measurements at the upstream end of the secondary canals of the main field research site subaks between May to November 2005, covering almost the entire cultivation period for that season.[191]

The daily and monthly water supply data calculated from measured river intake at the dam shows differences between the irrigated areas from the three dams (Table 6.8). Water intake

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[191] See appendix II for details on water flow measurements.

at Kapal dam is the lowest on average compared to upstream Penarungan dam and downstream Munggu dam. Supply variations (standard deviation) are in the range of 20–25 per cent. My own water flow measurements indicate that for subak Dukuh and subak Tegan, the conveyed water is slightly higher than the average intake at Kapal dam. Also, subak Dukuh receives more water than subak Tegan. Possible reasons for variations are uneven distribution at the diversion weirs, yearly water intake variations and accuracy of measurements. A study on water flows to subaks undertaken in South East Bali in 1997–1998 arrived at similar results with a daily average of 24.2 millimetres per day and a standard deviation of 7.8 (Lansing et al. 2009: 116–7).[192]

Table 6.8: Average monthly and daily dry season water supply at the dam and subak intake

Dry season April to September (mm)	*monthly*	*StDev**	*daily*	*StDev*
Penarungan dam, 1995–2005	714	±208	23.4	±6.9
Kapal dam, 1995–2005	536	±112	17.6	±3.7
Munggu dam, 1995–2005	625	±141	20.5	±4.6
Subak Tegan, May to September 2005	552	±105	18	±3.4
Subak Dukuh, May to September 2005	687	±63	22.5	±2.0

*StDev stands for standard deviation, a measurement for the range of variation from the average

Before getting an idea of the supply and demand ratio, we still need to consider water delivery efficiency. As discussed in chapter 3, irrigation scheme efficiency for good systems ranges between 50 and 60 per cent. Irrigation scheme efficiency is estimated by considering conveyance efficiency (e_c) —which considers water loss in the canal network through evaporation, percolation, seepage, overtopping, bund breaks and run-off— and application efficiency (e_a), which considers water loss in the field (Brouwer et al. 1989). I assumed conveyance efficiency for lined canals at 95 per cent and for earthen canals at 75 per cent,

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[192] Converted from litres per second and hectares to millimetres per day by a factor of 8.64.

considering a mixed clay and loam soil type, and application efficiency at 60 per cent for surface irrigation using the referenced indicative values (Brouwer et al. 1989). With respect to the Kapal irrigation network I calculated an irrigation scheme efficiency of 45 per cent, given that only a small part (4 per cent) of the total length of irrigation canals is lined (Table 6.9).

Table 6.9: Kapal irrigation scheme efficiency

Canals	*length (m)*	*% total scheme*	*lined (%)*	*Conveyance efficiency (e_c)*	*Application efficiency (e_a)*	*Total efficiency ($e=e_c*e_a/100$)*
Primary	2,307	2	22	2		
Secondary	15,182	16	22	13		
Tertiary	7,977	8	0	6		
Quaternary	71,210	74	0	55		
Total	96,676	100	4	76	60	45

Table 6.10: Monthly gross crop irrigation needs (IN_{gross}) and supply at Kapal dam

	Lowest	*Highest*	*Average*
Net crop irritation needs (IN_{net}) (Table 6.7)	236	283	260
Gross crop irrigation needs (IN_{gross}) (including 0.45 e and 0.26 return flow)	388	465	428
Intake at Kapal dam, 1995-2005 (Table 6.8)	424	648	536
Water balance	**36**	**183**	**108**

To obtain the gross amount of water that is required to be delivered by the irrigation system to cover crop irrigation water needs (IN_{gross}), we have to make provisions for irrigation scheme efficiency as well as return flows. Downstream subaks usually profit from excess, borrowed or off-flow water from upstream neighbouring subaks as well as local springs. This is considered vital to make up for any deficit caused by conveyance losses (Lansing et al. 2009: 117). The actual supply at Kapal dam appears to be sufficient for a dry season crop (monthly gross rice irrigation water needs (IN_{gross}) are smaller than intake at Kapal dam), unless the lowest supply meets the average or highest gross rice irrigation water needs (Table 6.10).

Monthly gross crop irrigation needs (IN_{gross}) over one cultivation season compared with water supply for subak Tegan and subak Dukuh show that for the peak season in subak Tegan, water demand is nearly equal or higher than supply, while for subak Dukuh supply is more than sufficient (Table 6.11, Table 6.12, Figure 6.11). These numbers have to be treated with caution as we assumed efficiency (at 45 per cent) and return flow (at 26 per cent) to be the same for all the subaks of the Kapal irrigation system, however this may vary.

Table 6.11: Monthly crop irrigation needs and actual supply, Subak Tegan dry season 2005

mm/month	*April*	*May*	*June*	*July*	*August*	*September*
	Transplanting: 24/4 – 22/5/2005, harvesting: 25/8 – 22/9/2005					
Gross crop irrigation needs (IN_{gross})	0	135	562	579	479	133
Actual supply	n.a.	643	598	555	517	446
Water balance	n.a.	508	36	*–25*	20	313

Table 6.12: Monthly crop irrigation needs and actual supply, Subak Dukuh dry season 2005

mm/month	*April*	*May*	*June*	*July*	*August*	*September*
	Transplanting: 31/3 – 14/4/2005, harvesting: 1/8 – 15/8/2005					
Gross crop irrigation needs (IN_{gross})	92	433	497	394	0	187
Actual supply	n.a.	714	680	665	631	745
Water balance	n.a.	281	183	271	631	558

The seasonal fluctuations in water needs also show that cultivation in subaks is synchronised, that is, all farmers plant at the same time or in a short period of time, usually between two to four weeks.[193] Water flow measurements show that water supply for subak Dukuh increases again in September (Figure 6.11). This increase is because subak Dukuh got ready for the next planting season, therefore required water to saturate the soil for the ploughing.

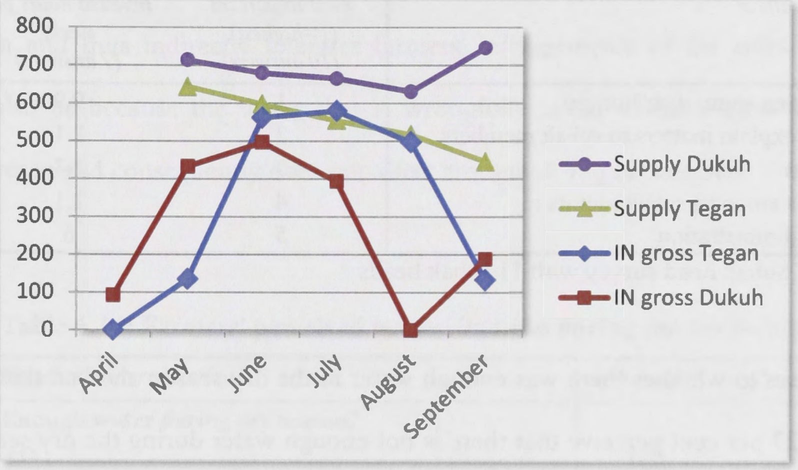

Figure 6.11: Seasonal fluctuations in water supply and gross crop water demand (IN_{gross}), subak Tegan and Dukuh, dry season 2005 (mm/month)

The analysis of the water supply measurements shows that there appears to be sufficient water available for (most of) the cultivation season to cover crop irrigation water needs for subak Dukuh with water shortages in July for subak Tegan. To complement the measured and estimated data, I investigated subak heads and farmers directly to find out what the general perception of the water situation is in the subaks of the field study area. Increased water use by other industries was considered the most pressing issue by six out of eleven subak heads and nine out of fifteen recorded that water availability was less compared to 20 years ago. Subak heads regard monitoring water distribution as the most time-consuming

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[193] Synchronisation allows breaking the pest cycles and is also convenient with respect to the performance of required rituals. In the main planting season there are more rituals that need to be performed and many of these are organised by the subak head, while in other planting seasons rice rituals are only carried out on the household level.

task and invest up to 9.9 hours on average in water control (Table 6.13). The head of Subak Perang/Serobian indicated he invested up to 42 hours a week to control the water situation, while others invest seven to eight hours a week.

Table 6.13: Subak heads' time spent dealing with subak matters

Subak *matters*	*most important (1=highest), (10 answers)*	*invested hours per week, (7 answers)*
Monitoring water distribution	1	9.9
Clarify/explain matters to subak members	2	2.1
Meetings	3	2.3
Conflicts amongst subak member	4	1.1
Subak administration	5	6

Source: Subak head survey with 11 subak heads

Farmer responses to whether there was enough water in the dry season showed that of the 178 surveyed, 27 per cent perceive that there is not enough water during the dry season to cover their needs (Table 6.14). Accordingly, of these 27 per cent nearly half believe (47 per cent) that generally water is not enough for the size of the subak and a further 28 per cent think that fields further upstream take too much water. Other reasons for water stress in the dry season given are bad infrastructure (15 per cent), bad management (9 per cent) and non-agricultural water use (2 per cent). The results of the survey do show that there is concern about the water situation.

When talking directly to farmers and subak heads in the field study area, subak Dukuh and the munduks in the most southern part of subak Tegan are those that experience water shortages in the dry season.[194] Two munduks at the tail end of subak Tegan are located south of the main road between Denpasar and Gilimanuk on either side of a road cutting south. There is substantial and continuing development along the two roads. This part of subak Tegan experiences difficulties in accessing sufficient water for the planting season,

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[194] Subak Perang also experiences water shortages. Here the focus shall remain on the main subaks for which I gathered most detailed research data, which are subak Dukuh and subak Tegan.

which commences up to a month after the other munduks north of the main road. One of the farmers whom I talked to has resorted to pumping water into the field from a nearby canal which carries water for other subaks. He argues that otherwise he would not be able to harvest a good rice crop. Pumping water from other irrigation canals is an act of stealing water. The subak head was aware of the difficulties that this part of the subak has with water and knows that farmers infringe the rules but says he has few options to change the situation and thus indirectly tolerates farmers' infringements of the rules. His passivity might also be because the water that is wrongfully taken irrigates other subaks further downstream and consequently does not affect any subak Tegan members.

Table 6.14: Farmers' perceived water situation during the dry season

Perceived water situation	*Answered*	*Percentage*
Enough water during dry season?		
Yes	130	73
No	48	27
Comments about water stress		
Water is not enough for the size of the subak	22	47
Rice fields upstream take too much water	13	28
Infrastructure is in bad shape that causes water stress	7	15
Water stress caused because of bad management	4	9
Other non-agricultural water use	1	2
Total of farmers who commented on water stress	47	26

Source: Farmers' survey, 178 farmers interviewed, data collected in collaboration with S. Lorenzen.

Figure 6.12: Subak Dukuh, irrigation canals and Panglan hamlet to the north

Source: Map prepared in collaboration with K. Dancey and S. Lorenzen

The experience of water shortage is somewhat surprising in the case of subak Dukuh, considering the calculated water needs and supply, which showed that this subak receives more than enough water. There are however a few factors that might explain the reasons, such as lower return flows and larger conveyance losses than estimated. There are no adjoining subaks to the north of subak Dukuh for possible return flows. Conveyance losses are assumed to be higher because the secondary canal first conveys the water through a settlement area before any of the rice fields are entered (Figure 6.12). Also, the main canal follows the road that dissects this subak. Along this road, land conversion from rice fields to settlement or small industrial areas has been taking place. The many small businesses springing up along the road specialise in local stone masonry and build altars for temples out of cement. Although it is prohibited to use irrigation water for other purposes, it happens all the time (Figure 6.13). These businesses also dispose of their waste into the canal system. The subak Dukuh head laments that he is constantly reminding businesses not to use the water.

Figure 6.13: Water withdrawal (white arrow) and waste disposal by cement businesses

To get an idea of how much water is being consumed by domestic and industrial uses, I have made some rough calculations of the water situation in subak Dukuh between May and September 2005. Data on agricultural, industrial and domestic water use shares are limited. One study estimates industrial usage at 10 per cent, domestic use at 8 per cent and agricultural use at 82 per cent in low- and middle-income countries (UNESCO 2010). Using these figures as a guideline for non-agricultural water use in the field research site and considering a lower water return flow as discussed above—assumed at 10 per cent instead of 25 per cent— I estimated the water balance for a 10 per cent and a 20 per cent reduced supply (Table 6.15). These calculations show that possibly actual water supply in subak Dukuh is much lower. In June 2005, the margin between water supply and crop water needs becomes particularly small or even minus in the case of a 20 per cent industrial and domestic water withdrawal.

Table 6.15: Subak Dukuh gross crop irrigation needs and actual supply, dry season 2005

mm/month	*May*	*June*	*July*	*August*	*September*
Gross crop irrigation needs (IN_{gross})	433	497	394	0	187
Reduced water return flow (10 per cent)					
Gross crop irrigation needs (IN_{gross}')	527	604	479	0	228
Water balance					
10 per cent reduced supply	116	7	120	-	443
20 per cent reduced supply	44	*–60*	54	-	368

The time use survey data for the two households show that they spent significantly more time on water-related activities in the field that is located in subak Dukuh: 18.5 days on average instead of the 6 days they spend on their field in subak Tegan (Table 6.16). This significantly higher investment supports the argument that water stress is a relevant issue in subak Dukuh. Farmers told me that they go out at night and sit next to the field for hours to ensure sufficient water supply, especially in the first month after transplanting when water levels are critical to the success of the crop. Farmers call this water monitoring activity *mencari air* (lit transl. 'looking for water'). What they actually do is manipulate the water flow to increase water into their fields. This technique, used in many subaks all over

Bali, is called 'borrowing'. The practice of water borrowing is an integral part of informal water negotiations, which is used on the farm-field level as well as on the subak level (S. Lorenzen 2008: 19, 192).[195]

Table 6.16: Labour input into irrigation on the farm-field level

Person-days/hectare	*Subak Dukuh*	*Subak Tegan*	*Total*
Case study A	23	11	34
Case study B	15	1	16
Average	18.5	6	25

Summary

The main issues arising from deagrarianisation and rural diversification with respect to water are declining water supply, waste in irrigation canals and pollution of irrigation water. In the field research site, the water situation presents an ambiguous picture. According to calculated water balances for subak Tegan and subak Dukuh, only subak Tegan would have had a water deficit in June 2005. Yet it is in subak Dukuh where farmers have to constantly monitor the water situation and borrow water. Subak heads and farmers alike do perceive water as an issue.

Urban and industrial developments are an issue in subak Dukuh. Making provisions for this type of water withdrawal from the irrigation water supplied to subak Dukuh shows that the water balance becomes more critical. Although waste is a visual problem, it has not been mentioned by farmers and the subak head as an issue that increases labour maintenance. The data on water management labour input on the farm-field level, on the other hand, illustrates the water stress situation in subak Dukuh.

The subak institutional framework offers informal arrangements to deal with problems of water stress such as water borrowing, and intra-rotational water scheduling in one subak.

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[195] For a detailed discussion on the practices of water borrowing refer to S. Lorenzen's thesis (2008: 124–32).

The fact remains that farmers have to invest more work. The degree to which water stress is caused by urbanisation and industrial development remains, however, unclear. Continued monitoring of the situation including recording of water balance data and labour investment would be a means to establish a more grounded analysis of the water issue.[196]

With respect to my conceptual model of the subak as social-ecological system, it appears that the water supply threshold has been approached, but not crossed. From my observation and discussions with farmers, rice yields in relation to water supply have not been an issue.[197] Labour investment into water management may increase in future if water stress increases, which would affect the labour thresholds in the technical dimension. Farmers and subak heads being able to manage water stress internally shows that the negotiable rules threshold (institutional dimension) is still intact.

LAND

With rural transformation, land is needed for development other than agriculture. Also, a growing population contributes to the conversion of agricultural land to settlement area. Bali's south-central region has substantially developed in the past couple of decades. Both tourism and related industries and urbanisation cut deep into subak land, dividing and reducing the area, especially near tourist destinations and the capital city of Denpasar. Following the main road from Denpasar to Tabanan on the way to West Bali one can no longer see many rice fields. Restaurants, grocery stores, car workshops, and food stalls have set up their commercial enterprises along the road. Between 1995 and 2004, Badung lost 13 per cent of its rice fields while urban settlement areas increased by 17 per cent (Figure

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[196] For example, the last five years of the eleven years of measurements by the public work department between 1995 and 2005 show a declining trend of river water flow which is, however, not statistically significant. A follow-up study analysing the data from 2005 onwards would allow for more clarification.

[197] Future studies could elaborate in more detail the developments of rice yields achieved in the field research site parallel to the assessment of the water situation.

6.14). A more detailed analysis of the districts in Badung regency shows that Kuta district in particular, which includes major tourist centres, experienced a more pronounced decrease of rice fields compared to the other districts further away, while growth of urban settlements was similar in all districts (Figure 6.15).[198] Kuta district accordingly lost nearly 40 per cent of its rice fields between 1995 and 2003.

