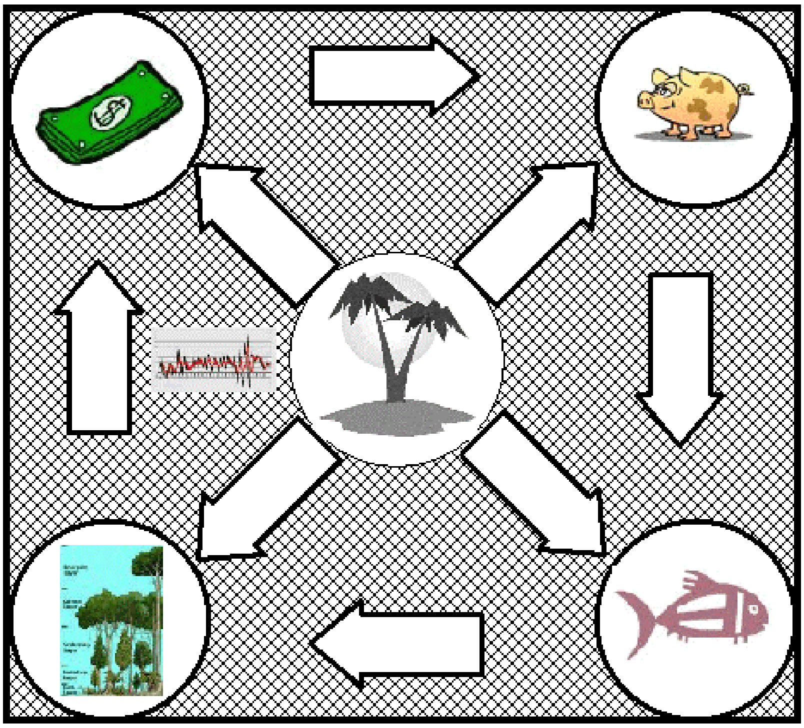
Social Ecology

Social Ecology Working Paper 80

Ecology, Rituals and System-Dynamics

An attempt to model the Socio-Ecological System of Trinket Island



Martin Wildenberg

November 2005

ISSN 1726-3816

iff Social Ecology | Schottenfeldgasse 29 | A-1070 Vienna | www.iff.ac.at/socec/

Wildenberg, Martin 2005: *Ecology, Rituals and System-Dynamic.sAn attempt to model the Socio-Ecological System of Trinket Island.* Social Ecology Working Paper 80. Vienna.

Social Ecology Working Paper 80

ISSN 1726-3816

Institute for Interdisciplinary Studies at Austrian Universities
Department for Social Ecology
Schottenfeldgasse 29
A-1070 Vienna
+43-(0)1-522 40 00-401
www.iff.ac.at/socec
socec.iff@unvie.ac.at

I.

Introduction

Sustainable development is the core aim of a number of organizations and people. It was introduced as a concept by the International Union for the Conservation of Nature and Natural resources (IUCN) in 1980. The classic definition of sustainable development is the one used in the Brundtland Report (WCED 1987), which defines sustainable development as "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*." Besides this common definition there is also the widely used model of the three columns of sustainability, namely the economic, ecologic and social column. Ideally sustainable development is a development in which none of these three realms grows on the costs of the other. This led some people to believe that the notion of "sustainable development" is an oxymoron (Hall 2000). Indeed one could argue that the ability of the "sustainable development" phrase to be used for various aspects of development or growth has led to its now wide spread use and its washy meaning.

Non-Sustainability Criteria:

Economic criteria:

- An economy based on increasing debt, especially international dept, because that dept requires the generation of foreign exchange to pay it, and the generation of foreign always implies the export of real resources (timber, agricultural products) which are generated through depletion of soils, forests, and imported fossil fuels.
- An economy that imports more goods than it can pay for (which of course generates the dept mentioned above)

Maintaining capital equipment criteria:

- An economy that is based on exploiting capital rather than living on interest. Thus agriculture that does not maintain the soil resources or fisheries that deplete the stocks of reproducing fish would not be sustainable from this perspective.
- An economy that imports increasing amounts of food. This may or may not be desirable, but it hardly seems sustainable based on what must be traded for that food.
- An economy that has no fossil fuels or significant industrial production and cannot easily pay from domestic resources.
- An economy that is not increasing the efficiency with which it turns inputs (land and energy and perhaps other inputs) into wealth

Social criteria:

- An economy that does not generate and maintain basic government services such as health care roads and education.
- An economy with large and/or increasing discrepancy between the rich and the poor.
- An economy with little stability for it workers.

Textbox 1: Non-sustainability criteria (Ayres 1996)

The problems of creating a common theory for sustainability lie in the difficulties of integrating ecological with economic with social with evolutionary theory to overcome the limitations of the single fields. Definitions of what is sustainable remain rather abstract making it difficult to develop criteria to determine if policies are sustainable or not. Ayres (1996) gives at least an array of criteria of "Non-sustainability" (Textbox 1).

This work is attempted to contribute to the development of sustainability pathways for a small group of islands, the Nicobar Archipelago. According to the criteria for non-sustainability given above there are some indications that the Islands are developing in an unsustainable way (increasing ineptness, dependant on exports, increasing imports of food).

This work is interested in the possibility of interlinking the cultural (or social) and ecological dimension both in a theoretical and practical way. As both the social and the ecological systems can be seen as complex systems, a system theoretic approach seems to be useful. The linchpins for interlinking the two dimensions are following research questions, which are addressed in this work:

- Do the pig-rituals respectively the creation of "piginess"[1] on Trinket Island have an influence on the resilience of the whole socio-ecological system of the island?
- If yes what features could be responsible for enhancing resilience?
- What would happen if the importance of pigs / pig-festivals dwindle?

The focus on the ritual use of pigs had two pragmatic reasons:

First the rituals focusing on pigs (especially the secondary ossuary feast) are the most intensive in the sense of resource use and time consumption. Additionally they provide obvious links to the ecosystem alone through the presence of the pigs, which forage the forest for food. Resource use and property rights are also attached to some of the rituals and link these to natural-resource-management.

The second reason was the existence of a rich literature and case studies on the Tsembaga of Papua New Guinea and their pig-cycle and its regulating effects. One of the first and best known of these is "Pigs for the Ancestors" by Roy Rappaport (1984). Supportive, critical and alternative approaches for describing the effects of ritual-resource use on the social-ecological system are described.

Few ,if any, existing case studies however deal with the question how the social-ecological system would react to a change of the ritual practice or what influences a change in environment (social, economic and ecological) could have on the performance of the rituals.

[1] The term "creation of piginess" was suggested by Mario Giampietro (LIPHE Summerschool) to describe the whole process of creating and maintaining the high status of pigs in the society.

They do not address the question how such systems could have evolved in past times and how they could change in future.

General Approach

Besides discussing the research questions one of the results of this thesis is a computable model of a “virtual” society on Trinket Island. This approach was chosen to be able to integrate qualitative with quantitative data. The computer model is constructed with the aim to show the influences of the rituals on the energy, material flows and populations of the Island. Although a model of the interactions in the social-ecological system of one of the Islands is presented, the aim is not to create scenarios for future development at this stage of the modeling process. The current model can be seen as a first general attempt to model culture-nature interactions on Trinket. It is based on data collected for conducting energy and material flow analysis. Due to the restrictions on traveling to the Nicobars it was not possible for the author to visit the Islands and collect data on sight, because of this restrictions it might be better to talk of a model of a “virtual” society.

The chosen modeling approach and the resulting model are designed in a way that they can be used as a basis for adaptive management approaches. Two possible management approaches are shortly presented in the thesis. One based on the work of the Resilience Alliance (Walker et al 2002) one on the procedural approach as presented by Mario Giampietro (2004).

As the model should be a starting point for the modeling process, a non-linear modeling approach (as described by Richerdson 2002) was found to be most useful. In this early stage the model ideally should fulfill following requirements:

- Show gaps in data and understanding
- Integrate available information of different sources with a focus on processes.
- Identify some important processes and stocks.
- Provide a basis for further discussions concerning human – nature interactions between:
    - Scientists of different disciplines
    - Scientist and other stake holders

A declarative modeling approach (Muetzelfeldt 2004) is chosen, as the design of the model is seen as important as the simulation itself. Crucial for many points made above is the presentation of the model in a form, which also describes its functional relationships.