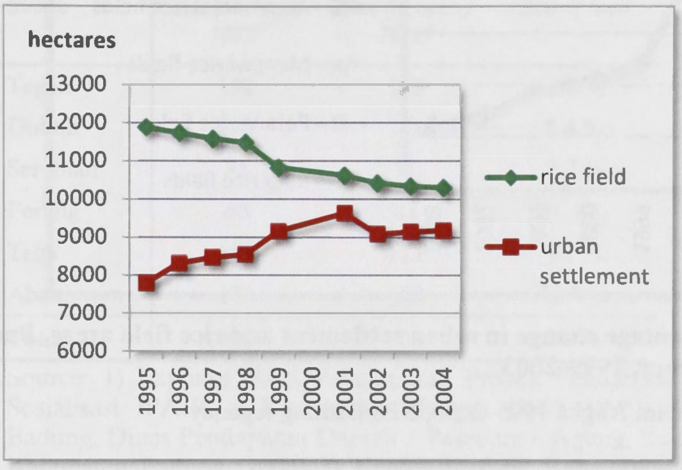

Figure 6.14: Rice field and urban settlement areas, Badung regency, 1995–2003
Source: Badung dalam Angka 1995–2003, BPS Badung regency, and Bali in Figures, BPS Bali, 2004

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[198] These figures suggest that so far, urbanisation in districts other than Kuta has been taking place on other non-rice land.

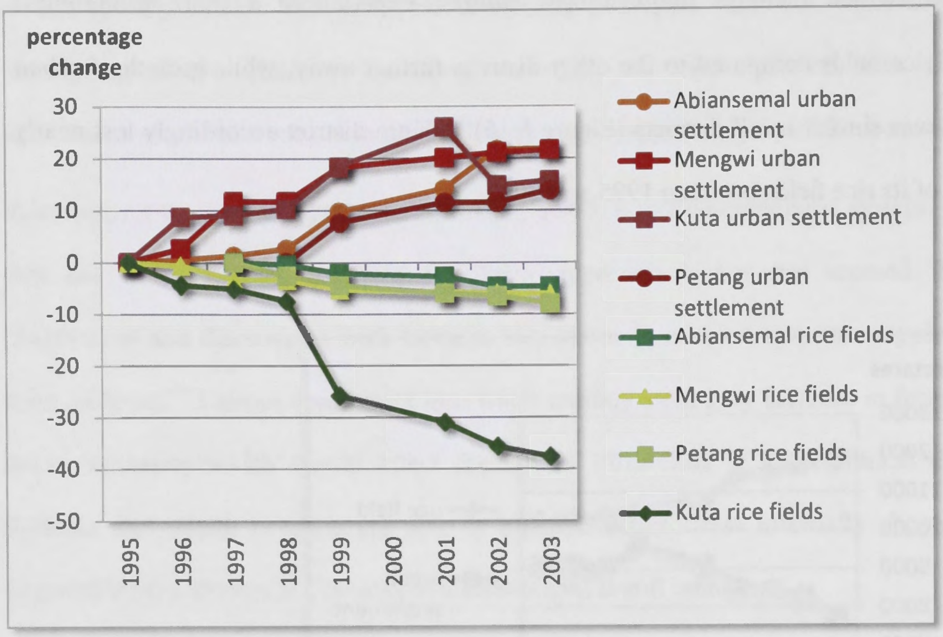

Figure 6.15: Percentage change in urban settlement and rice field areas, Badung regency, 1995–2003

Source: Badung dalam Angka 1995–2003, BPS Badung regency

In the research area, subaks lost on average 7.8 per cent of their irrigated rice fields between 1995 and 2002 (Table 6.17). Subak Teba lost the least amount of land while subak Perang lost the most land in this eight-year period. Presumably, there is a greater loss in subak Perang because of its close vicinity to settlements: Anggungan village and a housing estate (*perumahan*) to the south of Anggungan.[199]

Conversion of subak land occurs mainly in two ways: either by reduction along the fringes where urbanised areas meet subak land or by fragmentation on rice fields scattered along roads that pass through subak land. To understand the possible impacts of the recent land

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[199] A perumahan is a non-traditional settlement established at the outskirts of traditional villages in peri-urban areas. These settlements accommodate individuals and families who are not local but work in the vicinity as a means to reduce commuting time. There are no communal ritual activities such as in traditional villages as these housing estate lack religious congregational structures. Inhabitants are also not involved in any rice farming activity or own any land in the surrounding rice fields. Each inhabitant maintains his or her social and religious obligations with the home village. Although these estates have separate village councils, social cohesion between inhabitants is less than in a traditional village.

conversion developments on the functioning of the subak, I compared the average subak, munduk, members per munduk and membership field size data of the twelve subaks of pasedahan Yet Penet (which includes the six subaks of my main research site and the subaks from the wider context) from 1990 with 2005 (Table 6.18).

Table 6.17: Loss of irrigated land in research site

Subak	*Size (hectares) 1995¹⁾*	*Size (hectares) 2002²⁾*	*Loss of land*
Tegan	192	183	4.7 %
Dukuh	129	122	5.4 %
Serobian	73	71	2.7 %
Perang	60	41	31.7 %
Teba	173	171	1.2 %
Aban	173	150	13.3 %
Total	800	738	7.8 %

Source: 1) Laporan Hasil Pelaksanaan Proyek Pendataan Obyek Pelaksanaan Dan Sosialisasi IPAIR di Kecematan Mengwi (1995/1996), 2) Pemerintah Kabupaten Badung, Dinas Pendapatan Daerah / Pasedahan Agung, Bunga Rampai Persubakan di Kabupaten Badung (2004) 3) Kantor Statistik Kabupaten Badung / Badung dalam Angka, 2002 and 1995

Table 6.18: Average subak size and membership, pasedahan yeh Penet, 1990 and 2005

Year	*size (hectares)*	*munduk size (hectares)*	*member field size (hectares)*	*members / munduk*
1990	200	29.	0.39	78.
2005 *	162	24	0.41	64
Percentage change	**-19**	**-17**	**+5**	**-18**

Source: data for 1990 from (Sutawan et al. 1990), and data for 2005 from Subak head survey, 2005

Accordingly, the eleven subaks of the field research site lost on average 19 per cent of their irrigated area, while munduk sizes decreased on average by 17 per cent in the last fifteen years. This reduction in size is significantly larger than the average loss noted for the six subaks of the main research site between 1995 and 2003 (Table 6.17), which suggests that the loss of subak land was greater in the subaks of Panca Tirta Buwana. This make sense, because this subak federation has land close to the beach which is a favourite place for tourist and expatriate estate developments. Members per munduk have decreased by 18 per cent while member field sizes have slightly increased (by five per cent). Whether maintenance labour has increased with a diminished membership remains unclear. Also, whether the slight increase in member field size is due to incongruous membership recording or a real trend will need further careful investigations in the future.[200]

Subak land fragmentation in the research site is a particular issue for subak Tegan and subak Dukuh. Studies of aerial photographs of Google maps show that between 2002 and 2009 there has been increased development along the road crossing through Subak Dukuh (Figure 6.16). A rough calculation shows that the area occupied by urban settlement increased from 5.8 to 14.7 hectares (or by 8.6 per cent) while alternative land use increased from 1 to 2.7 hectares (or by 2.7 per cent) (Table 6.19). Alternative land use includes all non-rice crops, which can be perennial crops or short-term crops. Alternative land use can be of temporary or permanent nature which explains the variations in the period of 2002–2009. This alternative land use might also be an indication of how minimal agricultural diversification is in the field research area.

An important aspect of the urban and industrial development along the main road is the way this kind of urbanisation is spreading. While urban settlements for domestic purposes tend to develop along the margins of already established urban areas, the industrial settlements, as is the case in subak Dukuh, tend to develop more haphazardly and are scattered, albeit mainly along the road (Figure 6.16). The scattered development results from individual farmers selling off their rice fields. Often, rice fields are long and narrow, stretching perpendicularly from the main irrigation canal on either side to the east or west

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[200] Membership data have to be treated cautiously. Membership data can be skewed because many subaks have active and passive membership and it is not always apparent from the data whether passive members are included or not. Passive members pay a labour-substitute fee to be exempt from labour generally towards ceremonies only.

up to the off-flow canal. The selling of one such field results in a deep cut into subak territory. Those rice fields that are adjacent to converted land are particularly subject to compartmentalisation and are more likely to be converted to other uses. This development can be clearly seen in the seven-year period observed. Compartmentalisation also impacts on water flow and communication between farmers as fields adjacent to housing or businesses can no longer profit from seepage and overflow water (Figure 6.17).

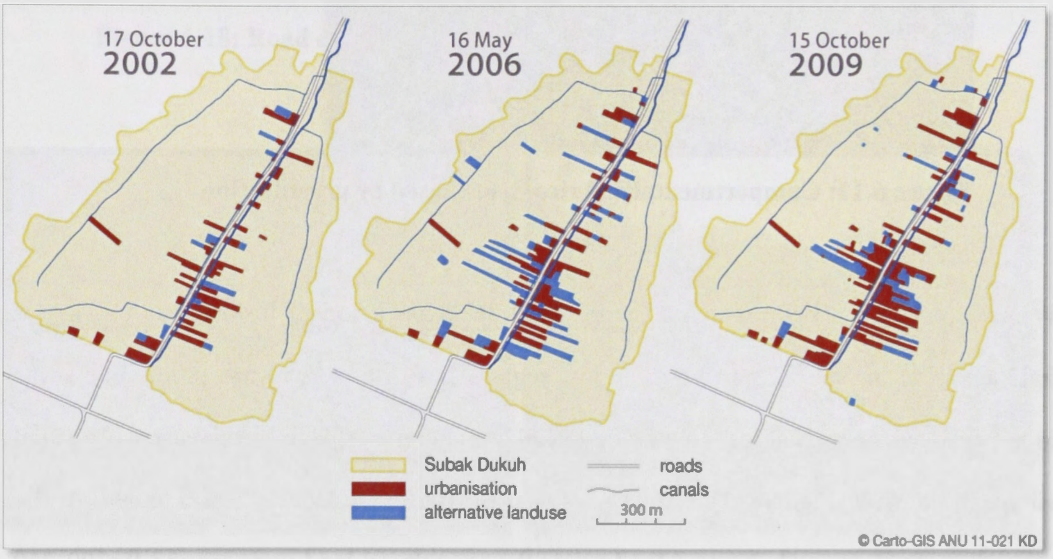

Figure 6.16: Urban and alternative land use developments in subak Dukuh, 2002–2009

Source: Map prepared in collaboration with K. Dancey and S. Lorenzen

Table 6.19: Urban and alternative land use development, subak Dukuh, 2002–2009

Year	*Urbanisation (hectares)*	*Alternative land use (hectares)*
2002	5.8	1.3
2006	7.9	5.6
2009	11.4	3.6
Increase 2002/2009	8.6 per cent	2.7 per cent

Source: Data collection by K. Dancey

Figure 6.17: Compartmentalised rice field caused by urbanisation

While in subak Dukuh fragmentation of subak land has a longer history, the process of fragmentation in subak Tegan has only just begun. Here, a new road was built while I was in the field which cuts across rice fields to link Anggungan village in the east with Kapal village in the west (Figure 4.1). Land prices near the road immediately began to rise. At the time of my field research, hectare land prices for agricultural land were around Rp300–350 million (30,000–35,000 US$). In the months of the construction of the road prices for land adjacent to the road increased to Rp600–750 million Rupiah (60,000–75,000 US$). Around two hectares of rice fields were already bought by individuals who planned to open a business. When I recently returned to the field site, many of the fields along the road were already converted for domestic or industrial use or lay fallow (Figure 6.18, Figure 6.19). Landowners emphasise the positive effect of the road, arguing that the new road shortens travel time to the market in the west. Those farmers who cultivate rice along the road can sell their rice for a higher price because transportation costs for the trader are lower. The subak head sees increasing problems with maintenance and operation of the canals.

Figure 6.18: Road development on Kapal side, 2005 and 2007

Figure 6.19: Road development on the Anggungan side, 2007 and 2009

Summary

Land conversion occurs mainly along roads, which is convenient for settlement and industrial development because of easy access. For farmers to have a rice field along a road increases the incentive to sell, in particular where demand for urban and industrial development is high. Diminishing subak land may impact on membership numbers, which in turn may affect maintenance labour. Fragmentation has an accelerating impact on the land conversion of urban-adjacent rice fields and affects water access and communication between farmers. I have shown that land conversion has been taking place in the past couple of years. Clear trends of land fragmentation along roads are, however, evident.

Given the lack of long-term data available I can only speculate whether land conversion is accelerating.

With respect to my conceptual model of the subak as social-ecological system, several dimensions are affected and thresholds approached. With the fragmentation and conversion of subak area, the land contiguity threshold is affected, which in turn may have a cascading effect on the water supply threshold. The negotiable rules threshold for sideways water flow is interrupted and communication between farmers reduced. With a lowered land contiguity threshold, the maintenance labour threshold may be affected with fewer members having to attend to an increasing work load.

CONCLUSION

Rural diversification has led to a rapid growth of other industries and general urbanisation with an increased demand for labour, water and land for non-agricultural purposes. The impacts of these developments on the present-day subak show a mixed picture. Although farmers now pursue off-farm work they continue to grow rice. The farm household is able to allocate labour to impending work in the rice fields, given the flexible organisational structure of the farming household and the minimal requirements for subak maintenance work. The analysis of irrigation water demands and supply has shown that in the peak season water availability becomes critical. Subak heads and farmers alike consider water stress as a pressing concern. So far, however, the subak institutional framework has allowed dealing with short-term water stress pertinently. Although subak land has decreased in the past couple of decades, this reduction appears to have had little impact on the functioning of the subak. Land fragmentation —which is a particular concern where roads cut through rice land— impacts more negatively on the functioning of the subak.

The changes that are occurring to the subaks in the field research site may not be entirely transferrable to subaks in other parts of Bali, in particular less to those in the uplands where rural transformation is not as imminent. The developments described within this chapter, however, are representative for many peri-urban regions of Southeast Asia.

With respect to my conceptual model of the subak as social-ecological system, so far, none of the thresholds have been crossed. The subak continues to exist and can therefore be considered resilient to the present-day disturbance of rural diversification. In the longer run, however, there are a few aspects that need to be considered. Rural diversification is an ongoing process and pressure on labour, land and water is continuing. With the younger generations working mainly off-farm and an aging farming community, labour availability will decrease. The continued fragmentation of subak land with urban and industrial development will impact on water availability and the general condition of the irrigation system. A decreased water supply in the longer run will negatively affect rice yields. Difficulties in accessing water, increased labour, lower yields and higher land prices create incentives for farmers to sell their land faster and give up farming, which may result in the subak as a social-ecological system losing its resilience and moving across to another basin of attraction. On the other hand, the subak has so far proven to be resilient to two disturbances and has been able to adapt by incorporating new Green Revolution technologies, allowing farmers to take on new off-farm work opportunities and dealing flexibly with water issues, and all along maintaining subak core principles. The next chapter looks at possible futures of the subak given the current trends and considering the subak's ability to adapt.

CHAPTER 7

FUTURE TRAJECTORIES OF THE SUBAK SYSTEM

INTRODUCTION

In the previous two chapters, I used my developed conceptual model of the subak as social-ecological system to analyse the impacts that past and recent developments had on the subak. I examined whether any thresholds, which demarcate the boundaries of the four-dimensional basin of attraction for the subak and similar farmer-managed canal-irrigated rice cultivation systems, were approached, crossed or changed in the course of or due to these disturbances. The analysis showed that the subak, despite considerable changes, persisted retaining its core principles.

The new entities that emerged with rural diversification and general urbanisation, however, will continue to compete for the resources that are important to the subak —in particular land, labour and water. This pressure will make it difficult to maintain the present high rice productivity levels. On the other hand, the Indonesian government envisages a revitalisation of agriculture as a means to ensure national food security, provide employment and support economic growth. The trend to continued deagrarianisation poses a challenge to the plans of the government, which raises questions about how the future of agriculture in Indonesia will unfold. This chapter discusses possible futures and potential trajectories of the subak and irrigated rice cultivation in Bali, taking into account past disturbances, and current trends and issues.

Conceptually, social-ecological systems can move away from their current basin of attraction across thresholds into neighbouring basins of attractions. Slowly changing variables can increase the potential for a system to move across (Carpenter et al. 2001; Holling 2001: 396; Carpenter et al. 2006; Kinzig et al. 2006; Walker et al. 2006). Considering the subak as a social-ecological system, I suggest that the continuous pressure on the resources of land, water and labour may act as slowly changing variables that are eventually reducing the subak's resilience, moving the subak across to another basin of attraction. This alternative basin exhibits a different identity in which farmers organise in different ways, include a different membership, maintain different physical boundaries to cultivate other crops, or land may lay fallow for farmers have moved on to engage in off-farm employment only.

Yet the full set of plausible alternative basins and what identity a social-ecological system might take on in these basins cannot be predicted for there are many uncertainties that influence the course of development (Carpenter et al. 2005: 39; Carpenter et al. 2006). Complex systems can respond in unpredictable and uncontrollable ways to changes. To circumvent the difficulties of forecasting, resilience scholars use scenarios, which are a tool to develop plausible accounts of the future, rather than predictions. Scenarios are representations of other possible basins of attraction. The workbook of the Resilience Alliance (2007b: 32) recommends to develop three to five scenarios. Scenarios are more powerful if presented as a small set with clear and striking differences (Shoemaker 1995: 30; Carpenter et al. 2006).

Here, I develop three possible future pathways or alternate basins of attractions. I base the three scenarios on my observations in the field, on my discussions with key stakeholders, on field research data and on the study of relevant literature. Each of the three scenarios of alternative basins of attraction uses particular assumptions about how variables that influence the subak as a social-ecological system change. These assumptions are based on the analysis of current trends and issues that the subak and similar irrigated rice cultivation systems face now and in the near future. Before I present the three scenarios, I discuss these current trends.

CURRENT TRENDS AND ISSUES

The pressure on labour, land and water resources is likely to continue in future, given the ongoing diversification of the rural economy. Land conversion to industrial and urban development will continue while an increasing proportion of the remaining rice land will be diverted to the cultivation of other cash crops (ADB 2006: 22). Groundwater use may become more prominent as a means of greater flexibility in conjunction with surface irrigation while the pressure on reallocating irrigation water to competing higher priority uses will increase (Turral et al. 2010: 553). Meanwhile, an aging rural community will lead to a markedly diminished agricultural workforce (Skeldon 1999). Income growth and further urbanisation combined with better education will encourage consumers to change their consumption patterns to a more diversified diet which is less focused on rice, and to a higher demand for convenience food (Dawe 2005b; Pingali 2006).

As land and water diminish there will be a greater demand put on the remaining agricultural resources to produce enough food for a growing population. The pressure on an already scarce resource base is likely to increase with climate change. Predictions made by climatologists point towards a rise in temperature as well as a decrease of annual precipitation by up to 15 percent in southern Indonesia, including Bali, which may adversely affect crop productivity (Case et al. 2007; PEACE 2007). Yet regardless of changing food patterns and the general diversification of agriculture, rice will remain the most important staple food in Asia (Pingali et al. 1997: 181).

A quick analysis of rice production in relation to population growth in Indonesia and Bali shows a varied picture. Bali's per capita harvested rice area decreased from 0.052 to 0.042 hectares while Indonesia's per capita harvested rice area declined less sharply from 0.057 to

0.052 hectares in the same period (Figure 7.1). While Bali's per capita rice production also steadily fell from 156 to 134 kilograms of milled rice in recent years, Indonesia's rice production recuperated from an initial fall and, since 2006, increased again, from 137 kilograms in 2000 to 144 kilograms of milled rice in 2008 (Figure 7.2). Not included in these figures are post-harvest losses estimated at about 21 per cent (Simatupang and Timmer 2008: 69). Including post-harvest loss, per capita milled rice available for consumption would be at 105 kilograms for Bali and 114 kilograms for Indonesia in 2008. This per capita availability is clearly below the current consumption rates for Indonesia, which average between 140 and 150 kilograms in spite of a trend towards a decline in rice calorie consumption (Agus and Mulyani 2005: 3; UNCTAD (United Nations Conference on Trade and Development) 2010). Targeted policies and research will be required to boost productivity as well as create incentives for farmers to continue growing rice to reverse the trend of a falling per capita rice production. If Bali is to remain focused on increasing rice production to meet per capita rice consumption, clearly, productivity has to increase and land conversion be halted.

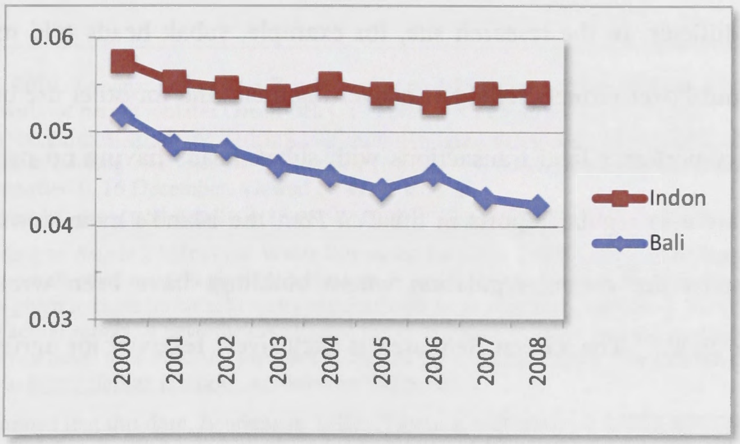

Figure 7.1: Per capita harvested area of irrigated rice (hectares), Bali and Indonesia, 2000–2008

Source: (BPS Bali 2005; BPS Bali 2010e; BPS Indonesia 2010b; World Development Indicators (WDI) 2011)

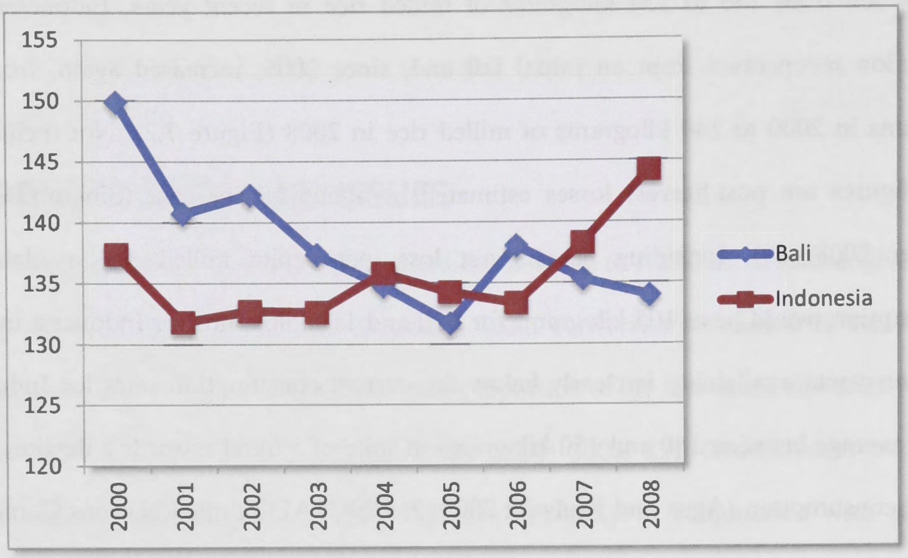

Figure 7.2: Per capita milled rice produced in Bali and Indonesia (kilograms), 2000–2008

Source: (BPS Bali 2005; BPS Bali 2006; BPS Bali 2010e; BPS Indonesia 2010b; World Development Indicators (WDI) 2011)

The Bali province spatial plan revision for 2003 to 2010 recognises the problem of Bali's declining per capita rice production, recommending an increase in productivity and cropping intensity, and a halt to land conversion (Anonymous 2002). Yet to halt land conversion appears difficult. In the research site, for example, subak heads told me that they have limited control over farmers selling or converting their land for other use because these days, the notary performs land transactions with subak heads having no means of intervention. There are also regular reports in the *Bali Post*, the island's main newspaper, about violations against the zoning regulation where buildings have been wrongfully erected in the 'Green Belt'.[201] The 'Green Belt' area is exclusively reserved for agricultural

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[201] See for example: Bali Post, 2009. 'Pelanggaran Jalur Hijau Terus Bertambah' [transl. 'Green Belt violations continue to increase'], 5 February. Viewed on 21/1/2011 at http://www.balipost.co.id/mediadetail.php?module=detailberita&kid=10&id=10750; Bali Post, 2009. 'Dewan akan Panggil Dinas PerizinanTerkait Pembangunan Depo di Jalur Hijau' [transl. 'Council's call to the licensing office with respect to the construction of a depot in the Green Belt'], 4 May. Viewed on 21/1/2011 at http://www.balipost.co.id/mediadetail.php?module=detailberita&kid=2&id=14046; Bali Post, 2009. 'Membandel, Pelanggar Jalur Hijau Diperingatkan' [transl. 'Stubborn, Green belt offenders warned'], 15 July. Viewed on 21/1/2011 at http://www.balipost.co.id/mediadetail.php?module=detailberita&kid=2&id=16834;

activities (Sutawan et al. 1999: 4). Pressure for land conversion is particularly high near tourist centres and along arterial roads, driven by a prospering tourism industry, growing a population and emerging non-agricultural industries.

Industrial development and urbanisation compete for water. Both the Bali provincial government as well as the national government have adopted new measures to address the increasing pressure on irrigation water availability. For instance, a national water law came into effect in 2004 that attaches high priority to irrigated agriculture.[202] A large dam project in Tabanan regency, constructed between 2003 and 2007, aims at addressing water shortages —which had led to rice farmers in this area abandoning rice cropping in the dry season— as well as securing water needs for domestic use and a growing tourist industry in the coastal area.[203] While I was in the field, I followed a drinking water project that was based on a participatory approach that included affected subaks in the decision-making process.[204] These examples show that water shortages have become an issue, nationally as well as regionally and that the government is trying to address these problems by developing new policies, extending capacities for water supply and including local stakeholders in the decision-making and planning process.

Bali Post, 2010. 'Langgar Jalur Hijau Bangunan Tanpa Izin Keluar 70 Persen' [transl. 'To 70 precent finished building without permit violates Green Belt'], 17 February. viewed on 21/1/2011 at http://www.balipost.co.id/mediadetail.php?module=detailberita&kid=2&id=30300; Bali Post, 2010. 'Langgar Jalur Hijau di Badung 30 Bangunan Dieksekusi' [transl. 'Green Belt Breach in Kabupaten Badung, 30 Buildings to be dismantled']), 16 December. Viewed on 21/1/2011 at http://www.balipost.co.id/mediadetail.php?module=detailberita&kid=2&id=45779.

[202] According to Article 29 (3) of the Water Resources Law No. 7/2004, the second-highest priority for water supply above all other needs is given to 'irrigation of small-scale farming in the existing irrigation system' (first priority is given to basic household water requirements including drinking water). While this law cannot influence actual supply, it nevertheless protects those irrigation systems that are in place as irrigation water supply to rice fields now officially precedes industrial development needs. The English translation of this law is available at http://faolex.fao.org/, accessed on 15/06/2010.

[203] It is planned that this dam, Bendungan Telaga Tunjung, will service 2,410 hectares of rice fields that currently lie fallow in the dry season plus provide for domestic use and the coastal tourism industry (Manik Agra 2006: 25).

[204] In 2005, commissioned by the provincial government, Japan International Cooperation Agency (JICA) together with researchers from Udayana University organised a workshop inviting public servants as well as heads of subaks along Penet river to discuss the positioning of a water diversion for a new drinking water supply pipe to Denpasar capital city. In this participatory process participants decided to position the drinking water pipe below the intake of the last subak downstream to avoid reduced water flows into subak territory.

The National Medium Term Development Plans developed by the Government of Indonesia for 2004 to 2009 and 2010 to 2014 both foresee a revitalisation of agriculture to ensure national food security (one of eleven national priorities), create employment opportunities and support economic growth (Republic of Indonesia 2005: 1; 2010). The Java-Bali region is accordingly to maintain its function as a key national supplier for both food production and food manufacturing. The development of the region is further directed at maintaining water sources and controlling the growth of urban and rural settlements (Republic of Indonesia 2010: I-63–4). To implement this revitalisation, large investments will be required for irrigation improvements, rural infrastructure, education and agricultural research as well as improved governance, transparency and accountability (ADB 2006: 20).[205] As envisioned, agriculture will be more productive, commercialised and diversified, environmentally friendly and less vulnerable to agronomic and market risks (ADB 2006; Republic of Indonesia 2010: I-53). Yet, despite a focus on more diversification, one of the revitalisation targets emphasises the importance of maintaining rice production levels at a minimum of 90 per cent of domestic demand (Republic of Indonesia 2005: 7; Suryana 2008: 4).

Given the trend of a declining harvested area and a growing population, Bali would need to increase production by increasing productivity and reducing post-harvest losses. Increasing productivity can be achieved by both increased yields and or intensified cropping. Swaminanthan (2011: 2300), for example, notes that on average only 40 per cent of potential yields are realised due to imperfect adoption of the Green Revolution technologies, such as improved irrigation, and application of fertilisers and pesticides. In Bali, productivity increases could be realised by increasing yields and cropping intensity, and improving irrigation systems (Anonymous 2002).

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[205] The Asian Development Bank's report (2006) outlines a strategic vision for agriculture and rural development in Indonesia which was developed in close consultation with the Indonesian government and its National Medium Term Development Plan.

Accordingly, Bali would have to increase its productivity from current 5.8 to 8.9 tonnes per hectare to maintain production at 90 per cent of domestic demand (Table 7.1). This calculation assumes that per capita consumption would decrease by 1 per cent annually between 2008 and 2025, from 140 kilograms to 118 kilograms, that population would continue to grow and harvested area continue to decline with the same average annual growth rates as between 2000 and 2008. If Bali can increase cropping intensity from current 1.77 to 2 crops per year, yields would have to increase to 7.9 tonnes. If, in addition, post-harvest losses can be reduced to 10 per cent, yields would have to improve to a level of 6.9 tonnes per hectare to meet per capita consumption needs.[206] If we were to consider a diversification of agriculture, however, the harvested area would decline further, and would need further productivity growth.

Table 7.1: Projected rice production indices for 90 per cent domestic demand for Bali, 2025

	Per capita consumption (kilograms)	*Population*	*Production (tonnes per hectare)*	*Harvested area (hectares)*	**Yield (tonnes per hectare)**
2008	140	3,409,845		143,999	**5.8**
Annual growth rate	*-1*	*1.71*		*-0.89*	
2025	118	4,403,125	1,089,038	122,191	**8.9**
2025 : 2 crops/year	118	4,403,125	1,089,038	138,069	**7.9**
2025: 2 crops /year and 10 % harvest loss	118	4,403,125	955,933	138,069	**6.9**

Source: Bali dalam Angka 2004/5, 2006, 2009 and own calculations

The vision shared by the ADB and the national government for a more productive, commercialised and diversified agriculture with Bali maintaining its position as one of the

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[206] The cropping intensity of 1.77 crops of rice annually is calculated from harvested area divided by total irrigated rice area (for 2005: BPS Bali 2006).

main food production centres requires an active farming community interested, willing and financially capable to invest in their farms to increase productivity and to diversify. At present, there are few incentives for farmers to invest into agriculture, take risks and be innovative. The main obstructions to innovation and risk-taking relate to farm size, sharecropping arrangements, availability of land for farming, higher labour requirements for non-rice crops, and lack of training and education.

Rice cropping has become a partial livelihood strategy providing mainly for household consumption. In the research site, current average farm sizes allow a household to provide for their own consumption and have a more or less steady income every four and a half months.[207] This income however is not enough to cover all the expenses of a household. One way to increase farm profitability would be to expand farm size. With average small farm sizes there is little scope for expansion unless farmers have low-risk possibilities to sharecrop additional land.[208] Sharecropping arrangements are, however, very loose contracts with no warranty for long-term availability. A non-farming landowner who lets his fields can stop a contract with a sharecropper at any time.

In the field research site, there is a general disinclination to diversify crop production. Although the agricultural extension service recommends farmers to rotate rice cropping with other non-rice crops, farmers in the research area prefer to include a fallow period

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[207] In the research area, the average farm size is around 0.46 hectares for all, owners, owner-tenants and tenants. There is little difference in average farm size comparing owners (0.47 hectares), tenants (0.41 hectares) and owner-tenants (0.53 hectares). With an average per capita rice consumption of 154 to 180 kilograms (milled rice), an average of four to five members per household and an average of five to six tonnes per hectare rice yield (unhusked pre-drying), an average household cultivating five rice crops over a period of two years can theoretically sell between 70-85 percent of its harvest while using the rest for its own consumption (246 to 360 kg per household and cultivation season). The selling of the rice crop results in an estimated average monthly income of 0.6 (for owners) or 0.4 (for tenants) million Rupiah not including expenses for wages for outsourced labour and farm inputs. Sharecropping agreements usually include a third of the earnings to be paid to the landowner. This calculation does not however include a bad harvest or the regular needs for rice for the frequent ceremonies. Each household is obliged to contribute its share of rice of a few kilograms to rituals in neighbouring households, ceremonies of the hamlet, village temples and kinship group. In summary, the earned income from rice cultivation might be considerably smaller accounting for the eventualities mentioned above. Compared to the on-farm income, an unskilled day labourer's monthly wage working 25 days in construction is around 1 million Rupiah. Yet work is not always guaranteed.

[208] Current traditional laws of inheritance warrant each child of a family an equal share of the parental land, causing continuous fragmentation into smaller parcels. Women lose their title once they are married and move to live in another family's compound.

instead. Many farmers I asked could not remember having ever planted anything save for rice since the Green Revolution began. Others said they had planted non-rice crops but only in the past. The main reasons for this disinclination are that non-rice crops are more labour-intensive from soil preparation to crop management, harvesting and marketing and require farmers to be present in the fields for longer periods.[209] That farmers prefer to grow rice only has been noted elsewhere in Indonesia (Heytens 1991: 43).

SCENARIOS

Amid the continued pressure on land, water and labour, uncertainty about the effectiveness of future agricultural policies implementation, and a farming community that may be unwilling to invest, the question of what the future bears for the subak becomes pressing. To this end, I have developed three scenarios situated around 20 to 25 years ahead in time that take into account these current trends and issues. At this point in time the current farming community will be too old to continue growing rice, given that the current average age of farmers I met in the field was 53 years with the oldest farmers between 70 and 75 years of age. The scenarios include considerations of the government's effectiveness with respect to investment and policy implementation, and farmers' individual and community innovative capacity. Pressures on land, water and labour are also varied, and again depend on the ability of the government to halt or reduce these pressures.