Due to the available data it was soon clear that the computer-model would not be able to answer the question what and how things would change with out pig-festival alone. Missing data could be defined and a participative data collecting method (spidergramms) was tested and proofed to be very useful.

Different levels were defined using “Triadic Reading” (Giampietro 2003). Than a descriptive mind-model of interactions and processes between these levels was developed. The importance of the pig-festival / pigs for the resilience of the social-ecological system and possible mechanisms enhancing resilience are identified and discussed through a comparison of related case studies found in literature.

Structure of the Thesis

The second chapter gives some information on the local context of this work: The Nicobar Archipelago and Trinket Island are presented in their local and historical setting.

In the third chapter an overview of terminology, concepts and methods dealing with complex systems and utilized in this work is given. The fourth chapter introduces the methods for data collecting, the concept of triadic reading for finding levels and the modeling tool SIMILE.

In chapter five a review of case studies and theories dealing with ritual resource use are presented.

Chapter six then deals with the applications of those methods and concepts in the case of Trinket Island. The information given in chapter one is viewed under the light of complex systems thinking. Conceptual models of processes in the social ecological system of Trinket Island are presented.

In chapter seven the resulting computer model based on the conceptual models developed in the previous sections and the available data is presented. First an overview over the general structure of the model is given, then results obtained by running the model are shown.

In the last chapter results of model runs are discussed and an attempt is made to answer the research questions.

II.

The Setting

Geography, Geology and Climate

The Nicobars are a group of twenty-four islands with a total area of 1841 km^2. Twelve islands are inhabited. Located in the Bay of Bengal they are part of the larger Nicobar-Andaman archipelago. They are separated from the better-known Andaman Islands through the "Ten Degree Channel". Turbulent waters make it difficult to cross for small vessels characterize this channel, which therefore has acted as a natural barrier between the people of the Andaman and the Nicobars.

The Islands are divided into three groups: (1) the Northern group with Car Nicobar, Teresa and Chowra as the main inhabited islands. (2) The Nancowry group with Nancowry, Kamorta, Katchal and Trinket as the main islands. (3) The southern group (Great Nicobar, Little Nicobar, Kondul and Pillo Millo) (Singh 2003).

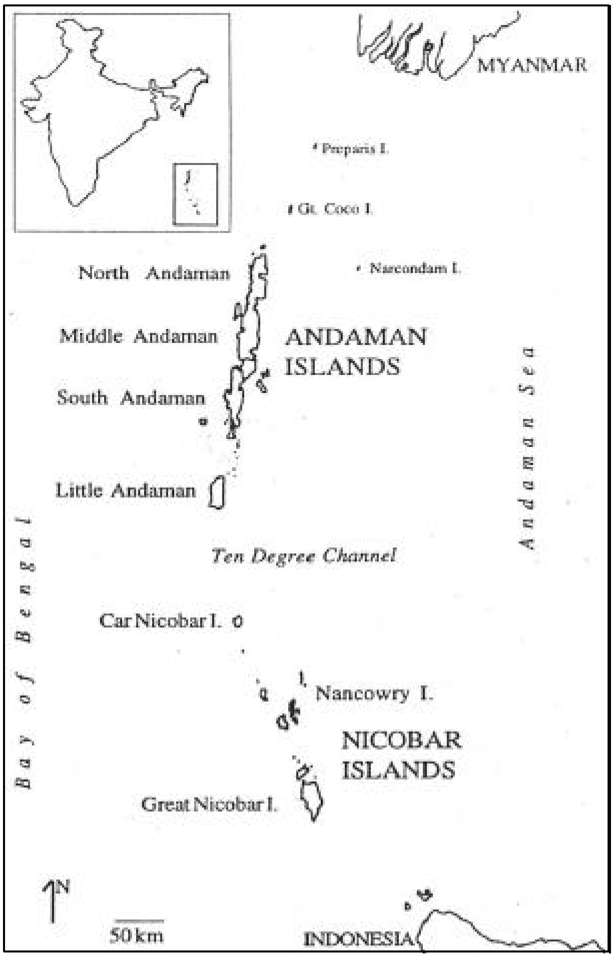


Figure 1: The location of the Nicobar Archipelago.

Due to their location in the equatorial belt the islands have a warm and humid tropical climate. Temperatures range from 18 °C to 34 °C with a mean annual temperature of 26.4° C. The average relative humidity varies from 65 to 89 per cent.

The mean annual perception ranges between 3000 and 4000 mm (Roy et al 2003). The rainfall is influenced by the southwest and northeast monsoon winds. The southeast monsoon arrives in May, lasts until the end of September and is often accompanied by high winds. In November the northeast monsoon starts often accompanied by cyclones. The intensity of the rains decline from February onwards until the southeast monsoon starts again (Singh 2003).

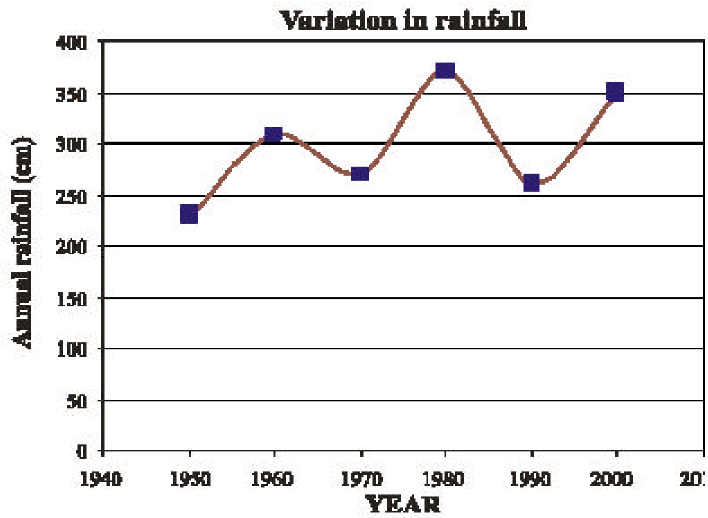


Figure 2: Rainfall pattern in Andaman and Nicobar Islands. (Roy et al 2003)

The Landscapes found on the Nicobars varies greatly from island to island. The highest point is Mount Thullier (641m) on Great Nicobar. Other islands like Car Nicobar, Chowara or Trinket are flat whereas still others like Tillangchong and Kondul have undulating hills with heights up to 300m.

The soil is composed of sandstones, slates and clay. It is immature, poor in drainage, with low moisture-retaining capacity (Roy et al. 2003). Soil cover is rather thin, varying between two and five meters. The soil is mild to moderately acidic with fine fragments of coral lime (Andaman and Nicobar Forest Department Report, in Singh 2001:14).

Fauna, Flora and Ecology

The fauna and flora of the Nicobars is rich in diversity and endemic species. The World Conservation Union (IUCN) recognizes the Islands as a hot spot of biodiversity.

The vegetation of the Nicobars can be divided into coastal and mangrove forests and the inland evergreen and mixed evergreen forests (Roy et al 2003). See **Table 1** for vegetation type and species composition. The vegetation bears significant resemblance to the phytogeoraphical Malaysian and Indonesian species. It is similar on all Islands. The only exceptions are grasslands, which are only found on the Nancorwy group. These grasslands are mainly dominated by *Cymbopogon sp.* and *Carex sp* one of the characteristic species is *Imperata cylindrica*. The origin of these grasslands is still discussed. Some authors (Roy et al 2003) say the grasslands occurred naturally due to edaphic adaptations. Indications confirming this view are the occurrence of an endemic quail (Sankran 1995 p4), an endemic palm (*Bentinckia nicobarica)*, and a species of frog (Singh 2003), all adapted to grasslands. The argument is that the specification could only have taken place when the grassland has existed a sufficient long time. However there are also strong arguments that indicate that the grasslands are man-made. *Imperata cylindrica* is known as a weed accompanying shifting cultivators throughout Southeast Asia (Kellman et al 1997 p198). Usually trees are able to invade *Imperata cylindrica* grasslands if these do not burn down regularly. The presence of humans generally fosters a higher frequency of ignition, either accidentally or intentional. There is no evidence that the inhabitants of the Nicobars have ever practiced shifting cultivation but some of them set fire on the grassland at the end of the dry season (Singh 2004 p76). The reason for burning the grassland is beside following traditions (*Tanal-seuh)* the easier access to wild boars for hunting (Singh 2003).

Satellite based vegetation cover and types mapped	**Vegetation types as per Champion and Seth (1968)**	**Species composition**
Andaman evergreen forest	Andaman Tropical Evergreen Forests (*Diptocarpus)* (1A/2C)	*Acronychia pedunculata, Morus macroura, Mussaenda macrophylla, Xanthophyllum* (*Dipterocarpus*) *vitellinum, Tylophora indica, Terminalia procera*
Moist deciduous forest	Andaman Moist Deciduous Forests (3A/C1)	*Terminalia procera, Thunbergia fragrans*
Mixed evergreen forest	-	*Knema andamanica, Macaranga triloba*
Lowland swamp	-	*Myristica* sp., *Atalantia alabarica, Baccaurea sapida*
Syzygium swamp	-	*Syzygium* sp., *Semecarpus kurzii, Syzygium cumini*
Mangrove	Mangrove (4B/TS1)	*Rhizophora mucronata, Bruguiera gymnorhiza, Heritiera littoralis*
Littoral forest	Littoral Forests (4A/L1)	*Tetrastigma serrulatum, Scaevola sericea, Hibiscus tilieus*
Scrub		*Melastoma* sp.
Upland grassland		*Trema orientalis, Ziziphus oenoplia*
Riverine (lowland) grassland		*Coix lacryma, Coelorachis glandulosa*

Table 1: Vegetation classes mapped by the Indian Institute for Remote Sensing and its equivalent in Champion & Seth (1968) classification and some of there characteristic species (Roy et al 2003 p154)

The corals surrounding the islands are the species-richest found in the Indian Ocean and the second richest worldwide (Andrews et al 2002). They consist mainly of fringing reefs with a barrier reef only on the western side.

Significant differences in the faunal profiles of the northern, central and southern Nicobars have been observed. The Indo-Chinese and Indo-Malayan regions influence the fauna. Large mammals are absent. The presence of crocodiles in the fresh water channels is (beside the geological evidences) an indication for a connection to the mainland. The islands are rich in biodiversity and endemic species. Eleven amphibians (two endemic) 43 reptiles (15 endemic) 56 species and subspecies of birds have been described (Das 1999; Andrews 2001; Andrews et al 2002). Never the less it can be assumed that there are some more species still waiting to be discovered. *"Any future explorations in the region will amply be rewarded by new and interesting species of high economic value owing to its isolated position."* (Roy et al, 2003 p35). The main terrestrial mammals are crab-eating macaque (only on Great Nicobar, Little Nicobar and Katchal), wild boars, civets, and several species of rats, bats, and shrews.

The People of the Nicobare Archipelago

Introduction

The Nicobare Archipelago falls under the Andaman and Nicobar Protection of Aboriginal Tribes Regulation (ANPATR) of 1956, which defines the region as a completely restricted territory to outsiders. Nonetheless, one third of the total population is made up of non-indigenous settlers, which can be divided into three main categories: ex-service man, Sri Lankan repatriates and private traders.

The tribal population consist of two distinct tribes, both belonging to the Mongolid group of people: the Nicobarese and the Shompens.

The Shompen live on Great Nicobar Island and are semi-nomadic hunter-gatherers. They are very shy people living in the forests and until recent times there has hardly been any contact to outsiders. Some groups engage in barter exchange with the Nicobarese who inhabit the costal areas of the Island. The current population of the Shompen numbers about 380 people (Singh 2003).

Through recent developments like the construction of a road and establishment of settlements of mainland Indians in their territory the life of the Shompen is affected. (Singh 2003)

History

The Nicobarese language belongs to the Austroasiatic family, which is dominant in Southeast Asia (Syamchaudhuri 1977). It is not exactly known when and from where the islands were first populated. Syanchaudhuri believes that the first immigrants were Mon-Khmer people starting from the Malay-Burma cost. He dates the arrival of humans on the archipelago in a time before the Christian era but not before 1000 B.C. (Syamchaudhuri 1977). Anyway the assumed dates when the Nicobares language became distinct from its parent language vary from 1000-2000 B.C. (Diffloth 1975) to 4000 B.C. (Benjamin 1976). After some time of isolation an intermingling of the natives with the people of Burma, China and Malaysia, who visited these islands for trade, took place (Justin 1990). The legends of the Nicobarese themselves tell various different stories about how the first people arrived on the islands. This also makes it difficult to draw definite conclusions about their origin (Singh 2003).

Due to their location on vital sea routes through the Indian Ocean the Nicobar Islands have been used as resting point and secure harbor by ships of many nations. Before the beginning of the European colonization of Asia the islands were already visited by Indian, Arabian and Chinese ships. At this time the Nicobarese traded food items in exchange for iron and clothes. Later the trade with coconuts, an occupation to which the Nicobarese should stick to until today, became an important factor (Singh 2003).

After being a Danish and for a short time an Austrian colony, the Nicobars became part of the British colonies in 1867. The British were the first colonial nation, which could successfully install an administration over the islands. This event was significant for the Nicobarese society, as they were now forced to adapt to a foreign administration. Simron Singh describes this period as follows:

"The foundation for future development in the Nicobars was already provided by the British during their seventy-eight years of control. In this period, the English achieved much success in setting up a regular system of administration over the Nicobars, which the Danes prior to them had repeatedly failed to establish. By the time India took over the Islands in 1947, a basic network of administering the islands had been set up. The authority of the administration came to be acknowledged by the Nicobarese as well. By now, the Nicobarese were somehow acquainted with the idea of being governed by a state and having to abide their written laws. Apparently, the Nicobarese had found it impossible to resist a power superior to their own, and had gradually come to integrate an external system of civic-state within their own traditional one." (Singh 2003 p245)

The British period ended 1947 when the islands were taken over by independent India. The islands remained under the direct control of the central government in Delhi. The Nicobares were listed as a “Schedule Tribe” in 1950. Two years later John Richardson, from Car Nicobar and bishop in Burma, was nominated to represent the tribes of the islands in the Indian parliament. This made Car Nicobar become the axis of the Nicobar archipelago (Singh 2003), whereas Port Blair on the Andamans remained the administrative headquarters of the Andaman-Nicobar Archipelago.

“In order to integrate the Nicobars into the development process, the administrative structure on Car Nicobar was further developed. […] Senior officers from several welfare and administrative departments were also positioned at Car Nicobar. However, besides carrying out development and welfare programmes, the local administration were not allowed to interfere in tribal affairs unless serious law and order issues arose. The Nicobarese continued to own their land legally, and to manage their own day-to-day affairs through their tribal system of leadership and elders that was recognized in lieu of the “Village *Panchayats”* (village local self governance elected bodies) on the Indian mainland.”(Singh 2003 p246)

In July 1956 the Andaman and Nicobar Protection of Aboriginal Tribes Regulation (ANPATR) was enforced with the aim to protect the interests of the aboriginal population. Several parts of the Andaman and nearly the whole Nicobares were declared “out of bound”. Entry into these areas was highly regulated and required a special pass, which could be issued by the deputy Commissioner, or his nominated representatives (ANPATR 1956 in Singh 2003 p 247). A direct consequence of this development was that the old trading relations with the Burmese and Malays who came for coconuts, swiflet nests, sea cucumber and shells was disrupted. In 1992 the concept of “Tribal Council” was introduced on the Nicobars. A tribal council was formed on every important island. Smaller islands were merged together with their neighboring islands. Members of the tribal council are the elected village captains[2] and a chairperson to head it. The tribal council is recognized by the Indian government as the only official institution. The administration must consult the tribal council before any projects are implemented and be responsive to requests from the council (Singh 2003).

Economic Development and Globalization

As mentioned above the first contacts with the Nicobar Islands existed for at least 2000 years. Much of this contact was due to the Arab, Indian or Chinese sailors looking for secure harbors or food items and water. Trade with the Nicobarese was only a by-product. On the other hand the Islands were also frequented by Malays and Burmese probably since 1000 A.D.. The Malays and Burmese were looking for sea cucumbers, ambergris and since the 16th century or so for swiftlet-nests. These items were dedicated for the Chinese market. There was not much trade involved because the Malays and Burmese harvested these resources largely by themselves (Singh 2003).