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[209] Firstly, the fields need to be drained completely and raised seed beds have to be prepared to allow for controlled irrigation. Tractors to plough dry fields are not easily found as most tractors in use are specialized in ploughing in wet conditions (puddling). Secondly, most non-rice crops require a more regular crop management for a successful harvest. In the harvesting period, which for many non-rice crops spans over a longer period of time, farmers need to continuously monitor for fear of theft. Thirdly, while rice can be stored for several months, non-rice crops have to be taken directly to the markets for sale. Marketing of non-rice crops is not as well organised as the marketing of rice. Moreover, rice cultivation allows farmers to take better advantage of readily available off-farm employment opportunities in comparison to the cultivation of other crops. These factors explain why farmers are disinclined to grow crops other than rice.

SCENARIO 1 – DISINTEGRATED WATER USER ASSOCIATION

This scenario is based on my own observation of the current situation in the research site and the context of peri-urban agriculture, contract farming and water pumps (Box 7.1). Peri-urban areas, such as the field research site, are characterised by rapid population growth, rising land values and a piecemeal development process of changing local economic and employment structures from agriculture to manufacturing, resulting in mixed land use (Hudalah et al. 2007: 505). Peri-urban population growth is particularly high and fast compared to total population growth (Midmore and Jansen 2003: 14; Hudalah et al. 2007: 505). In countries such as Vietnam, Thailand, the Philippines, China and Malaysia, agricultural production in peri-urban areas has shifted from rice cultivation to predominantly vegetable production, which can be more profitable (Midmore and Jansen 2003: 15; Khai et al. 2007: 192). In peri-urban Hanoi, Vietnam, for instance, rice still covers more than half of the peri-urban areas dedicated to agriculture, yet intensive vegetable production has increased in importance despite a lack of water in some areas in the dry season (Anh et al. 2004: 23–4).

Vegetable production requires secure land tenure and higher labour input compared to rice and often large investments into technology to maintain competitiveness. Expansion of the vegetable production area by single households is limited because of its high labour demand (Midmore and Jansen 2003: 16). Peri-urban areas with respect to vegetable production have the advantage of being in proximity to retail markets, which reduces transportation and storage costs, and they can also facilitate urban waste and waste water disposal by using it as compost in production (Midmore and Jansen 2003: 21; Anh et al. 2004: 51). For long-term sustainability of vegetable production in semi-urban areas, however, public investment is required to support investment, infrastructure, processing facilities, marketing options and land tenure security (Midmore and Jansen 2003: 22).

This scenario represents the 'business as usual option'. My main assumptions are that there is high fragmentation of remaining rice fields, high competition for water, and labour replacement by immigrating inter-provincial labour unfamiliar with the way Balinese share water and manage their irrigation system, with the government unable to implement most of its agricultural visions and policies in an effective way.

In this alternative basin of attraction, the farmers turn into individual operators who pursue different strategies cultivating either rice or high-value cash crops on a short-term contract basis. Farmers' choice of strategy depends on market demand, land and household labour availability and financial capacity. With uncontrolled piecemeal land conversion, rice fields are getting compartmentalised and water availability is low and unpredictable. Farmers rely on pump irrigation where possible. The artificial swamp has turned into mainly dryland crop cultivation.

The high competition for water, a disintegrating farming community, uncontrolled urban and industrial waste disposal and land fragmentation has reduced the efficiency of the canal irrigation system. There is no water allocation coordination such as rotation amongst water users and proportional water sharing has disappeared. Every farmer takes as he pleases what little is available. The subak irrigation infrastructure has decayed after years of neglect, with leadership to organise maintenance having become non-functional. Conflict over water is common and efforts by the government to reorganise farmers into water user associations are unsuccessful.

Farmers working the fields are no longer exclusively of local origin. With plenty of off-farm work available and young Balinese being better skilled they are far more likely to find work off-farm which is more attractive and better paid. Most farmers are tenants who sharecrop the fields of the affluent middle-income Balinese. Contract farming is limited to short-term periods due to the unreliable sharecropping arrangements and a highly volatile market with varying demands for different cash crops. Cultivation is no longer synchronised and labour input depends on the type of crop cultivated.

The subak institution has disappeared, as only a few locals remain to grow rice as a subsistence crop with decreasing yields due to growing in unfavourable conditions of limited water availability and pollution. In addition, non-local tenants have little understanding of the workings of a subak and only limited needs for a communal irrigation system as they mainly rely on their own means of water acquisition.

In this scenario, rice production would be unable to keep up with population growth, as the harvested area would decrease and productivity either be maintained at the current level or decrease as well.

Box 7.1: Scenario one – disintegrated water user association

Another type of farming that is becoming more frequent is contract farming, where agricultural enterprises contract farmers to grow a certain crop. The contract farming relationship can vary greatly with respect to contracting parties, number of farmers participating and degree of organisation amongst farmers, type of crops contracted, degree of financial and technical support, and general terms, formality and length of contract.

Contract farming can be beneficial in reducing transaction costs for both farmers and the contracting agribusiness such as reduced production risks, improved access to markets, quality control, investment into production technologies and economies of scale in processing, transport and marketing (Simmons et al. 2005: 514–5). Contract farming can be an attractive option, yet land tenure can be an issue. Where tenants mainly sharecrop land, longer-term contracts are less likely to succeed.

Turning to more individualistic options to access irrigation water such as pumps may become an attractive alternative, yet such options reduce the incentives for farmers to collaborate in maintaining community irrigation infrastructure. Water is being drawn from groundwater reservoirs, drainage canals or rivers, possibly affecting neighbouring communal irrigation systems. Pump irrigation has become more important in Vietnam and in the Philippines (Dawe 2005a: 222). Hayami and Kikuchi (2000: 43) discuss a case of farmers in the Philippines who preferred the more costly individual pumps over a deteriorating communal irrigation system. In Indonesia, groundwater has been so far mainly used for domestic purposes and increasingly by industry (IGES 2006: 44).

Current key reinforcing trends for scenario one in Bali

Part-time farming continues as a viable option for Balinese rice farmers. Because the community ages, however, and younger Balinese mainly work off-farm, the knowledge and skill base to work the land continuously diminishes. Balinese who do not want to work their land have the option of finding a sharecropper. These days, sharecroppers tend to be from the same or a neighbouring village.[210] In Ubud, a major tourist centre, where plenty of off-farm work is available, local fields are nowadays sharecropped by farm labour from villages further away and on a contract base (MacRae 2005b: 213).[211]

As the economy further develops and Balinese become more affluent, there will be fewer people available to sharecrop the land of landowners who do not want to farm. Land will either remain fallow, be converted or cultivated by labourers from outside the area. A large number of Javanese seasonal labourers come regularly for shorter periods to Bali to harvest rice fields for a trader.[212] These seasonal labourers could potentially take over sharecropping of the remaining rice fields. While I was in the field, Javanese labourers who worked for a trader to harvest the rice, instead of returning home, leased farming land off Balinese rice farmers during the official fallow period when farmers ought to grow a palawija crop.[213] For a small amount of lease money the Javanese grew water melons on fallowed rice fields.[214] Leasing of land by Javanese has also been observed in a study undertaken in 1999 where they grew floriculture products in rice fields in Denpasar that were easily reached by cars (Sutawan et al. 1999: 14). Theoretically, Javanese could take over the sharecropping of the rice cultivation with a shrinking Balinese workforce. They would be more inclined to diversify cropping as they have no off-farm working options.

Javanese however have a different approach to farming (there are no subaks or similar institutions in Java) and appreciation of the land. This was mentioned a few times while I was in the field in relation to the Javanese harvesting teams. These teams, which mainly consist of men, camp alongside the fields they are to harvest. They often bring along their

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[210] Sharecropping arrangements in the research area are currently as follows: The owner receives a third of the payment for the harvested rice and has no obligations towards any costs incurred such as paying the tractor, fertiliser and pesticide expenses as well as hiring of labour to do the transplanting or weeding. Another arrangement which is used less frequently is that the owner pays all the costs incurred but receives half of the earnings from the sold rice crop.

[211] See figure 1.6 for map to locate Ubud on Bali.

[212] As part of the tebasan system, see chapter 6 for a detailed discussion.

[213] Palawija is a non-rice crop which is grown after every two crops of rice. See chapter 5 for more details.

[214] At the time of my research, farmers get paid 1 million Rupiah per hectare o 10,000 Rupiah per 0.01 hectare.

wives, who then live in these simple self-made tents along a road but still next to the fields and not in urban areas. This is quite a disturbing fact for Balinese, whose belief system forbids them to have any form of sexual relationship in a rice field and any offence would require extensive elaborate purification rituals to undo the deed. Some also mentioned the more general fears about crime and Islamic takeover.

In the field research site, I met one farmer who was using pump irrigation to irrigate his rice fields.[215] Clearly, as long as the subak structures are in place, use of pumps will be the exception. More individualistic means of water withdrawal appear to turn into a viable option in cases where water availability is unsatisfactory and labour investments into maintenance too high. A study in East Java showed that high level of inadequate water supply and untimely distribution are the most influential factors in the emergence of conflict and water stealing (Pasaribu and Routray 2005: 482). Accordingly (ibid : 489), leadership accountability with respect to management has a strong influence on the success of the irrigator group. Increased water pressure combined with a membership that has become less Balinese and which is less understanding of the underlying principles of the subak institutional framework may eventually lead to the decay of solidarity amongst farmers and greatly reduce system performance. With a disintegrating communal irrigation system and reduced allocation of water, farmers in the future may well resort to pump irrigation. This trajectory to more individualistic solutions could be further encouraged where waste disposal is frequent and high, or where the farming community declines disproportionate to the size of the irrigation system and maintenance requirements.

At present, the two major vegetable-producing areas are located in the highlands of Bali (Baturiti and Kintamani). Across Indonesia, the production and harvest area has increased in recent years and diversified from the more traditional growing areas in the highlands to lower altitudes and lowlands (Johnson et al. 2008: 12–14). Whether vegetable production

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[215] See chapter 6.

in Bali's peri-urban regions can take off and act as an additional supply for a growing demand or as competitor to the highland producers remains to be seen. A mixed-cropping farming system that would also include livestock could be a viable option in peri-urban areas in Bali for those who own most of the land they cultivate. Either contracted to agribusinesses or directly marketing in local markets is a possible option. Yet affordable labour supply might be a problem due to the higher on-farm demands and competition from better-paid off-farm employment opportunities due to the vicinity to urban areas.

Diversification to vegetable production or mixed farming would also require more security in terms of land tenure for longer-term investments to become economical. The peri-urban farmers in Hanoi, for example, only rent 12 per cent of the total cultivation area (Anh et al. 2004: 46). In the field research site, 42 per cent of farmers exclusively or partially sharecrop the land they cultivate and only 58 per cent are landowners. Compared to Hanoi, this is a much higher percentage. For farmers to diversify successfully to vegetable production, they will require acquisition of new knowledge, technologies, financial support and a policy shift to a less stringent focus on rice self-sufficiency.

In the above case the subak system, with its strength in sharing water equitably, its high productivity in terms of rice yields and its cultural heritage, would clearly be lost.

SCENARIO 2 – JAPANESE MODEL WITH PAID ECOSYSTEM SERVICES

The ideas for this scenario were gathered from a literature review of the Japanese farming sector and its development in the past decades and payment of ecosystem services (Box 7.2). It has been widely recognised that ecosystems provide a variety of different services beneficial to humankind (Costanza et al. 1997; MA 2003; MA 2005). With the gradual loss of natural environments due to land conversion, degradation or pollution, fresh water, oxygen production, waste decomposition, climate regulation and aesthetic values are declining. Recognising and protecting ecosystem services allows for a more integrative approach and long-term perspective to mitigating human development impacts on nature.

Payment for ecosystem services —which includes biodiversity conversation, carbon sequestration, watershed protection and aesthetic landscape preservation— is a market-based approach that compensates those maintaining the ecosystem services (Milder et al. 2010). Accordingly (ibid.), these payments —which are made either directly by the public sector or the private sector on a voluntary basis or under regulatory obligations, or indirectly by consumers of certified products— can provide important livelihood benefits to poor people while ensuring the long-term viability of their agricultural production base.

Multifunctionality of agriculture is a similar approach to the discussion on recognition and protection of ecosystem services though it focuses exclusively on cultivated ecosystems. Recognised 'multi-functions' or agroecosystem services of irrigated rice cultivation systems in Indonesia are flood mitigation, prevention of soil erosion, water preservation, preservation of rural amenities for recreation and preservation of aesthetic, cultural and religious values (Agus and Husen 2004; Sutawan 2004; Agus and Husen 2005; Agus et al. 2006). Japan has equally developed a multifunctionality concept which has been applied to the agricultural sector by means of specific agricultural policies to preserve the cultural landscape (Groenfeldt 2006: 75).

Japan has a history of farmers engaging in off-farm work, such as craft or trade, spanning more than two centuries (Kada 1982; Bray 1994: 210–17; 1998: 58–62; Francks 2005). After World War II a small-scale rural industry developed that allowed rural households to further diversify and survive within a developing modern Japanese industrial economy (Kada 1982: 370; Francks 2005: 454).[216] Again, similar to other Asian rice-producing regions and contrary to expectations of Western scholars, Japanese rice farming units became smaller (strengthening the position of family units) rather than larger with

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[216] Francks (2005) argues that the rural industry developed complementary to technological change in rice farming so as to adapt to the variable availability of off-farm labour.

The main element of this scenario is that the subak system would have transformed to an agency-managed rice production system in which farmers become public servants. In agency-managed irrigation systems, allocators, maintainers and users of irrigation water are not exclusively farmers. The authority in such systems lies with a government-appointed authority (Dayton-Johnson 2003: 317). The government pays these public servants to maintain the subak cultural heritage, the rice terraces, the canal irrigation system, and the associated rituals, with rice production focused on local rice varieties for a premium market.

In this alternate basin of attraction, it is assumed that the Balinese society would have developed rapidly into a high-income region with a prospering economy. This affluent society can afford and is willing to keep the traditional rice production system intact. Farmers are organised in loose organisations that resemble the original subaks but which have been formalised and made uniform. Public servants from the public works department maintain the physical irrigation infrastructure. Financing of payments towards subak maintainers is derived from taxpayers and consumers.

Most Balinese have moved on to work in non-agricultural industries and in the services sector. Land conversion near urban areas has been high yet controlled and consequently less fragmented. The residual irrigated rice cultivation areas have remained contiguous to avoid reduction in irrigation system performance. With less land under rice cultivation, water pressure has eased and water availability is sufficient.

Land and labour resources have become scarcer but are stabilised thanks to the protective policies effectively implemented by the government. The government has developed a payment system that pays farmers and subak leaders in remaining subaks for their maintenance services. Local rice production, which enjoys a high demand by the local population, is protected by supported rice prices and import restrictions. Due to rising incomes, farmers have been able to make considerable capital investments to buy machinery in order to replace the shrinking labour force.

Farming households continue to combine part-time farming with off-farm work. Cultivated land sizes remain on average small. Rice cultivation has become an attractive additional income for those who own land or sharecrop that of their relatives while their main income comes from off-farm employment. Others grow rice as a pastime, having retired early from public or private off-farm employment in the city. The farming community consists of a mix of owners, owner-tenants and tenants which are exclusively local Balinese to ensure the cultural heritage is preserved.

Box 7.2: Scenario two – Japanese model with paid eco-system services

modernisation, and thus unsuitable for capitalist entrepreneurship/farming (Bray 1994: 210, 213).[217]

Since the 1950s, along with rapid economic growth and extensive urbanisation, part-time farming in the Japanese rice farming sector has become even more popular. Off-farm work gradually changed from casual to full-time employment and off-farm income increasingly exceeded on-farm earnings (Kada 1982: 367–8). Meanwhile, households started narrowing their on-farm focus to rice growing only, abandoning other on-farm activities because rice farming is most compatible with part-time farming and off-farm work (Kada 1982: 370). However, Japanese rice farmers were able to continuously increase land and labour productivity mainly by investing in mechanised cultivation (Kada 1982: 370; Bray 1994: 165). With continued demand for labour off-farm, rural households made technical and organisational changes to rice cultivation to adapt to these demands (Francks 2005: 464–5). Other factors such as better access to education and improvement in extension services also contributed to productivity increases (Bray 1994: 166).

Japanese rice farmers have also benefited from high rice prices due to a continued demand of urban consumers for Japanese-style rice and governmental subsidies and protection of domestic rice production (Greenland 1997: 171, 184; Francks 2005: 460, 464).[218] There is also a cultural tradition around rice cultivation which requires farmers to keep and cultivate the inherited land (Bray 1994: 217; Francks 2005: 461).

Increasingly, however, Japanese rice cultivation faces issues such as an aging farming community and a decline in rice consumption, which question the strong yet costly protectionist policies of rice farming, such as the artificially maintained high rice prices

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[217] Bray (1994: 149–50) argues that the intensification of Asian wet-rice cultivation systems relies more on labour than capital because the general trend in technical development has focused on raising the productivity of land. Capital played a subordinate role to labour for the specificities of wet rice cultivation (and the topography) restrict European-type mechanical rationalisation.