As the Europeans entered the region they recognized the Nicobar Islands as a shelter and resting place. Nonetheless the number of ships anchoring at the Nicobars increased and with them the amount of traded items. At about 1756 when the Danes first attempted to colonize the islands the most sought after articles by the Nicobares were cloth and iron. Besides using the iron for tools and weapons both articles were regarded as status symbols. In exchange the Nicobarese traded native food (coconuts, tubers, fruits, chicken, pig), products made of cane and "preciosities" (ambergris, sea-cucumber and swiftlet nests). The trade with preciosities played a little role as they were mainly extracted by the Malays and Burmese and not traded by the Nicobarese.

From the nineteenth century onwards the trade with coconuts became more important. The Nicobars became known for there cheap exchange rates and were visited by ships from Burma and India on a regular basis. Beside coconuts, areca nuts, empty coconut-shells[3], seashells, rattan, tortoise shells, sea cucumbers, ambergris and swiftlet nests were purchased. The Nicobars were now not only regarded as a safe harbor but increasingly also as a place profitable to trade with. With the establishment of a regular trade system the Nicobarese became more and more dependant on imported commodities for their daily sustenance (Singh 2003). In 1888 E.H. Man writes:

"…the Nicobarese, now fully appreciating the advantages of intercourse with the outer world, are more anxious than ever to encourage the visits of these traders, from whom they hope to procure supplies of such articles as they have long since obtained at Nancowry [Penal Settlement] and learnt to regard almost as necessaries of life" (in Singh 2003 p296)

As the Nicobars became more and more dependent on trade and traded items the world-economic situation began to influence life on the Nicobars. The First World War was perceivable on the Nicobars in a decline of exports from the Nicobars and a raise in the prices for rice and other commodities. The Annual Report of 1935 – 1936 describes a shortage of coconuts for human consumption and pig-feeding as a reaction to a fall in copra prices and due to a shortage in land on Car Nicobar (Singh 2003: p299).

[2] The term "captain" to name the village head goes back to the trading relations established with European ships.
[3] For making hookahs, pipes used for smoking.

Maybe as reaction to these events some Nicobarese started to produce and marked copra by themselves.

When becoming a part of India the situation changed to some extent. India pursued a policy of welfare and economic upliftment towards tribal people, with the aim to raise their living standard to that of mainstream India. The philosophy behind the development policy of India has some critical content, emphasizing the validity of individual development paths for different people (e.g. Nehru 1959 in Singh 2003 p 250). The problem was that these ideas were formulated at a high institutional level and not forced into laws (which would have been difficult). The result was that the way of handling the aboriginal tribes was mostly dictated by economic and personal interests of some individuals (Sachchidananda 1972; Fürer-Haimendorf 1985).

The Indian development approach towards the Nicobars had following consequences:

(1) Car Nicobar became the most important island in the inter-island hierarchy of the archipelago. On the one hand due to its role as district headquarter, on the other due to it high population number. Car Nicobar became the focus for development and welfare projects; it showed "*the way forward in all aspects of live*" (Singh 2003).

(2) The export of copra, as a source of cash, was encouraged.

Other economic options such as improved variety in crops and poultry were supported with state subsidies.

(3) Fair price shops under the Public Distribution Scheme ensured the distribution of food and kerosene oils, and other consumables.

(4) Breakdown of the fetish of Chaura pots and the replacement of a new form of fetishism attached to foreign goods that are now easily available from existing distribution networks has led to the disintegration of the former inter-island-trading network.

Today the main economic-activity of most of the Nicobarese is the trade with coconuts respectively copra the dried coconut-flesh. The copra is marketed to local co-operatives or to private traders in exchange for money or rice, sugar, clothes and other necessities. The form of the trade ranges from barter-exchange to typical cash-economy based trade. Food sources are: fish, coconut-oil, roots and vegetables grown in gardens, livestock (fowl goats and cows), rice and non-timber-forest-products (NTFP). Traditionally the local available pandanus (*Pandanus sp.*) was the main stable food until it was replaced by rice.

In the last five years the Nicobars were integrated more deeply in the regional/global economy. As a result the fluctuations of the copra market had an immediate impact on the Nicobars. Simron J. Singh argues that the Nicobarese have been and still are involved in unequal trade relations. Considering Trinket as example and using the concept of Haustein (1989)[4] he states that the islanders pay 43 Rupees [Rs.] per kilo import and receive Rs. 18 for each kilo of export (i.e. copra). This has led to a growing ineptness of the people.

Social Organization

The forms of social organization vary between the island groups. In the central Nicobars (and therefore also on Trinket) the smallest unit is called Kamuanse and includes the joint family. The Kamuanse holds the property rights on land (gardens and plantations) and is the vital part in every day's economic decisions. There is no concept of central leadership of one person over a village or island in traditional Nicobarese society. Issues concerning the whole community were discussed by men how were respected due to their age or experience or their status (defined e.g. by the number of pigs) (Barb 1847 in Singh). Several related Kamuanse form a Kamunchia whose members assist each other in times of need e.g. in contributing resources towards a big feast. If a Kamuanse grows too big it splits into two and the property is re-organized by the head accordingly. Only uncultivated land can be given away as the plantations are invariably owned by the one how planted the tress. The Nicobarese make a distinction between land ownership and plantation ownership. The right on the plantation expires when the palms are old and cannot bear fruit any more. Serve conflicts may arise when somebody attempts to plant coconut trees on another's land without permission.

In the traditional systems on Nancorwy islands the woman had more power then men. The management and ownership of livestock and resources usually was with the eldest daughter of the family. The residential patterns after marriage were uxorilocal. Singh (2003) states that with the increasing outside influence, in particular with the spread of Islam and Christianity, women are gradually loosing their privileges in the society and matrilocality is becoming a thing of the past.

Rituals and Belief System

The original believes of the Nicobarese are animistic. Appeasing the spirits through the agency of the *menluana* (doctor priest), ritual healing, and observing rites of passage mark the main elements of Nicobares religion (Singh 2003). In the worldview of the Nicobarese humans and nature are treated as a single spiritual, moral, and regenerative system. The

[4] Haustein introduced the concept of calculating tonne prices, whereby the weight of the products as well as their respective prices are aggregated and a value/weight ratio is derived.

Nicobares distinguish between “nature”-spirits and the ghosts of their ancestors. Christianity entered the islands in the early 1920’s. In the following a intermingling of archaic religious forms with Christian believes and feasts took place. Nevertheless the traditional believes are eroding, the role of the supernatural and rituals is becoming less important. This is also affecting the role of the pig as status symbol and central sacrifice object. Although even Nicobarese converted to the Islam often still continue holding pigs, especially the youth disapproves the economically unprofitable pigs (Singh p.c.).
In the following three aspects of the traditional belief system are presented: First the inter-island trade net-work. Second a ritual/festival that marks the change of the winds (in the Nicobarese Archipelago the changing of the wind determines the seasons). It is of interest for this work as it imposes taboos on certain types of resource use. The third is the Ritual held for the secondary ossuary festival. This is the biggest festival both in duration and resource demand. The interpretation of its effects on the resilience respectively sustainability of the whole socio-ecological system will be discussed later.

Inter-island trade

The system of inter-island trade was in place at least until two decades ago and possibly has persisted for centuries or even millennia before (Singh 2003). The trade usually took place between December and April a relatively dry season characterized by northeast winds. As the historical descriptions are sketchy and the first field-based attempt to study these inter-island trade systems was published in 1976, it is only possible to attempt a vague reconstruction of the system.
Rules and regulations governed the trade relations. There were restrictions on the production of some products (e.g. pots and canoes). The only island allowed to produce clay-pots was Chaura, they also were the only ones allowed to trade with Car Nicobar. Breaking these rules would bring death and disease, while using the pots of Chaura would bring fortune and prosperity.

***Kinleava* (a festival to mark the change in winds/season)**

The Northeast winds are welcomed with the celebration of the *Kinleava* festival during the *Oliov* months (i.e. from November to April). A main feature of this festival is the erection of *kanaya*(s) – poles of approximately 20 mts height decorated chiefly with tender coconut

leaves - in front of the village. The purpose of the feast is begging for abundance of resources from the ancestors and the divine.
With the end of the *Kinleava* festival restrictions on the use of certain resources e.g. Giant Barracuda (*Sphyraena barracuda*) are lifted and other taboos are enforced.

***Kinruaka* (Ossuary feast to give secondary burial)**

Kinruaka is the biggest ceremony that takes place in the Nicobar Islands. Its purpose is to provide a secondary (or even a third) burial to those deceased. Upon death, the surviving members of the household must not harvest coconuts from plantations that had been owned by the deceased. A sign on the house indicates that the inhabitants still have obligations against the dead. Not being able to fulfill the claims for a proper ossuary festival will in this way not only annoy the dead ancestors but also lead to derision in the entire community (Singh p.c.). It is only during the Kinruaka ceremony that the inheritors can rightfully become owners of that property and the sign is removed. Preparations for Kinruaka starts already a year in advance once sufficient pigs are available, a process which can take up to fifteen years.

Trinket Island

Environment and People

In the subsequent text a short description of Trinket Island is given, which is the main focus of this research.

The first people coming from neighboring islands settled here in the middle of the nineteenth century. Before that they had already maintained and harvested coconut plantations on Trinket or Laful as the Nicobarese call it. Trinket is located in the central Nicobars next to Camorta and Nancowry. Parts of Camorta serve as location for the headquarters of the Indian administration. Camorta also has shops belonging to mainland Indians, from whom the people of Trinket purchase the essential commodities they need.
The Island has a size of 86.3 km^2 and is rather flat. It is covered by a dense tropical forest[5] (55%), by grassland (32%) mangroves and coconut palms. In large parts of the Island a species poor, shrubby secondary forest replaces the original forest cover, probably due to

[5] Classified as Andaman Tropical Evergreen and Andaman Semi-evergreen Forest

overuse. Water availability is not a problem on Trinket. There are several wells used for small-scale irrigation.

Dense coral reefs surround Trinket Island, making it accessible only for small boats and by people capable of maneuvering through the corals. Due to this low connectivity the Island has remained more isolated from outside influence than the other islands of the Central Group.

Simron Singh describes the lifestyle of the islanders as follows:

“As compared to the other islands in the central group, the people of Trinket are largely self-subsistent (for example, from fishing, pig rearing and horticulture) and follow indigenous beliefs with respect to rituals and showing high regard for ancestral spirits.” (Singh 2003)

But as on the other Islands modern live is infiltrating Trinket with an increasing speed. The number of television sets increased from one in 2000 up to nine by 2002 following the electrification in 2001.

The data of the Indian census, which is conducted every ten years, shows that the Population has increased nearly fourfold since 1961 (Figure 3). At present there are three main villages on Trinket: Safed Balu, Trinket and Tapiang.

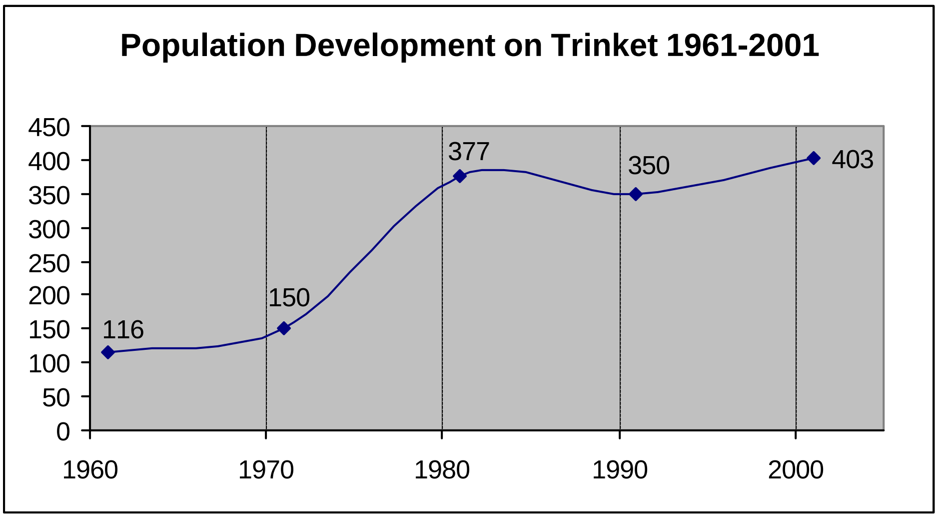


Figure 3: Population development on Trinket

Social Metabolism on Trinket

In this chapter a short description of the biophysical relations on Trinket is given. The data presented is taken from the work of Simron Singh (2001 & 2003). It is built upon field samples of two consecutive years (2000 and 2001). For a review of the methodology see: Schandl et al 2002.

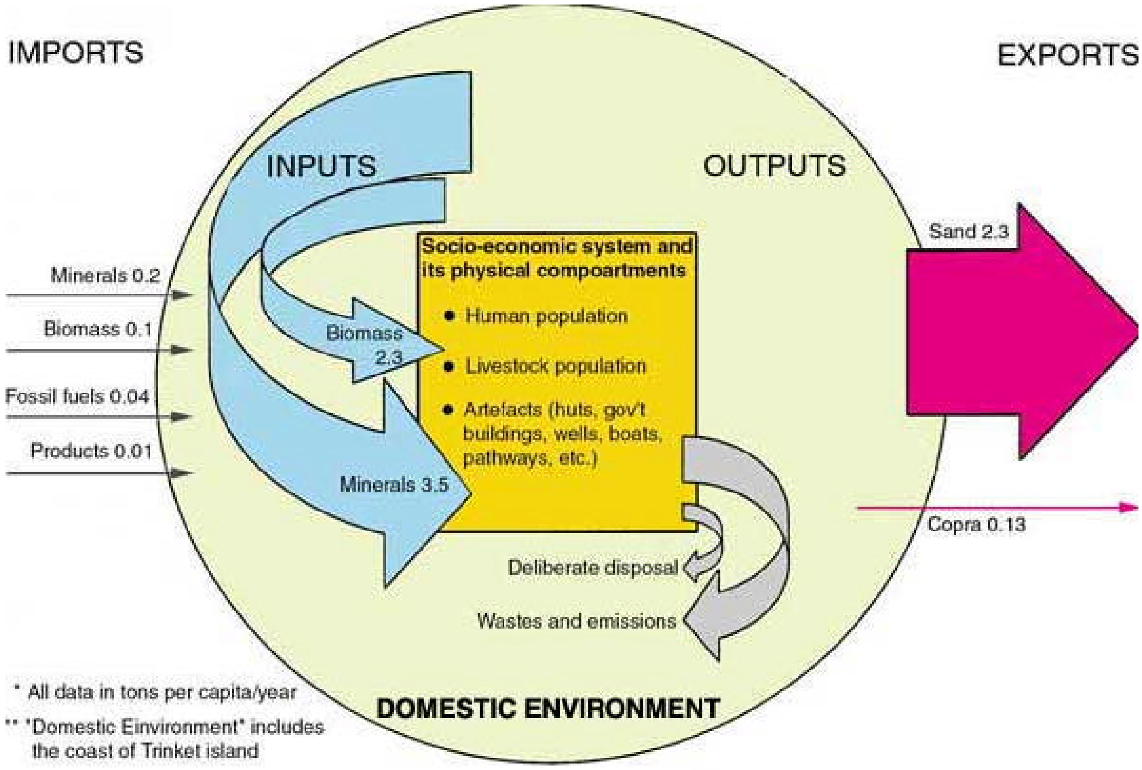


Figure 4: material flows on Trinket (Singh et al 2001)

Materials extracted from within Trinket's domestic environment consist mainly of biomass (wild catch from sea and land, forest produce, fuel wood and water) and minerals (sand and gravel). The imports consist of biomass (rice and sugar), fossil fuels, minerals (cement steel) and consumer goods (such as clothes and soaps). On the output side only exported materials are accounted for. Exports are comprised mainly of a huge amount of sand (for the construction of buildings by and for government establishments) and copra (for industrial use). Although by mass, sand greatly exceeds copra, the economic gain from copra is much higher than that from sand (Singh 2003).