[218] According to Greenland (1997: 171) the price for rice paid at the farm gate in Japan was tenfold that of the world market price in the 1980s and 1990s.

(Gordon 1990; Fujiki 1999; Sato 2001; Fukuda et al. 2003; Yamashita 2010). Land consolidation efforts due to small-sized farm units' high production costs and conservation efforts to maintain rice ecosystem services such as biodiversity, erosion control, water storage and cultural landscape protection are also underway (Iiyama et al. 2005; Matsuno et al. 2006; Ichinose et al. 2007).

Current key reinforcing trends for scenario two in Bali

The narrow focus on rice growing is a characteristic feature of many subaks in the lowland plains of South Central Bali. As discussed earlier, farmers are disinclined to grow non-rice crops and prefer to keep fields fallow for labour input into rice cultivation is easily combined with off-farm work.[219] A recent survey of 300 smallholders in Badung and Gianyar showed that slightly more than 50 per cent of household labour was employed off-farm (Patrick 2004: 39). In the field research site, too, 42 per cent of interviewed farmers work off-farm and agricultural diversification is low.

Labour replacement with farm machinery will be influenced by on-farm labour availability. Presently, Balinese farmers still mainly rely on labour outsourcing if physically intense labour such as ploughing, transplanting and weeding is needed, because of the low cost. With a prospering economy, off-farm employment opportunities will increase, which may lead to a shortage of on-farm labour. By that time however, Balinese might be able to afford to invest in machinery to replace or reduce physically demanding labour input, for the future farmers' financial capacities will have improved as well. A much improved education system will also allow young Balinese to take a more sophisticated approach to farming.

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[219] See also chapter 6

There is a trend to more formalisation and push for uniformity of subak organisational and institutional structures. The government's official recognition of the subak in 1972 as a customary law society that deals with the irrigation and cultivation of rice has initiated this trend. The two most important ceremonies with respect to rice cultivation used to be organised by all the subak along one river at specific times in the rotational cultivation schedules.[220] These days, these ceremonies are organised on the regency level by the regency governments once a year to be attended by all subak heads of the regency.

There are also efforts underway to record and catalogue the rulebooks of every subak where subaks get funding to write down their rules to be deposited at the government. Since the early 1980s the government has been running subak contests (*lomba subak*) (Sudra 1993). Subaks are encouraged by sedahans to enter the competition, which requires them to compete against other subaks in different activities pertaining to the subak.[221] One of the contest activities is the writing down of the rules to be officially signed by the relevant authorities. Those subaks which win this yearly competition receive prize money to invest into the further development of the subak, such as for example infrastructural improvements or investment in collectively owned subak machinery. Yet the contest process is also aimed at producing greater conformity across subaks (Parker 2003: 153).

Since Green Revolution times, subak heads have become more involved in government-related activities. Subak heads were often invited to attend meetings of government agencies relevant to rice production and were expected to pass on acquired information to their farmers' groups (Sutawan 2002). These days, the government pays subak heads an honorary salary to do their job. While the salary is below an actual wage level, it

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[220] The two largest ceremonies at the caldera lake temple to ask the goddess for water and at the *Masceti* temple to ask for protection from pests and disease.

[221] These contests, which are aimed at fostering the preservation of the subak cultural heritage, the continued improvement of rice production, and the strengthening of the leadership and farming community, assess items such as the completeness and quality of ritual offerings, and subak infrastructure including religious structures (Sudra 1993).

nevertheless gives farmers the impression that subak heads have become public servants.[222] To receive their payments, subak heads in the field research area regularly meet at the sedahan's office on the premises of the village administration office. They wear public servant uniforms given by the government.[223]

In Bali rice has been and is still an important aspect of Balinese culture and ritual. The subak as an institution, although losing its importance, was and still is one of the three main pillars of Balinese society together with the temple congregation and the hamlet (Geertz 1980b; Warren 1993).[224] The aesthetics of rice terraces as well as the cultural aspects of rice cultivation and the subak as an important part of Bali's tourism image will need to be weighed against the costs it would require for its continuation. A current trend in and around Ubud and other inland tourist centres is that hotel owners are paying farmers who cultivate hotel amenities surrounding rice fields to grow local rice varieties and maintain the landscape. This type of payment is an example of voluntary payment by the private sector for ecosystem services. The beneficiary of the services are the hotel guests, who can continue to enjoy the beautiful landscape from their rooms and the hotel owners, who can avoid potential land conversion and maintain the marketing value of their enterprise.

With the continuing trends of households engaged in part-time farming, more formalisation of subak structures and a common willingness to preserve the subak cultural heritage, Balinese rice production may potentially move towards a system similar to the Japanese model. Yet there might be pitfalls with a further formalisation of subak structure directed

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[222] Each subak head in the field research site received a monthly honorary salary of Rp200,000 in three-monthly instalments while sub-subak heads receive Rp150,000. This amount is equivalent to Rp6,700 and Rp5,000 respectively a day, which adds marginally to the income from rice production yet is very meagre compensation for the time and effort they spend on subak matters.

[223] At these meetings, the sedahan is informed of any matters related to the cultivation and irrigation management, such as for example the rotational planting schedules, communal maintenance work, infrastructural repairs, planning of ceremonies and their preparation, land use changes, any funding that is required and issues arising with farmers.

[224] The hamlet is responsible for regulating community life. The temple congregation organises and coordinates the vast religious rituals related to a customary village, which comprises several hamlets.

toward an agency-managed irrigation system. Rules defined by an agency and formalised over large regions may be unsuitable for local management issues, with farmers given little freedom to adapt rules to changing circumstances as they used to do (Lorenzen 2008: 16).

In the past, irrigation systems that were exclusively or partially managed by an agency rather than by farmers themselves have generally struggled to perform (Coward 1980; Ostrom 1992: 23–39; Horst 1998: 78). Farmers were unmotivated to maintain communal irrigation infrastructure or share water equally, the staff appointed to operation and maintenance at the system level proved either poorly trained or short in numbers, and interaction between agency staff and farmers was flawed (Coward 1980; Ostrom 1992: 23–39; Horst 1998: 78). Sutawan et al. (1999: 15) found that the government's take-over of operation and maintenance on the secondary level had weakened the functioning of a subak in South East Bali as farmers had lost a sense of responsibility and ownership towards their irrigation system.

The willingness of Balinese to pay a premium for locally grown local rice varieties will possibly increase in the near future. Urban consumers prefer Balinese rice, especially traditional varieties. According to MacRae (2011), traditional and organic rice varieties sell for anything up to three times the ordinary rice price with demand higher than supply for these specialty varieties. Combined with the current national policy to focus on rice self-sufficiency of more than 90 per cent and limited rice exports, these two trends support the trajectory towards a Japanese model of protected rice farming.[225] It will ultimately be a balancing act for the government between consumer demands for affordable rice and the economic viability of farmers' rice production, and whether with greater economic prosperity returns to farmers will be increased as Greenland (1997: 186–7) suggests.

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[225] Indonesia has generally a deficit and thus allows only limited rice exports controlled by the parastatal organisation BULOG (See for example Sidik 2004; Haryati and Aji 2005).

SCENARIO 3 – COMBINED AGRIBUSINESS AND ECOTOURISM

I developed this scenario with the help of a particular case study, which I have followed over several years supplemented with observations of current initiatives, such as ecotourism and organic farming, and discussions with my Balinese colleague who was involved in the case study (Box 7.3).[226]

Ecotourism is defined as responsible travel to natural areas that conserves the environment and improves the welfare of local people (TIES 2006). Ecotourism can also include cultural, rural and farm tourism (Burger 2000: 18). There are several initiatives that support ecotourism or sustainable tourism, and have developed criteria for best practices or certification schemes.[227] A study in the US has shown that ecotourism can enhance environmental conservation and biodiversity and can contribute to the welfare of the local population (Winter 2003). Ecotourism has been growing fast at 20 to 34 per cent annually since 1990, with more than two-thirds of Australian and US travellers considering active protection of the environment and support of local communities to be part of a hotel's responsibility (TIES 2006). Agrotourism is an expansion on ecotourism, focusing exclusively of a tourist's experience of agricultural life at first hand.

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[226] Wayan Alit Arthawiguna from BPTP Bali has first brought this idea to my attention as he developed the notion of 'agroecotourism'. He is duly acknowledged here.

[227] The United Nations Foundation, which promotes sustainable tourism to protect local natural and cultural resources as tool for poverty alleviation, has developed criteria for standards development: http://www.unfoundation.org/global-issues/sustainable-development/promoting-sustainable-tourism.html, accessed on 27/1/2011. In 2008, the Global Sustainable Tourism Criteria (GSTC) were launched. They are a set of 37 voluntary standards for tourism businesses to implement: http://www.sustainabletourismcriteria.org/index.php, accessed on 27/1/2011. The Green Globe is a certification label for the sustainable operations and management of travel and tourism companies and their related supplier businesses that considers sustainable management, social-economic, cultural heritage and environmental issues: http://www.greenglobe.com/, accessed on 27/1/2011.

The main argument for this scenario is that the tourism industry develops towards ecotourism and sustainable tourism, which has a greater demand for certified environmentally friendly products and services such as locally produced traditional rice, organic or fair-trade certified rice, other certified food and non-food products as well as rice field and culture adventures. Assuming that a more affluent middle class has likewise a growing demand for eco-products, sustainable land practices and preservation would further encourage this trend. This in turn, combined with a growing number of young well-educated Balinese who might be interested in working in a more attractive and economically viable rice production system, would help to initiate projects all over Bali that combine tourism, marketing of products and services, and cultivation and irrigation of rice in a number of different ways.

This scenario would entail that the subak farming community —so far mainly combined in the irrigation and cultivation of rice— would embrace the marketing of its produce as unit. Land fragmentation would be put on hold with the formation of strong producer groups creating sufficient incentives for farmers to keep their land. The newly developed businesses would be able to find alternative and innovative ways to save and negotiate water successfully with competitors. The government would play its role in that its policy for a more diversified and competitive agriculture would be implemented and continuously monitored, decreasing the pressures on land and water.

With direct deals undertaken with the tourist industry various marketing models would emerge. Some subaks would directly be attached to a single or a number of adjacent hotels. Farmers get paid to deliver rice produced in an environmentally friendly way and at the same time maintain the landscape for tourists who stay in these hotels. Other subaks acquire a business manager who takes over the marketing of the rice crop combined with the cultivation of other high-value cash or niche market crops delivering to specialised markets in and around tourist areas, in expatriate communities and in the capital city.

This scenario requires young Balinese to return to the fields of their ancestors. They have benefited from a good education system, acquiring knowledge about sustainable agricultural practices and business management. They have managed to increase their cultivation area by establishing long-term relationships and contracts with landowners who have abandoned agriculture. These farmers have been able to make significant investments and commitments to the subak and the business side of it.

Box 7.3: Scenario three – combined agribusiness and ecotourism

There is a growing niche market worldwide that offers premium prices for organic produce (Willer et al. 2008; Elzakker and Eyhorn 2010: 10). In Indonesia 41,431 hectares are dedicated to organic agriculture in 2008 with the Indonesian government taking on an active role in support of organic agriculture (Willer et al. 2008: 18–19; MacRae 2011). Organic farming —not to be confused with traditional agriculture farming practices— abstains from using chemical fertilisers and pesticides and encourages sustainable farming practices such as biological pest control, increasing biodiversity on-farm, composting and recycling of harvest residues.[228]

Other initiatives focus on reducing chemical fertiliser and pesticide input, such as for example LEISA, short for 'low external input sustainable agriculture', which encourages farmers to protect and fertilise the crop with locally available material, and focuses on social aspects of production.[229] Fairtrade certification aims at supporting communities of farmers in their development for better business and decent working conditions, offering a premium price for the produce, which is expected to be invested into further community development.[230] Products that are labelled either fair-trade, organic or both, have gone through a certification and auditing process to ensure that the business has complied with specific standards in producing these products. Certification and support of organic farmers in Indonesia is, however, still minimal.

Another alternative to conventional rice production is the system of rice intensification (SRI), which has gained more attention in Southeast Asia in recent years. This alternative crop management system was originally developed in Madagascar in the 1980s (Watts et al. 2005). SRI requires changing cultivation techniques, such as for example different transplanting methods, reduced irrigation and mechanical weeding. Because of the changed

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[228] For more details on organic agriculture, visit the IFOAM (International Federation of Organic Agriculture Movements) website: http://www.ifoam.org/, viewed on 30/1/2011.

[229] For more information, visit http://www.leisa.info/, viewed on 30/1/2011.

[230] For more information, visit http://www.fairtrade.net/, viewed on 30/1/2011.

techniques, less seed, fertilisers, pesticides and water are used and higher yields can be achieved. In principle, SRI takes the same approach as the LEISA initiative, reducing external input and producing fertiliser from local material. In Indonesia, there are several field trials that apply SRI or similar systems with varied cultivation techniques, with mostly positive results.

The main reasons farmers and consumers alike turn to alternative production methods are concerns over human health, food safety, the environmental consequences of conventional agriculture, and farm household and farm animal welfare (Winter 2003: 507). Recent research into these alternative food production systems has raised concerns about the quality differences between conventional and alternative produce, in particular in regards to the plausibility and substantiality of the claim, and the ability to verify the labelling process (Watts et al. 2005: 29). Where farmers are mainly focused on production for their own consumption and the demand for organic produce has been artificially raised through the support of international aid projects, the benefit of the organic certification has been particularly questioned (Thavat 2010).

Corporate farming seeks to increase smallholders' advantages to compete on an international market in reducing production costs, increase tradable production volumes and the quality and standard of production. In contrast to contract farming, smallholders form a unity that negotiates with agribusiness partners or the market. Corporate farms can enter into contracts with agribusiness. Corporate farming has been mainly known in the western world, such as the United States and Eastern Europe, where farmers unite and become employees of a corporate farm to reduce production and investment costs and increase their benefits.

Current key reinforcing trends for scenario three in Bali

In Bali, there is a growing demand for a premium market of specialty products such as traditional and certified rice and other products by the tourism industry, a large expatriate community and a growing local middle class (MacRae 2005b: 217–8; MacRae and Artha Wiguna 2011). In recent years, numerous new food shopping centres appeared along the arterial roads through the tourist centres and urbanised areas. These shopping centres have a growing demand for local produce which could potentially be supplied by new market-oriented subaks.

In tourist areas, there are hotels that have entered into contracts with farmers who work neighbouring fields, paying them a wage for growing traditional rice varieties. On several occasions I met tourist guides who would take their customers to the rice fields, explaining all about the subak and rice cultivation. These latter events, however, are hardly connected with local farmers who are mere bystanders when the tourist guide collects his fees. There are several small initiatives all over Bali, but mostly of individual farmers who grow rice and other crops for a growing organic market which serves mainly the expatriate community and tourists.[231]

On the provincial level, the government and the local university alike recently announced a turn to more sustainable alternative ways of agricultural production while at the same time striving to link farming more effectively with the tourism industry. Accordingly, the government has provided funds for all subaks in Bali as part of the national revitalisation program and the provincial efforts to a greener economy (Atmodjo 2010).[232] The investments are expected to support farmers to maintain the subak and to halt land conversion. The School of Agricultures at Udayana University, the local public university

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[231] See for example accounts from MacRae in Inside Indonesia (91, Jan-Mar 2008): Food for the Future http://www.insideindonesia.org/edition-91/food-for-the-future and (MacRae 2011).

[232] Erviani, N.K., 2009.'Bali allocates Rp46.9b to revitalize 'Subak' System' (Jakarta Post), 14 April. Viewed on 20/2/2011 at http://www.thejakartapost.com/news/2009/04/14/bali-allocates-rp469b-revitalize-subak039-system.html, Erviani, N.K., 2010. 'Authorities working to revive Subak' (Jakarta Post), 5 October. Viewed on 20/2/2011 at http://www.thejakartapost.com/news/2010/05/10/authorities-working-revive-subak.html.

in Denpasar, Bali, has just announced that it plans to develop a model of agrotourism in Bali to promote Bali's traditional farming system, the subak.[233]

The ability of subaks to develop into more market-oriented organisations would be one of the keys for this scenario to become reality in one form or the other. Yet there seems to be certain conservatism inherent in the subak. The main weakness of the current set-up of the subak is its lack of a business side for marketing the produce. Geertz (1972: 29) stressed that subaks are by no means collective farms because the subak never engages in the actual process of cultivation or marketing. In fact, the rules set out in the awig-awig mostly concern matters of irrigation, rituals and administration (MacRae and Artha Wiguna 2011). The subak offers solely an institutional framework to support cultivation and irrigation of the rice crop and to make sure that the required rituals are appropriately performed.

Marketing has always been organised separately. Since the Green Revolution, rice has been purchased by traders directly from the fields pre-harvest. Farmers have little knowledge about the market situation and how to access the more exclusive niche markets. According to a study undertaken in 1999, the main obstacles identified for subaks to turn into agribusiness are low motivation, for the benefits are unclear, a high percentage of sharecroppers who are unwilling to invest, as well as low business managerial and organisational skills of farmers (Sutawan et al. 1999: 12; Sutawan 2000b). A local project with several subaks involved producing organic rice suffered similar issues.