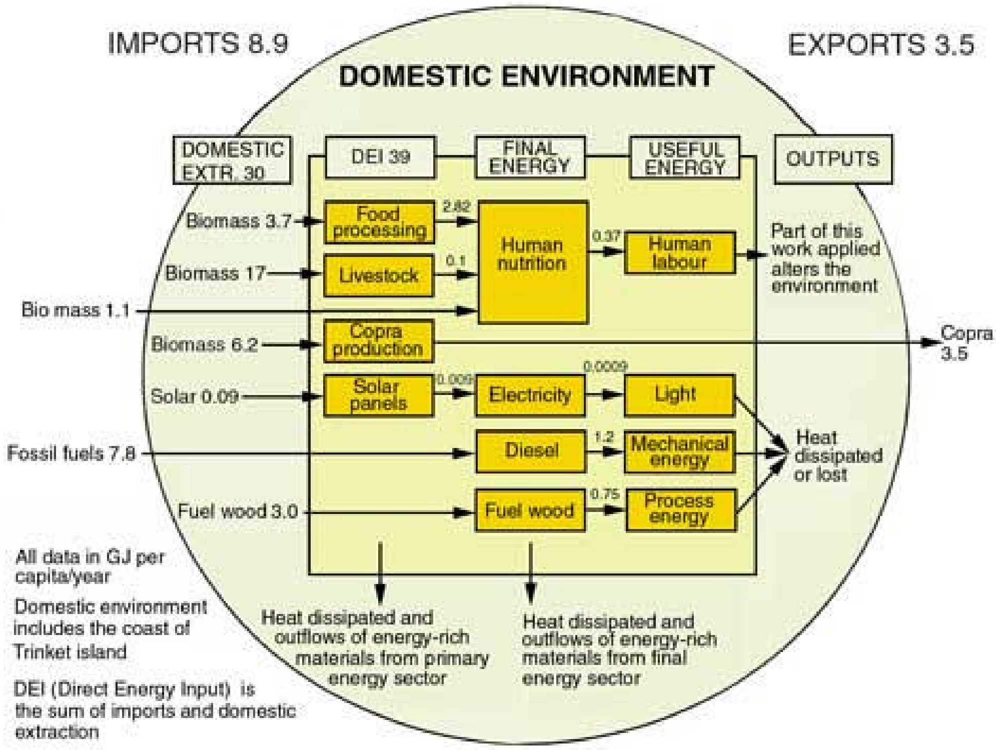


Figure 5: Direct Energy Input (DEI) – Direct Energy Consumption (DEC) on Trinket for the year 2000 (Singh et al 2001).

The Direct Energy Input (DEI) was calculated to be 39 GJ/cap/year in 2000. About 23% (or 8.9 GJ) is imported in the forms of biomass (rice, sugar, flour) for humans (1.1 GJ) and fossil fuels (7.8 GJ). The remaining 77% (30 GJ) is domestically extracted and mostly comes from biomass. Two thirds of the harvested energy goes into human (3.7 GJ) or livestock (17 GJ) bio-metabolism, one third of the harvested biomass goes into coconuts (6.2 GJ) for copra production and fuel wood (3 GJ). From the fuel wood 1.6 GJ go into copra production and 1.4 GJ are used for domestic cooking.

The Domestic Energy Consumption (DEC) is calculated by subtracting the exports (copra) from the DEI and figures 35 GJ per year and person. The total efficiency of energy use was calculated to be 7% on Trinket.

Simron J. Singh (2003) points out four striking patterns in the energy flows and conversion processes on Trinket:

(1) A rather inefficient system of animal husbandry with an input of 17 GJ and an output of only 0.1 GJ (or 0.7%). [Modern animal husbandry systems output ca. 10%]

(2) Export of biomass far exceeds imports leading to one-way flow of nutrients.

(3) Only human labor is used as useful energy for delivering work. Mechanical energy is used only for running boats on the sea.

The analysis of the MFA shows that Trinket is still a traditional and largely subsistent society but there are also results indicating that Trinket is moving towards a more market oriented economy.

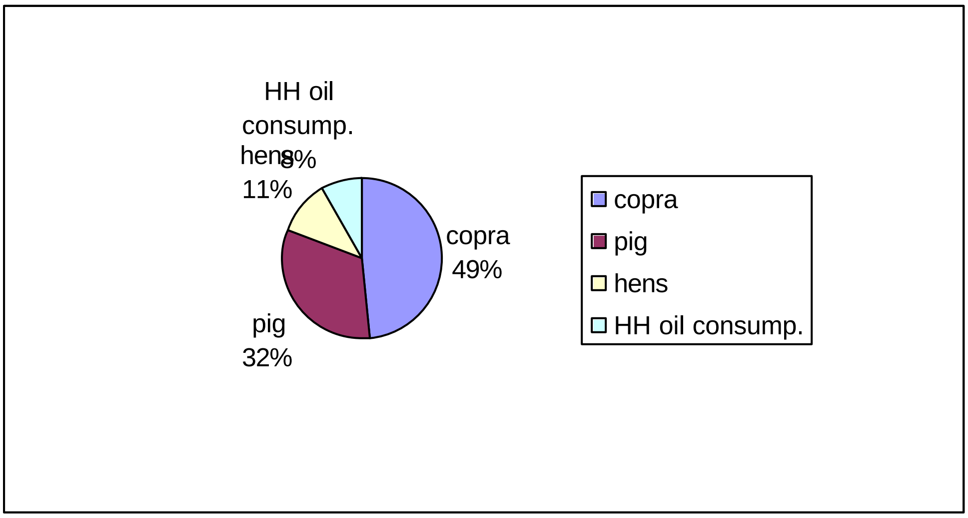


Figure 6: Fraction of Coconuts consumed by pigs (32%), humans (8%), and chicken (11%) and used for copra production/export (49%) (Data from Singh 2001).

In the next section of the work an overview of theory and methods, related to concepts of system dynamic and used for the description of human – nature relations is given. These tools will then be used to describe and discuss some aspects of the Nicobarese respectively Trinket society in more detail. As already mentioned pigs play an important role in the live of the Nicobarese. The people invest considerable amounts of time and resources into their pig-herds. A striking evidence for the status the pigs enjoy is that they are fed a significant amount of coconuts, on which the whole cash-economy of the people depends (Figure 6).

III.

Theory & Terminology

Describing and Understanding Social-Ecological Systems

"In a complex reality it is unavoidable to find multiple legitimate views of the same problem" (Mario Giampietro 2004)

The Socio-Ecological System

This work is concerned with humans and their interactions with the environment. There is a certain dualism in the approach of traditional western science towards the humans and the ecosystems which they live in and interact with and which their society depends on. Until now there is no "*single, universally accepted way of formulating the linkage between social system and natural system*" (Berkes et al 1998 p9). The ecosystem definition given below speaks of "*biological-components*" which also includes the humans. Still there may be some unease when humans are just classified as "*biological-components*" as they also posses culture[6].

However, the central question of this work is what consequences changes in the ritual practices on Trinket Island might have for the functioning of its social-ecological system. It is not only focused on the effects of social change/transition on nature, but also on events that trigger or influence change. Methods and theories that are able to integrate both the human biophysical component and the cultural component/social-system were therefore utilized. Most of these approaches are rooted in some notion of systems theory with a focus on processes rather than on the individual system components (e.g.: Rappaport 1984, Meadows 1973, Forrester 1971, Giampietro 2004, Resilience Alliance [Url. 1]). It is therefore useful to introduce some basic concepts of system theory at the beginning of this chapter. In the following constitutive concepts and theories in ecosystem respectively sustainability sciences used for this work are presented. To understand the role of simulation modeling in this context a short sidestep to methods of applied ecosystem management is taken.

[6] The discussions about whether nature is a cultural construct or not are not subject of this work. (For a discussion on this topic see e.g. Ingold (1996).) What is the concern of this work is the more pragmatic notion that culture is interlinked with nature somehow, and that different cultural attitudes towards nature have implications for the management of the environment.

The term used here to refer to an ecosystem including the social-system is: *socio-ecological system* – to cope with the conceptual dualism between nature and culture a focus on processes was applied – analogue to the one suggested by Davidson-Hunt:

"An Ecological perspective that moves beyond the individual/cultural and nature/cultural opposition through a focus on processes. As such they are consistent with the resilience concept and provide ways of operationalizing resilience." (Davidson-Hunt et al 2003 p68)

This approach is also closer to the way most societies see themselves and their relation to the environment. (Berkes et al 1998).

Complex Systems (at a Glance)

One way to illustrate what a complex system is, is to first describe what it is not. A distinction has to be made between simple systems (capable of creating a different kind of complex dynamics e.g. chaos), complicated systems and complex systems.

Simple systems

Simple systems have a small number of components acting according to linear laws, e.g.: a perfect Pendulum. Simple systems can generate "complex" dynamics like chaos, e.g., a forced pendulum. The system has no emerging properties and adaptability.

Complicated Systems

Complicated Systems have a large number of components that interact with each other. This interaction is governed by well understood rules. A defect in any key component can bring the whole system to a halt. Complicated systems only at best have a limited set of possibilities to adapt to a changing environment. Examples are machines such as airplanes or cars.

Complex Systems

Typically have a large number of components. The components interact with each other (and the environment) based on rules, which may change over time and usually are not well understood. This results in two typical features of complex systems: Emergent properties and adaptive change.

Amaral (2004) states that it is far from trivial to come up with an "*all-encompassing definition of complex systems*". He proposes the following general definition:

"A complex system is a system with a large number of elements, building blocks or agents, capable of interacting with each other and with their environment. The interaction between elements may occur only with immediate neighbors or with distant ones; the agents can be all identical or different; they may move in space or occupy fixed positions, and can be in one of two states or of multiple states. [Complex systems are typically far from equilibrium. For example living organisms are in a permanent struggle with their environment to remain in a particular out-of-equilibrium state, namely alive] The common characteristic of all complex systems is that they display organization without any *external* organizing principle being applied. The whole is much more than the sum of its parts." (Amaral et al 2004)

Consequences of using system dynamics concepts for ecosystem/sustainability science are an emphasis on uncertainty, recognition that the organization of a system at different scales matters, and that there emergent properties exist. Some of the authors citied in this work (Giampietro 2003, Gunderson 2002) have stated that the negation of just these features in the past was the main reason for the error-proneness often observed in many sustainable development projects.

Ecosystems are often exemplified as **the** examples for complex adaptive systems. Modern ecosystem approaches therefore often utilize the concepts and terminology of complex system theory. A mutual use of these terms and concepts in different scientific disciplines could also help bridge some problems of interdisciplinary research.

The Ecosystem Approach

"Ecology does not have a set of general laws, so it is virtually impossible to provide robust predictions about individual organisms, populations or whole ecosystems." (J. M. McGlade 1999)

Already in 1884 Haldane wrote that organisms and their environment have to be seen as unit. In 1971 Eugene Odum stated: "*The ecosystem is the first (or lowest) unit in the molecular to atmosphere levels-of-organization hierarchy, that is complete, that has all components, biological and physical, necessary for survival.*" Several definitions of ecosystems exist. McGlade (1999) gives a quite general one: *An Ecosystem is a spatio-temporal component of the biosphere, determined by past and present environmental forcing functions and interactions amongst biota. Within the boundaries of an ecosystem we can expect to see homogeneous and/or characteristic patterns in the dynamics, structure and evolution of its biological components* (see also Stommel 1963; Steel 1978; Powell 1988; Hogg et al 1989; May 1989).

Ideally all subunits of an ecosystem should be seen as equally important. This has not always been the case though. McGlade (1999) gives two examples of approaches, which focus on different aspects of ecosystems, especially when defining boundaries. The first approach stresses the biotic elements of an ecosystem. The assumption is that ecosystems are networks of interacting populations subject to natural selection, predation, competition and population growth. The abiotic factors are seen as external influences. This approach basically builds on the work of Lotka (1956) and Volterra (1931).

The second approach emphasizes the role of energy and material flows in the ecosystems. The role of single species or populations is neglected. Lindeman (1942) and Odum (1969) developed this functional view of the ecosystem.

The importance of both approaches has been recognized. In ecological modeling and simulation (especially for management issues) both concepts are often combined.

The complexity and system dynamics approach is also used to understand and describe ecosystems. Ecosystems are seen to possess intriguing structural qualities, such as resilience, hierarchy, scale, nesting, dissipative structures, autocatalytic design, and descriptors of dynamics, such as nonlinearity, irreversibility, self-organization, emergence, development, directionality, history, co-evolution, surprise, indeterminism, pulsing, and chaotic dynamics (Abel et al 2003).

The effect of change in the rates of processes on ecosystem resilience, stability and structure is a main subject of research. Approaches like the resilience – concept the adaptive cycle, panarchies (Holling 1986, Gunderson et al 2002.); and the role of niche-construction in evolution (Odling-Smee 2003) are some of the outcomes of this development.

The change in the view of what ecosystems are also required a new view of how the processes in an ecosystem shape specific features of interest. The stability of ecosystems and succession patterns has been in the center of interest for a long time. Equilibrium based approaches are seen as not able to deal with the features described above. In the following the resilience concept and the adaptive cycle are introduced as examples for a system based approach for describing stability and transitional patterns in ecological and socio-ecological systems.

Resilience and The Adaptive Cycle

Engineering Resilience vs. Ecosystem Resilience

Resilience has been defined in two very different ways in ecological literature (Gunderson et al 2002). The first more traditional is also termed “engineering resilience”. It concentrates on stability and emphasizes equilibrium and steady state. The resistance of the system against disturbance pushing it out of equilibrium and the speed of return back to the equilibrium are used to measure resilience. The second definition termed “ecosystem resilience” emphasizes instabilities. Systems can flip from one state or stability domain into another. Resilience is measured as the amount of disturbance that can be absorbed before a system changes it structure. In this work the term resilience will refer to the concept of the “ecosystem-resilience” as presented above.

The Adaptive Cycle

The concept or metaphor of the adaptive cycle was developed by Holling (1986) to describe the different phases of system behavior in (managed) ecosystems. These systems show a tendency to repeat characteristic behavioral phases e.g. succession states.

Note that the adaptive cycle is more a metaphor than a theory “[…] it *is a metaphor to help interpret events and their gross causes*” (Gunderson et al 2002).

The cycle was first used to describe temperate ecosystems (e.g. boreal coniferous forests, grassland). Later it was also adapted to ecosystems in other regions of the world and even to human organizations (e.g. bureaucratic) and economics.

In a traditional ecology view of the succession processes two phases are emphasized: The first is the rapid colonization of disturbed areas (exploitative phase). The second is the conservation, the slow accumulation and storage of energy and material in established (Climax) ecosystems (conservation phase). The organisms engaged in the exploitive phase are termed r-strategists the ones predominant in the conservation stage K-strategists. The r-types are usually so-called pioneer species, characterized by exponential population growth – often leading to a final collapse – and excellent dispersal strategies. The K – strategists are seen to maintain their population close to some maximum sustainable population. Generally they have less offspring (but invest more into them) and are more specialized then the r-strategists.

Holling now adds two additional functions: (1) the release or “creative destruction” (a term borrowed from Schumpeter (1950)) (2) the reorganization phase. The release phase is termed **O** the reorganization phase **a**. In a two-dimensional view the adaptive cycle has two properties: The potential and the connectedness.