The project I have followed began with a few farmers in a subak in 2005 and has since grown to several subaks that grow almost exclusively organic rice. The project started out initially because farmers had an organic 'waste problem' which was soon turned into an enterprise producing organic compost with the help of a local agricultural scientist and a

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[233] The Jakarta Post, 2011. 'University seeks to develop agrotourism in Bali', 23 January. Viewed on 2/3/2011 at http://www.thejakartapost.com/news/2011/01/23/university-seeks-develop-agrotourism-bali.html.

local farmer-entrepreneur. The project has since expanded and encouraged farmers to invest in more cattle, compost the cattle manure and progressively substitute compost for chemical fertiliser. Farmers have noticed an increase in biodiversity in the fields, have lower production costs and gained new employment opportunities in the production and sale of surplus compost (MacRae 2009: 6).

Low input costs and high market prices have also been noticed by organic farmers in other places in Bali (MacRae 2005b: 220). Organic farming on the other hand generally involves more labour, which has not been mentioned by MacRae as an obstacle to conversion. The main labour involved in organic production I noted that is different to conventional farming is related to the production and application of organic compost. Chemical fertiliser has a higher nitrogen content, which implies that to achieve similar results with the organic compost, a significantly larger amount of compost has to be applied, in the range of four to six times more. This compost has to be produced and carried to the field, which involves significantly more time and labour. When I revisited my field site I learnt that one of the subaks was involved in an organic project, applying composted natural fertiliser and SRI practices. Yet the project was abandoned after one cultivation season. Farmers argued that the labour-intensity increased significantly, but that with no organic market rice had to be sold at the normal price and thus, no incentives were really created.

The combined marketing of organic rice produced in the highland project subaks experienced several setbacks. Initially, the majority of their rice was sold on the local market with only a small margin above the ordinary rice price (MacRae 2011). To access the specialised markets for a higher price, a company was set up which was led by businesspersons from Denpasar. The idea was that farmers would be supported in the development of quality produce to access national and international markets for a better price. Farmers were, however, very sceptical towards the business model, which had to be revised several times. The trust building turned out to be more difficult than expected. The anticipated transformation of the subak into a commercial agribusiness eventually failed due to gaps between priorities and worldviews of farmers and the company, and the company's lack of knowledge about farming (MacRae and Artha Wiguna 2011). The subaks in the project area have since joined a government initiative which aims to help local farmers' organisations to start the marketing of their produce (MacRae and Artha Wiguna 2011).

The key feature for a change to the production of organic rice in that project was that they are located in the highlands, where urbanisation and land conversion is still very low, most cultivators are full-time farmers and average land owned or sharecropped is above one hectare. MacRae (2009: 6) adds that the trust and respect among the local farming community of two people—the local farmer entrepreneur and the local agricultural scientist—was important for the project.

In subaks where the percentage of sharecropping is high, this scenario will not offer a viable future. Sharecropping agreements are volatile and can change from harvest to harvest, unless those who sharecrop are able to establish longer term relationships with landowners or enter more formal written contracts to lease the land. MacRae (2011) emphasises this issue too in regards to the project mentioned above: those whose holdings were small or who were tenants could not become economically viable. A further hindrance to this scenario becoming reality is the fact that many households in Bali practice part-time farming on small-sized holdings. These farmers invest their time and energy in finding better-paid off-farm work rather than committing to new ideas and investments on-farm (MacRae 2011).

Full-time farmers with larger land holdings and secured sharecropping arrangements will be more likely to organise the marketing of their produce cooperatively. The business model will have to be adapted to local circumstances, with those involved in the business side of it clearly needing a strong trust base with the farming community in order for the marketing to become a success. Once the marketing side is organised, there will be little obstacles in the way as current demand for alternatively produced rice is higher than supply.[234] Further research and hands-on experience will be required for a better linking with the tourism industry in order to become a viable part of this scenario. Possible services that subaks could offer would be for example, a day in the rice field, with tourists performing tasks in hands-on learning about rice cultivation and irrigation.

If this scenario became reality, subaks would turn into entrepreneurs marketing their premium produce to the growing niche market. While some subaks would deliver the produce to shopping centres, hotels and restaurants, others would offer tourism activities on-farm. Agricultural production would be diversified yet still have a main focus on rice production. The cultural heritage of the subak would be preserved with this scenario yet it might also be amended to include the marketing side.

CONCLUSION

The three scenarios describe different potential trajectories of the subak (Table 7.2). Depending on government implementation of its revitalisation policy and its ability to monitor land conversion, any of the scenarios can become more likely. The trajectories also depend on the future generation of farmers: will they have gained a better education that allows them to be better positioned with respect to risk taking and investment into their farms? A further key point in defining the scenarios is how the situation develops with land conversion, water availability and sharecropping arrangements. At present, the sharecropping arrangements appear to be a major obstacle for subaks to follow scenario three.

What is important to keep in mind in discussing the scenarios is that subaks and rice cultivation in different regions faces different challenges. As exemplified by the highland

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[234] I W. A. Arthawiguna 2008, personal communication.

subak project, farmers in the uplands usually tend to own larger areas of rice fields and a smaller percentage of farmers sharecrops fields. In those subaks that are close to urban areas or tourist centres the incentive to convert land is high, yet there are also options in finding new markets for there is a greater demand from consumers living nearby. This demand is not only for food products but also for recreational activities. Accordingly, any of the scenarios I have developed could become reality in different areas.

Table 7.2: Overview of three scenarios of alternate basins of attraction

	Scenario 1 - Disintegrated WUA	*Scenario 2 - Japanese PES*	*Scenario 3 - Agribusiness Ecotourism*
Features	Subaks have disintegrated with a loose framework to share water, a few grow rice but water situation is critical, land leasers grow high-value cash crops on short-term basis, using pumps for irrigation	Japanese model, government/society pays for ecosystem services that rice terraces remain intact and that rice is produced on remaining cultivation areas with strong policies to protect national rice market	Agribusiness model, subaks enter business relationship with tourist businesses with support for processing and marketing, specialising in combined eco-agriculture and eco-tourism
Water	High scarcity of water, non-negotiated with other stakeholders, high competition for diminishing water resources	Medium scarcity, government implemented negotiations with other stakeholders	Medium scarcity, dealt with different cultivation methods, negotiated with other stakeholders
Labour	High shortage and replacement of local labour, younger Balinese do not return to farming, tenants mainly and a few remaining old age owners	Medium shortage, mechanised, some younger generations return, mixed tenants and owners, paid by government	Medium shortage, younger generation returns with better skills, owner-tenants mainly, able to accrue additional land
Land	Farm sizes become smaller, high land fragmentation	Farm sizes varying, fragmentation put on hold by payments for ecosystem services	Farm sizes slightly bigger, fragmentation, put on hold by strong producer group contracts
Irrigation facilities	Needing repair or broken, replaced by pumps for river or groundwater	Intact, maintained by government officials	Intact, maintained by producer groups
Financing	No financing	Government-paid ecosystem services	Producer groups or cooperatives, plus business manager, tourism industry invests
Subak head	No head or no means of power nor influence	Becomes full government official	Leader of producer group (cultivation and irrigation)
Production	Rice for subsistence (water insecurity leads to lower yields) and high-value cash crops	Rice for national market only	Niche market or high value crop production, with possibility of export of specialty rice
Processing, Marketing	Short-term contract farming with sharecroppers/leasers	National government controls price and sale	Organised by agri-business entity
Institutions	Non-existent or ineffective	Formalised and uniform rules for all subak	Strong independent institutions, redefined to adapt to business side
Cultural heritage	Disintegrating	More or less maintained	Maintained, adapted
Household income	Part-time farming, poor	Combined part-time farming and off-farm work, income derived from higher off-farm	Tendency to full-time farming, moderate to good income from farming

Organic agricultural movements currently tend to spring up especially near tourist areas and in the mountainous regions of Bali where either farming conditions are ideal or markets exist. In the research site, all scenarios may happen. Yet with the current developments of heavy and largely uncontrolled urbanisation and industrial development, a variant of scenario one might very soon begin to develop. Here, many farmers see more benefits in selling their land rather than cultivating it. Especially those fields close to roads are prone to be sold quicker as land prices are raising fast, which will lead to high land fragmentation.[235]

The scenarios are a mere beginning of a future discussion that will be needed to define the value of the subak and rice cultivation in Balinese society. Shoemaker (1995) discussed a detailed process that includes several steps for developing scenarios for corporate businesses, which include framing basic pre-conditions, constructing basic themes, checking plausibility, and identifying research needs. For my scenarios I have followed part of his suggestions.

A future exercise would be to redefine the suggested scenarios, which would allow identifying further research needs and developing models in a participatory process integrating multiple stakeholders. Stakeholders could include members of the subak, different governmental departments involved in irrigation and cultivation matters, and members of the public as well as subak scholars. A more detailed analysis of market and policy trends, population growth trends, and tourism industry development as well as environmental issues could supplement the further conceptual development of the scenarios.[236]

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[235] High land fragmentation (*Landschaftszerschneidung*) is high on the public agenda in Switzerland and other densely populated regions in Europe and a well-researched area for the ensuing impacts such as loss of biodiversity, decreasing mobility of flora and fauna, reduction or loss of habitats, as well as increased conflicts over type of land use (Jaeger 2001).

[236] Rice fields are a significant producer of the greenhouse gases methane and nitrous oxide, which contribute to climate change and which will have to be mitigated (Matsuno et al. 2006). Rice field emissions of methane are estimated at between 12 and 20 per cent of total methane production (Matsuno et al. 2006). Excessive use of

With respect to my conceptual model of the subak as social-ecological system, scenario one and two represent alternative basins of attraction, while scenario three represents an adapted subak system. In scenarios one and two, the farmer-managed canal-irrigated system dissolves to become either a dryland-crop production system (scenario one) or an agency-managed canal-irrigated rice cultivation system (scenario two). In scenario three, the subak has remained a farmer-managed canal-irrigated rice production system, yet it has become united in marketing its produce. Accordingly, the shape of the basin of attraction has changed.

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pesticides and nutrients also have negative effects on the environment influencing long-term productive capacity of soils and water (MA 2005).

CHAPTER 8

CONCLUSION

Irrigated rice cultivation in the intermontane basins of Southeast Asia has a long history. The rugged terrain necessitated the development of specially adapted techniques to build terraces along the contour lines of the slopes and a gravity-fed canal irrigation system to capture water and deliver it to the bunded fields. The growing of rice in inundated fields year after year proved to be very productive with fertility of soils sustained through biochemical processes of the submerged soils and the nutrient-rich irrigation water. The construction and maintenance of such elaborate rice production systems required the continued willingness of generations of farmers to invest labour and to collaborate in sharing the costs and benefits.

One of these farmer-managed canal-irrigated rice cultivation systems is the subak in Bali, which is famous for its efficient water use and high rice productivity. The subak is firmly embedded in local Hindu culture with an institutional framework that guides farmers and subak heads in sharing water equitably. The allocation and distribution of water is proportional, based on principles of transparency, while irrigation system maintenance is organised in an egalitarian manner. The sustained productivity of the fields at a high level is mirrored in sophisticated offerings and rituals that govern cultivation and irrigation of rice and which require a considerable amount of time, labour and finances to prepare and celebrate. Rice and water are essential ingredients of Hindu Balinese religion. Every prayer in the temple ends with a sprinkle of holy water (*tirta*) on the heads and hands of the congregated worshippers. Grains of uncooked rice are placed on forehead, temples and throat with some eaten and the rest cast over the head. Every offering contains rice in various forms: uncooked, cooked, coloured or plain. Water sanctified at the temple is brought home and to the rice fields to protect both farmers and food crops.

The twentieth century brought considerable change to the subak as well as to many other communal systems by modernising and commercialising rice production to feed a rapidly growing population. The Green Revolution introduced new agricultural technologies that changed the way rice was cultivated and irrigated. Meanwhile, a larger process of structural change began which diversified rural economies formerly mainly based on agriculture. Although small-scale farming persists these days, contemporary farming communities engage in diversified livelihoods with part-time farming and multiple off-farm occupations becoming the norm. Expanding urban settlements and industrial development are competing with the agricultural sector for resources, which raises questions about the future of the subak and other similar rice production systems.

In Bali, the significance of rice and water, and the subak in daily life declined with the diversification of the rural economy and a prospering tourism industry. Diets are diversifying with rice consumption decreasing.[237] Younger Balinese turn their backs on working in the mud. They prefer the numerous and more attractive jobs offered off-farm by prospering tourism and related industries. Rice cultivation is in competition for land and water with other industries and expanding urbanisation. The remaining farming communities, particularly in the peri-urban areas, struggle to make ends meet with less labour, land and water. On the other hand, the terraced landscape that has evolved over centuries as an inherent part of Bali's cultural landscape —carefully fine-tuned and maintained by the subaks and generations of farmers— is one of the attractions for tourists of the island. The subak is also one of the five public corporations of present day Balinese

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[237] Per capita calorie consumption in Indonesia between 1999 and 2009 shows a clear trend toward more protein-rich foods and ready-made meals while rice consumption has decreased by 12 per cent in the same period (BPS 2010a).

village polity around which Balinese social life is organised.[238] In that respect, the subak acts as a preserver of this specific cultural heritage, the ways in which rice is cultivated, irrigated and celebrated.

At the beginning of my thesis, I have posed questions as to whether the subak as a communal farming system has the necessary tools to adapt to the contemporary challenges, whether it can continue to exist, maintain its productivity and efficient resource management, and preserve the cultural heritage. To answer my questions, I have used social-ecological systems and resilience theories to develop a conceptual model of the subak that served as analytical framework for the analysis.

Social-ecological systems theory implies that social systems and ecosystems are interconnected, that components of these systems are interdependent, interact with each other and changes to one component impact on other components. The way natural resources are managed (social system) influences the way the natural environment (ecosystem) responds and conversely a specific ecosystem influences the way natural resources are managed. Social-ecological system theory recognises that such systems are complex because these multiple components interact in non-linear ways. The subak system is equally complex in that it consists of multiple layers of physical and social structures that overlay each other and define the way irrigation is managed and rice is cultivated.

To acknowledge the multiple aspects of what constitutes a subak, the conceptual model consists of four dimensions that are demarcated by dimension-specific thresholds: (1) a physical dimension (rice fields and irrigation infrastructure), (2) an ecological dimension (ecological features of the rice agroecosystem), (3) a technical dimension (the ways in which rice is cultivated and irrigated), and (4) an institutional dimension (the rules-in-use that guide farmers in the management of the natural resources and the production of rice).

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[238] Together with the customary village and hamlet (*desa adat* and *banjar adat*), the administrative village and hamlet (*desa dinas* and *banjar dinas*), the temple congregation (*pemaksan*), and kinship groups (*dadia* or *soroh*).

Using four dimensions to analyse the subak allowed for an interdisciplinary approach that is more holistic in seeking to understand the dynamics of change by accepting that, in reality, the complexity of such a system can never be perfectly represented.

The added concept of resilience in my analysis provides a way to understand how the subak has evolved over time and how it continues to exist in present times. Resilience implies that social-ecological systems are defined by thresholds, which can be approached or potentially crossed if a system is exposed to a shock or disturbance. To remain resilient requires the system to reorganise and adapt to imposed changes without losing its specific identity. I have considered the Green Revolution and rural diversification as two such disturbances; the latter is still ongoing.

Bali has attracted national and international researchers from various disciplines who have written extensively on various aspects of Balinese life in different times. There is a library of scholarly work ranging from performing arts to literature, ethnography, tourism, development, economy, ecology, agriculture and engineering. Interestingly, this large body of literature tends to be compartmentalised within the different disciplines, the studies interacting only marginally with each other by citing the odd article from another discipline here and there. Likewise, several scholars have extensively researched the subaks, but only a few have attempted an interdisciplinary approach.[239]

This is in stark contrast to resilience and social-ecological systems theories which work at the crossroads of disciplines and methodologies, promoting interdisciplinary integration rather than compartmentalisation. In this thesis, I have attempted to work as inclusively as possible, reading as widely as feasible and working with different methodologies. I have availed myself of agricultural science, economics and policies, institutional theories,

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[239] One researcher who cut across his fields of study, collaborating in his research with other disciplines, is Stephen J. Lansing, an anthropologist, who has been working together and publishing research with archaeologists, and institutional economists as well as information technologists, mathematicians, biotechnologists, marine scientists, and ecologists.

political economy, irrigation engineering, and ecology combined with an extensive literature review on Bali using my conceptual model of the subak system as the guiding framework. I have supplemented the analysis with quantitative and qualitative data gathered during one and a half years of intensive field research that included anthropological as well as agricultural science methodologies.

The need to combine different disciplines to the analysis of the resilience of social-ecological systems represents both a strength and a challenge in keeping a justifiable balance between academic rigour and in-depth analysis, and inclusiveness of interdisciplinary perspectives and methodologies. In this thesis I was selective, applying in-depth analysis to the material at hand specifically where it supported the argument, for a comprehensive analysis of all aspects would have gone beyond the scope of this thesis. A future study might follow and amend the insufficiencies and gaps.

SOCIAL-ECOLOGICAL SYSTEMS AND RESILIENCE THEORIES

The application of social-ecological systems and resilience theories is still in its infancy. Although the concept of resilience was developed in the early 1970s, it was initially only applied to ecosystems. While a social perspective was added quite early to the resilience concept in terms of adaptive ecosystems management, the first book on linking social and ecological systems was published in 1998 (Berkes and Folke 1998; Folke 2006: 255). Unsurprisingly, many of the papers published since, as well as the workbooks that the Resilience Alliance provides for resilience assessments, still have a strong focus on ecosystem management although the theories explicitly advocate an integrative approach.

It is the ecosystem that potentially crosses a threshold or several thresholds. It is the ecosystem that, if losing its resilience, is potentially rendered unproductive or unsuitable for a group of people or a society to beneficially make use of its resources. Accordingly, the people develop adapted management strategies to prevent the ecosystem from losing its resilience.[240] The people or society manages for resilience of the *ecosystem*. The integrative approach combining social systems and ecosystem appears to be relapsing into the dichotomy of society, or the social system on the one side, and the ecosystem on the other. With respect to the conceptual model of the subak as a social-ecological system, the social and ecological components are inseparable for the social component cannot exist without the ecological component and vice-versa. Therefore, Balinese farmers only have a limited capacity to manage for resilience of the subak as a social-ecological system. The subak is just there as long as farmers are willing and interested in growing rice according to the institutional guidelines that they have set upon themselves to collaborate with. The interest of farmers to continue growing rice is also dependent on rice price, agricultural policies or regional climate events —factors which local farmers are unable to influence.

The integrative and comprehensive approach emphasised in the resilience and social-ecological systems theories poses challenges. Scholars also seem to have trouble with the issue of inclusiveness, such as the system boundaries of social-ecological systems. To determine the boundaries of the ecological component of a social-ecological system is generally straightforward because the ecosystem is very much location-specific. The boundaries of the social component, however, create a challenge because they are much more fluid in spatial and temporal terms. Theoretically, if we were to emphasise the strong interconnectedness that is inherent in the term social-ecological system, the boundaries one imagines would have to be one single imaginary line around the system in spatial and temporal terms.

Given this premise, the representation of humans, in particular, in social-ecological systems becomes inaccurate because they move in and out of the system. Are humans a part of the system or not? Humans make individual choices about their livelihoods that have a great impact on their own lives but little impact on the social-ecological system they are 'using' or

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[240] (See for example Carpenter et al. 2001; Resilience Alliance 2007a; b).

are temporarily 'part' of. For example, a Balinese farming household can be a 'temporary part' of several subaks because they might cultivate more than one rice field in different subaks and they might also cultivate a piece of dry land (*tegalan/kebun*) that is not part of any subak, yet could still be in its own way considered a social-ecological system. There are also subtle nuances of tenure, type of labour provided (gender, exchange, paid, household) and individual livelihood choices which seem to vanish in the resilience assessment. Whether, for instance, exchange or paid labour is used for the cultivation does not influence the resilience of the subak system. Nonetheless, it is important on the individual household level because inter-human relationships have changed. In developing my conceptual model, I tried to avoid integrating humans as a fixed component into the social-ecological system. In my view, it is the farmers' labour, techniques, knowledge, experience and the institutional framework they apply that form the social components of the subak as a social-ecological system.

Resilience theories imply that a system that is continually exposed to change and adapts accordingly, continuously evolves. If, however, a system with continuous evolution eventually develops into something quite different, is it then still the same system? In this thesis, I have attempted to clearly define system boundaries using thresholds that identify the subak as a farmer-managed canal-irrigated rice production system. If system boundaries are crossed, and resilience lost, the subak as social-ecological system would turn, for example, into an agency-managed rice production system, such as in the Japanese case scenario. On the other hand, it could be argued that the transformation to an agency-managed system was just another adaptation. It appears that in the end, the choice of what constitutes a particular system and what is beyond is very subjective depending on each individual researcher's definition of the system's identity and the thresholds that demarcate the system boundaries.

Finally, the multiplicity of terms that the Resilience Alliance supplies for a resilience assessment in its workbooks and on its website poses a challenge in itself because several terms appear to have very similar, if not identical meanings yet the context is different and real-world applications of how to proceed are lacking. For instance, the very term 'resilience' is sometimes defined as the combination of 'identity, functions, structures and feedbacks', sometimes as 'structures and controls' and other times as 'identity' that includes the other terms (Carpenter et al. 2001; Holling 2001; Walker et al. 2004; Resilience Alliance 2007b). The myriad of papers since produced offer several variations of this definition and some highlight the multiple meanings. I think, however, that an ongoing discussion is needed to establish a better and uniform understanding of what these terms in the real world exactly imply, especially because the very term resilience is crucial in defining what constitutes the social-ecological system and what the boundaries are.[241]

Given the challenges that these concepts present (de-linked social-ecological systems, definition issues and lack of application), I adapted and simplified the suggested assessment process and developed my own conceptual model of the subak as a social-ecological system.[242] I defined the basin of attraction for farmer-managed canal-irrigated rice production systems in which the subak as a social-ecological system conceptually resides using the four dimensions described earlier. For each of the four dimensions I determined thresholds that I consequently used for my analysis of the events that have changed and shaped the subak system. I used the threshold discussion to support my evaluation of the

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[241] (See for example Cumming and Collier 2005; Gallopin 2006).

[242] For example, I omitted a detailed analysis of the adaptive cycle, an iterative and cyclic process, which is another essential characteristic of social-ecological systems. The adaptive cycle features four distinct phases, in short: a period of rapid growth, a long phase of conservation, a very rapid breakdown and a reorganisation phase (Holling 2001: 393–5; Walker et al. 2002; Berkes et al. 2003a: 16–8). Knowing in which phase a system resides may help in choosing the correct management and policy interventions (Walker et al. 2002; Resilience Alliance 2007b). To assess in which phase a particular social-ecological system resides, it is necessary to develop a historic profile which identifies periods of major events that changed the system (Walker et al. 2002; Resilience Alliance 2007b). Although the number of events is not defined, it appears that there should be more than one to identify recurring patterns and different phases. To develop a historic profile for the subak that goes beyond the twentieth century is difficult because, although research material is available, scholars debate in which form the subak may have existed in colonial and pre-colonial times (see chapter 1 and chapter 4). In my analysis, I did identify two events that changed the system (the Green Revolution and rural diversification), but I was unable to determine with certainty in which phase the system might reside given the limited scope of the historic profile. On the other hand, I availed myself of the idea of rapid breakdown as an indicator that thresholds are being approached or crossed. A future resilience assessment of the subak system might be able to go into more details.

positioning of the subak as social-ecological system in the basin of attraction; and to assess whether any of the two examined events have pushed the system across thresholds.

Considering the subak as a social-ecological system acknowledges the complexity that renders a detailed analysis difficult. The thresholds I have defined and used for the analysis I considered as most crucial in determining the resilience of the subak. Nonetheless, I am well aware that they only ever are partial and subjective, representing fragments of the 'true' boundaries that demarcate the resilience of the subak as a social-ecological system. In my choice of thresholds, I had to be inventive given the limited availability of real-world examples. I included quantitative and qualitative thresholds, which may be debatable.[243] In spite of these limitations, this thesis might provide useful insights in how to tackle resilience assessment of small-scale social-ecological systems and their (combined social-ecological) resilience.

Ideally, an assessment involves a whole body of expertise of practitioners and researchers as well as other constituencies to include a diversity of different perspectives (Resilience Alliance 2007a; b). Here, I have relied on the available literature on subaks as well as my one and a half year-field experience as a means to grasp the variety of perspectives needed without direct stakeholder participation. This thesis might therefore serve as a precursor for a more in-depth study on the resilience of the subak as social-ecological system in Bali that includes active participation of stakeholders.

RESILIENCE ASSESSMENT OF THE SUBAK

Evaluating the subak as a social-ecological system using four dimensions was like looking at the subak through different lenses. Applying the ecological lens and tracing the subak's

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[243] For example, the local origin of members threshold is a qualitative threshold as I am unable at this point in time to define what percentage of membership is required to be of local origin to define this farming system as a subak.

evolution through time from before the Green Revolution to the present indicated that major changes occurred at the time of the Green Revolution with the introduction of new agricultural technologies. The subak's ecological dimension was characterised by high biodiversity levels, low external input of nitrogen and a staggering of planting seasons to control pests and diseases. At the time of the Green Revolution, both the increase in nitrogen input and decrease of biodiversity combined with the abandonment of staggered cultivation cycles led to temporary breakdowns in rice production. While nitrogen input and biodiversity levels remained changed, the return to the staggering of cultivation restored the growth of rice productivity. Current changes caused by rural diversification appear to have mainly affected the water supply. Yet so far, subaks are managing temporary water shortages with water borrowing and staggering of the cultivation season. The current trends of expanding urban and industrial development will influence the future availability of water.

Applying the physical lens to the subak showed that the subak features an intricately devised irrigation system and associated temple structures, and contiguous areas of bunded rice fields. The hierarchically set-up irrigation system contains a dam, tunnels, a bifurcating canal system and proportional water dividers based on continuous flow, which was partly permanently and partly temporarily constructed before the Green Revolution. With the Bali Irrigation Project, as part of the Green Revolution in Bali, the irrigation structures were altered and new irrigation technology introduced which ignored basic principles of proportional water division and continuous flow. The resulting water shortages and conflicts over joint management rights were only resolved once the basic principles were restored and new management organised. The one-dam-one-subak irrigation system set-up was permanently changed to the one-dam-several-subaks irrigation system. The ongoing diversification of the rural economy affects mainly the availability and contiguity of land, in particular land in close proximity to urbanised areas and tourist centres where land conversion and fragmentation is high. So far, the subak works around converted land areas.

Long-term water availability and communication among farmers, however, will be affected if these developments continue.

Looking through the technical lens at the subak reveals that traditional labour techniques and temporary irrigation facilities require high labour input into the cultivation, irrigation and ritual celebration of rice. The ability of the farming household to organise labour for cultivation —using exchange labour for peak demands— and of the subak to organise labour for irrigation maintenance appear to be crucial for a well-functioning rice production system. With the introduction of the new Green Revolution technologies, labour productivity has increased. Labour for maintenance of the irrigation system has become minimal with the degree of permanent irrigation structures increased. Annual labour input for cultivation increased because farmers now grow more rice crops per year (up to five crops over a two-year period). The change from a mainly subsistence-based economy to a cash-based economy changed labour relations from exchange to paid labour. This change did not, however, affect the ability to coordinate labour to attend to peak demands in the cultivation of rice. Rural diversification allowed more household members to work off-farm. Peak labour demands are flexibly managed on the household level, depending on the availability of intra-household labour and the finances to hire extra-household labour. A current trend is a slight increase in irrigation maintenance work, in particular for subaks in peri-urban regions given the close proximity to urban and industrial settlements and their ways of disposing waste into irrigation canals. This increase in labour maintenance may render future mobilisation of labour more difficult.

Looking through the institutional lens shows that the subak is characterised by principles of equality, transparency and egalitarianism, a ritual system attached to the temple network and social monitoring tools that go beyond the subak boundaries. The principles of equality, transparency and egalitarianism guide farmers in sharing water and maintaining irrigation facilities. The decision-making about the timing of the cultivation season is dependent on a ritual system attached to a hierarchically linked temple network located at each water diversion weir. Compliance to rules is reinforced by the fact that Balinese are organised in incongruently overlapping social groupings, which function as a social monitoring tool. The Green Revolution indirectly affected the institutional dimension. The changes applied to the physical infrastructures and instructions to abandon the staggering of cultivation seasons corrupted the guiding principles and disregarded the informalities of daily irrigation management. With the acknowledgement of the importance of the temple network and the creation of inter-subak federations for water allocation and cultivation cycles coordination, the institutional subak framework became reinstituted. Rural diversification, so far, has had little impact on the institutional dimension. Presently, the trend of growing land fragmentation —compartmentalising rice fields and reducing communication among neighbouring farmers— may influence in the long run the informal rules of everyday water management. The trend of local labour being replaced with non-Balinese —for rice harvesting and cultivation of high value cash crops in the rice-fallow periods— may likewise influence the manners in which water is shared. Both these trends will affect the efficiency of the irrigation system.

PERSEVERANCE IN THE FACE OF CHANGE

This thesis has provided detailed results of how rural diversification affects subaks in peri-urban areas in Bali. At the same time, this study allows for a local perspective on current issues of national and supra-regional importance, as research on contemporary Southeast Asian farmer-managed rice production systems is rare. For the time being, the subaks of my field research appear to be resilient to the forces of rural diversification. Water shortages are managed internally both on the household and subak level, and both households and the subak are able to mobilise labour to attend to impending work in cultivating and irrigating rice. Land fragmentation is occurring, yet so far, appears to have little impact on the overall functioning of the subak.

The trend of increasing withdrawal of land, water and labour is likely to continue in future given a prospering rural non-farm economy. There is further a danger that Bali might end up in an economic pitfall with a focus too narrowly on tourism. At the same time, Indonesia's ambitious national development plan foresees a revitalisation of agriculture and Bali to retain its role as one of the centres of national food production. This plan can only be realised and current trends put on hold, if existing policies and investments are effectively implemented and monitored, and incentives created for Balinese farmers to continue to farm such as for example better education and improved marketing options or financial support for maintaining the cultural landscape.

The three scenarios which I developed in the last chapter have shown different trajectories that the subak may follow depending on how current trends and issues unfold. Subaks in peri-urban areas and near tourist centres clearly face different challenges to those subaks in the uplands where the pressures on resources is less intense and off-farm employment further away. In peri-urban areas, clearly, the threat for subaks to disappear is greatest given the current trends. On the other hand, I demonstrated that the subak has so far remained resilient to both the Green Revolution and ongoing rural diversification. The subak incorporated new agricultural technologies, and allowed farmers more flexibility in pursuing a diversified livelihood, while all along tenaciously retaining its cultural and institutional framework that supports farmers and subak heads alike in dealing with water shortages.

Ultimately, it lies in the hands of Balinese society, the government and farmers alike whether the subak as a farmer-managed irrigated-rice production system can survive. Subaks and rice cultivation as a cultural heritage will need to be weighed against the costs it would require for its continuation. Recent developments, such as the nomination for inscription on the UNESCO world heritage list of three specific sites related to subak activities,[244] or the new agrotourism model promoted by the local university, demonstrate that Bali is aware of the threat of the potential disappearance of the subak.

Alternatively, improved education, the opening of new marketing opportunities for speciality produce (rice or other high-value cash crops), increased viability of payments for ecosystem services options combined with the inherent characteristics of Balinese social organisation may open up new pathways for farmers to continue the subak in ways that are unimaginable as yet. It is the intent of this thesis to put the subak back on the agenda and encourage discussion to begin imagining these new futures of Balinese irrigated rice cultivation.

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[244] The final nomination of cultural landscapes centred on subaks and water temples has been submitted in 2009 and is currently reviewed by technical staff at UNESCO in Paris (S. Lansing 2010, personal communication). For more details visit: http://whc.unesco.org/en/tentativelists/5100/, accessed on 4/2/2011.

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APPENDIX I – RESEARCH METHODOLOGIES

Qualitative data collection included participant observation and observing participation in farming households' daily activities, in sub-unit and subak organised meetings, maintenance sessions and ceremonies, focus groups with farmers, and semi-structured and ad-hoc interviews with women farmers, farmers, subak heads, government agencies involved in either irrigation or cultivation of rice as well as other key persons, such as local and international academics working in similar areas, villagers and people I met casually on the street. Participating in the cultivation and irrigation of a rice field of 0.2 hectares in a subak of the research area allowed access and insights into practical day-to-day crop and irrigation management knowledge. Two farm households supported me in this undertaking. They were also a useful resource for ad-hoc interviews and discussions about different issues of rice farming and the subak. The focus groups were a great opportunity to test my assumptions and preliminary conclusions. While in the field I presented preliminary research findings at three international conferences which allowed for further evaluation and exchange with academics in similar research fields.

The quantitative data which I collected was in the form of detailed time use surveys with three farming households, a structured farmer survey with 178 farmers and subak head survey with 11 subak heads, geo-referencing of irrigation infrastructure, and measurements of water flow. The time use surveys were undertaken with three families who variably engage in farming. Participants recorded their daily activities for the previous day for a period of five months.[245] The farmer survey was conducted with the help of informants who

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[245] All participants individually filled in survey sheets on a daily basis for the previous day. The survey sheets were divided into half-hour steps, starting at four o'clock in the morning until midnight. The information collected contained what type of activity, with whom and where the activity was carried out. During an initial trial period of two weeks we visited the families every day to discuss difficulties and to adjust the time use sheets to the suggestions of the participants. After this trial, we gathered the time use sheets once a week at the families' homes, skimmed through the sheets and followed up ambiguities directly with the participants at the time of collection. The activities were coded and recorded in Microsoft Excel. I then used statistics software (GenStat) to calculate frequencies and Excel to analyse the data.

visited farmers in the rice fields. The informants interviewed these farmers using our developed questionnaire with questions on household composition, cultivated rice fields, off-farm work, perceived difficulties in terms of water allocation and distribution, the role of ceremonies, the importance of the rule book (awig-awig) and the expected qualities of a subak head. Measurements of water flow were taken at the secondary canal level in the period from May 2005 to November 2005 where the water is diverted into the single subaks. For the analysis of the data I used a statistics program and Excel, and mind maps complemented with a detailed literature review.

To understand the processes in the ecological dimension of the subak I recorded harvest data and studied weeds, as well as the use of fertilisers and pesticides. Detailed interviews with individual farmers helped me to understand the changes that took place with agricultural modernisation on the field level. I gathered data on water measurements for four dams at the lower course of Penet river from the department of public works. I also measured water flow into the subaks of the main research area. Both these data gave me some insights on water supply to the subaks. I calculated and tabulated water needs for one cultivation season of rice in the field research area comparing this data with water inflow at the dam level and at the subak level. Participating in the cultivation and irrigation of a rice crop enabled a better understanding of the processes that are taking place in the ecological dimension by experiencing directly how the land is prepared to create the artificial swamp, how the rice plant grows, how water is needed in different stages of the cultivation cycle, and what factors influence the yield.

For the analysis of the physical dimension I undertook surveys of the irrigation infrastructure of the six subaks of the main research area, and also gathered data relating to size of subaks and type and existence of irrigation infrastructure from government agencies for the eleven subaks of pasedahan Yeh Penet. A survey undertaken with the eleven heads of subaks delivered additional data useful for analysis of the physical dimension. In follow-up interviews with subak heads as well as interviews with civil servants working in irrigation I was able to further clarify matters relating to the physical dimension.

To extend my knowledge of the technical dimension, I recorded labour invested and expenses incurred in the cultivation and irrigation of rice as well as the way the crop is managed and irrigated. The time use surveys which I undertook with three families shed light on peak labour demands in rice cultivation and also showed how a household manages fields in different subaks where fields are planted at different times of the year. Taking part in communal work and other meetings and rituals on the munduk and subak level helped me to further my understanding of the working of a subak in both technical and institutional terms. The farmer survey allowed for an insight into household labour allocation, field sizes cultivated and relationship to the subak. This information also supported the analysis of the institutional dimension.

For the institutional dimension, I collected and studied the rules books of the subaks, and used the follow-up interviews I undertook with subak heads after the surveys to comprehend more about the institutional set-up of the subak of the research site. The practical participation in the management of a rice field helped me to understand how farmers daily manage the irrigation of their fields, what informal and formal rules are applied and what kind of rituals are carried out. Ad-hoc and semi-structured interviews with subak leaders, government officials involved in irrigation and cultivation of rice and other key persons allowed for a better picture of the subak's relationship with external government agencies.

Appendix II – Water Flow Measurements

River water intake at dam level

I have collected water discharge measurements from the Department for Public Work (PU)[246] for four dams along the Penet river: Munggu dam, Kapal dam, Penarungan dam and Luwus Carang Sari dam) dating from January 1995 to March 2005, in the case of Munggu dam, Kapal dam and Penarungan dam to September 2005. Water intake and overflow is measured and recorded twice daily (morning and evening).[247] Daily averages are calculated and averaged fortnightly.

Water flow measurements at the subak level

I have recorded water flow in the secondary canals of the six subaks of the main research site (subak federation Sad Buwana Tirta), which divert irrigation water into individual subaks, in the period from May to November 2005 (Figure A.1).[248] Measurements were taken daily at three different positions where canal width exceeds two metres. Otherwise, one measurement was taken in the middle of the canal transect. I instructed a farmer woman, who lived in close proximity to the diversion weirs. In the beginning, we did the measurements together, and then she did them by herself.

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[246] Departemen Pekerjaan Umum Kabupaten Badung, 2005. 'Laporan Pengukuran Debit Sungai pada Bendungan yang dikelola Pemerintha Kabupaten Badung' [transl. Survey report on river discharge from dams managed by the regency government of Badung] Denpasar, Indonesia: Public Works Department Badung Regency (survey report).

[247] Intake is the water diverted from the river into the primary canal, while overflow is the water that is not being diverted, flowing back into the river. Overflow and intake together equal total river discharge.

[248] There were no measurements taken for the first fortnight of July and the month October, for which I estimated inflow by using averages of previous and succeeding fortnights.

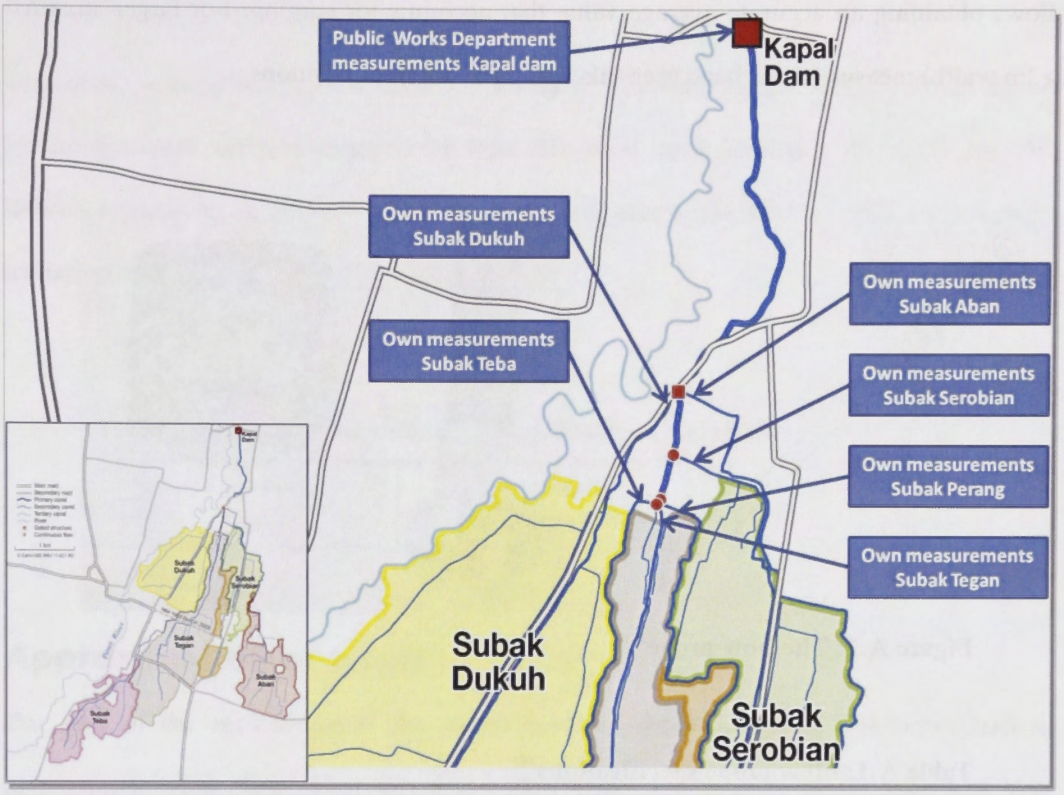

Figure A.1: Water flow measurement locations

Two measurements were recorded: water level and water velocity. Water level was measured with a meter, water velocity with a micro propeller.[249] The probe comes with a propeller at one end and a computer on the other (Figure A.2, Table A.1). The propeller is pointed directly into the flow. The water flowing through the housing accelerates the propeller. The computer at the head end of the flow probe measures and calculates stream velocity. Measurement of velocity is taken every second and average and maximum velocities are calculated automatically. For small streams the probe has been moved smoothly and evenly back and forth from top to bottom of the flow for about 30 to 40

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[249] The micro propeller, a FP101 Global Flow Pobe from Global Water, was kindly let to me by Professor J. Steven Lansing.

seconds as recommended by the company' instruction leaflet.[250] This way of measuring allows obtaining an accurate average value that accounts for surging. For larger streams (>2m width) measurements have been taken at three different positions.

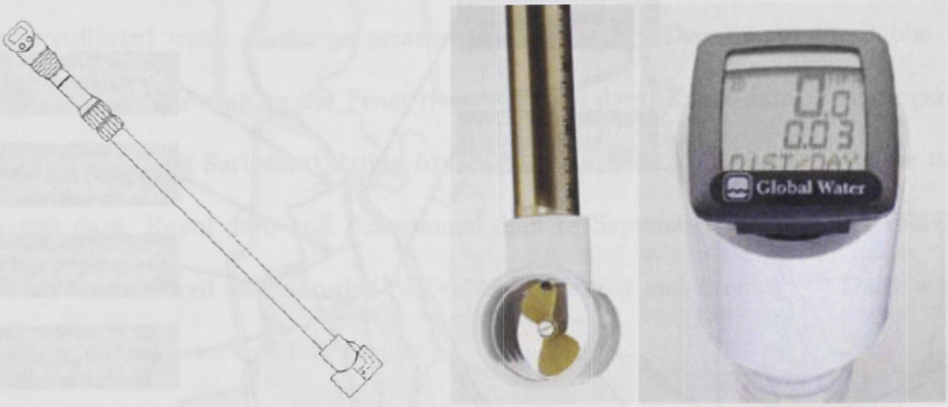

Figure A.2: The flow probe[251]

Table A.1: Flow probe specifications[252]

Type	**FP 101**
Range	0.09-4.57m/s (0.3-15ft/s)
Accuracy	0.03m/s (0.1ft/s)
Averaging	True digital running average. Readings taken once per second.
Sensor Type	Protected Turbo Prop propeller with electro-magnetic pickup.
Materials	PVC, anodized aluminium, stainless steel bearing
Operating Temperature	-18° – 49°C (0°-120° F)

Calculation of water flow

To be able to calculate water flows per day and month for each subak, velocity and water level height is needed. Cross-sectional area diagrams for each canal section were drawn to

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[250] Global Water Instrumentation, 2004. 'FP101-FP201 Global Flow Probe User's Manual.' Viewed on 1/3/2011at http://www.globalw.com/downloads/flowprobe/flowprobe_manual.pdf.

[251] Global Water Instrumentation, 2011. 'Flow probe'. Viewed 1/3/2011 at http://www.globalw.com/products/flowprobe.html.

[252] Global Water Instrumentation, 2004. 'FP101-FP201 Global Flow Probe User's Manual.' Viewed on 1/3/2011at http://www.globalw.com/downloads/flowprobe/flowprobe_manual.pdf: 8.

establish the area. The average velocity V times the cross-sectional area A equals flow Q in cubic meters per second: Q=V*A.

In general, velocity increases when water level rise. The velocity and water level are driven by the upstream manipulations of the inlet. However, downstream water users can also influence water levels and velocities. As a generalisation velocities in rivers as well as in irrigation canal can vary up to +/- 25%.[253]

Table A.2: Conversion table for water flow measurements

1 l/s/ha	8. 64 mm/day
1 mm	10 m3/ha

Approximation of water velocity

For part of the measurements the micro propeller malfunctioned. I therefore had to approximate water flows. Correlations between height and velocity for the month of May and June were analysed at first (Figures A.4-9). The linear regression showed almost no correlation between height and velocity measurements. Therefore height measurements were divided according to the normal distribution into three groups (values below 25%, between 25% and 75%, and above 75%) and then averaged again. Standard deviations varied for these new values between 8 and 28%. Some values had to be neglected for they would not allow a positive linear regression line. Finally the equation of the linear regression was used to calculate the approximate values for velocities with the measured water levels.

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[253] P. Perez 2005, personal communication.

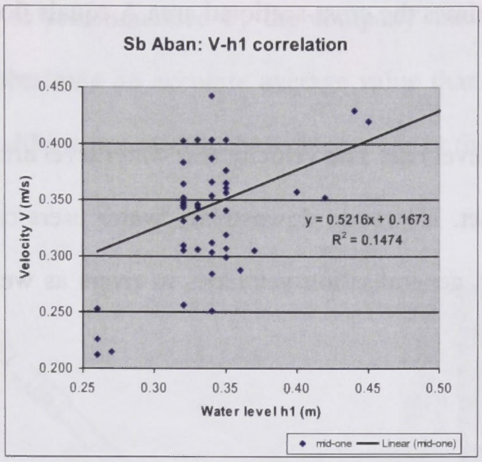

Figure A.3: Velocity approximation subak Aban

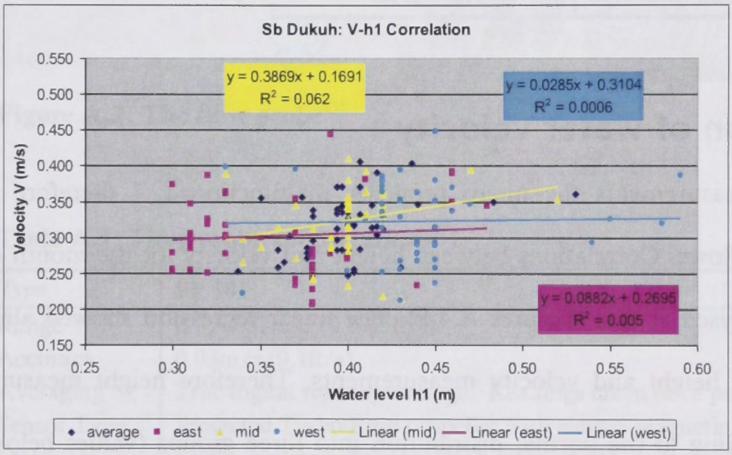

Figure A.4: Velocity approximation subak Dukuh

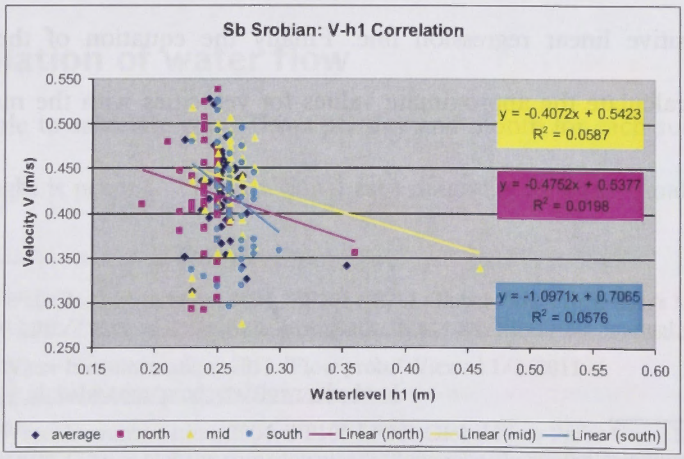

Figure A.5: Velocity approximation subak Serobian

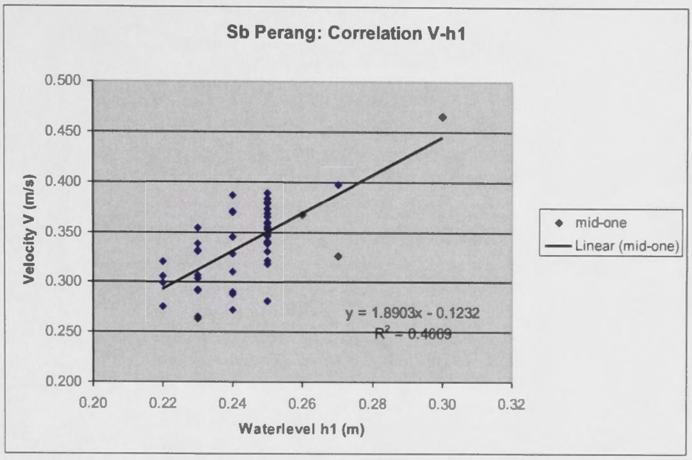

Figure A.6: Velocity approximation subak Perang

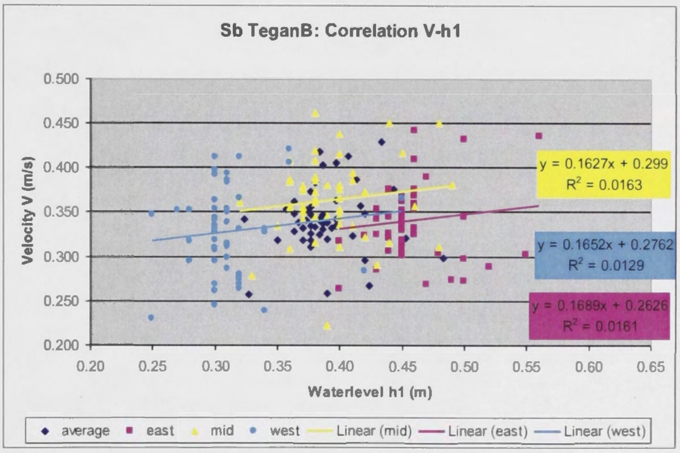

Figure A.7: Velocity approximation subak Tegan

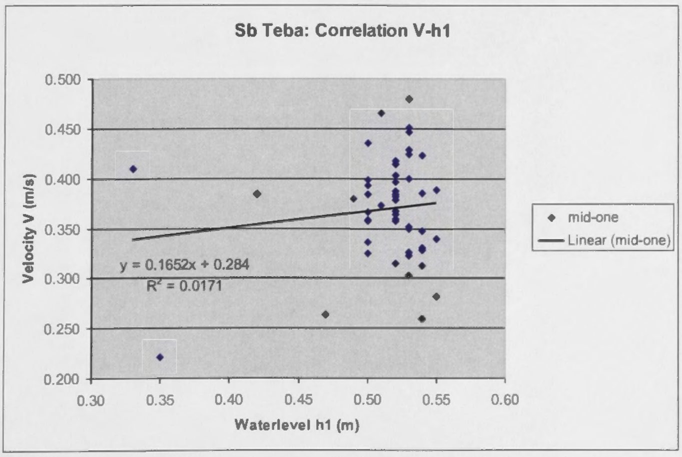

Figure A.8: Velocity approximation subak Teba