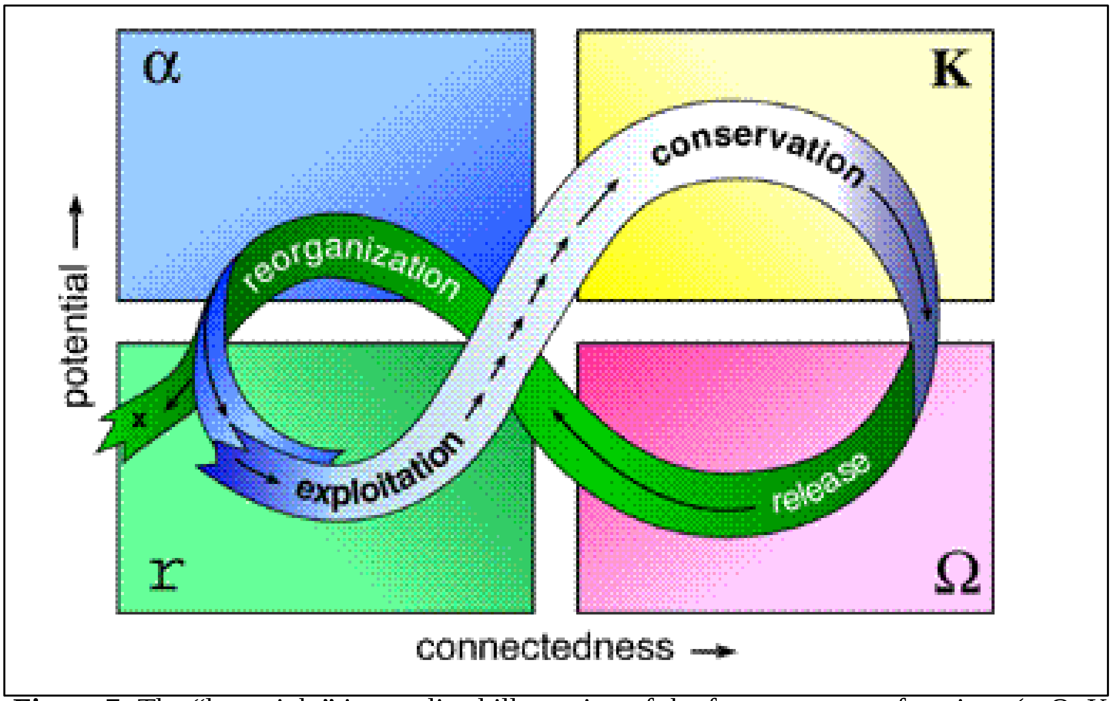


Figure 7: The "lazy eight" is a stylized illustration of the four ecosystem functions (r, O, K a), and the flow of events among them. The length of the arrows indicates the speed of change in the different phases (short arrows = fast; long arrows = slow). The x-axis shows the degree of connectedness the y-axis the potential of the accumulated resources. (in Gunderson et al, 2002 p34)

In the K-phase of a system the accumulation (potential) of biomass and nutrients is high and tightly bound (overconnected in system terms). This leads to an increasingly fragile system. Then some sudden events release the biomass and nutrients and lead to the release or O phase). Such events can be: forest fires, drought, insect pest, or intense pulses of grazing. The ensuing phase is the reorganization or a phase. In this phase the nutrient loss is minimized and the nutrient availability reorganized. The pioneer species appear and utilize accumulated and emerging energy and nutrient sources.

The third dimension of the adaptive cycle

Adding a third dimension to the "lazy eight" (Figure 7) reveals that the "eight" results in viewing a three dimensional object on a two dimensional plane (Figure 8). The z-axis now describes the resilience of the system. One can see that the resilience of a system changes through out the four phases of the adaptive cycle. The notion that the resilience is not a static feature of a system but evolves with the system is an essential attribute to the concept of evolution in natural systems.

The ecological resilience (and the potential) is high in the a-phase of the cycle. Connectedness is low internal regulation weak. The a-phase is the phase with the highest uncertainty and so with the "*greatest chances of unexpected forms of renewal as well as unexpected crisis. […] novel re-assortments in ecosystems of species in ecosystems generate new possibilities that are later tested.*" (Gunderson et al 2002)

Resilience remains high in the r-phase. Connectedness is low and the system can be easily influenced by outside factors – creating opportunities and constraints.

The r-phase progresses to the K-phase as the pioneer-species are slowly replaced by K-strategists. In economy this is the phase when, after a new market opportunity has given rise to several competing companies, one or two "winners" establish themselves. In the K-phase the connectedness (e.g. close interrelations between species) and the potential grow. In this process the ecological resilience starts decreasing. The system becomes more vulnerable.

In the end the system is an "*accident waiting to happen*" (Gunderson et al 2002 p45). The resilience is now at such a low point that events that would not have changed the system before may now provoke crisis and destruction. Through the high potential and connectedness strong destabilizing feedback loops can develop. These processes are usually preliminary as they soon run out of resources (e.g. forest fires run out of fuel, insect pests run out of food).

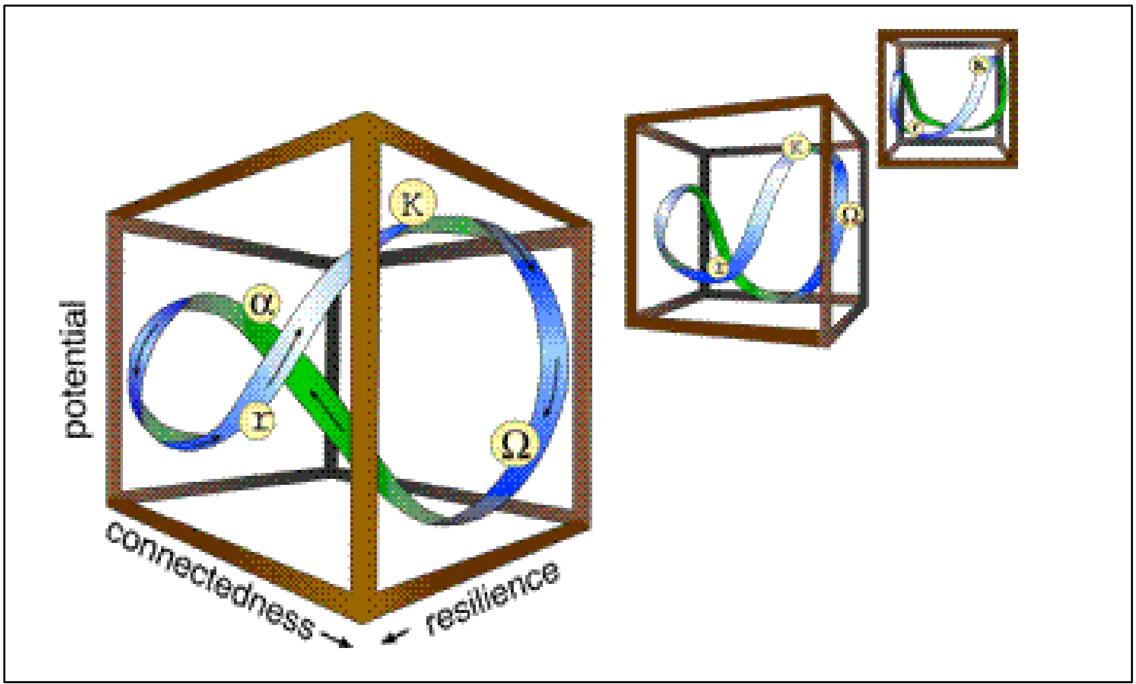


Figure 8: Resilience is another dimension of the adaptive cycle. The appearance of a figure 8 is shown to be the consequence of viewing a three-dimensional object on a two-dimensional plane.(Gunderson et al 2002)

Resilience of Socio-Ecological Systems

The concept of resilience as described above can also be applied to socio-ecological systems. The resilience of socio-ecological systems is described by Carpenter et al (2002) as the amount of disturbance a system can absorb and still remain within the same state. The degree to which the system is capable of self-organization (versus lack of organization, or organization forced by external factors) and the degree to which the system can build and increase the capacity for learning and adaptation

The greater the resilience of the system the easier it will absorb shocks and be capable to adapt to changes. The adaptive capacity of a society is constraint by its institutions and by the environment. Social-ecological resilience is determined by the livelihood security of an individual or group. This security involves the access and entitlements to natural resources (Berkes et al 2003). The resilience of social systems is also influenced by the interactions of different levels or hierarchies (see Figure 9):

"The power of sense making and signification not only provides a powerful shaping force, it also provides an third hierarchy, equal to time and space, for structuring social system dynamics. Our meaning systems have the ability to insulate us and separate us from the physical ground of our being absorbing large amounts of uncertainty. This ability of social systems to create structures of signification, which provide a "virtual reality", is key to understanding resilience in social systems. Routines and even resources may suffer a hard loss of resilience but as long as the structures of signification stay in place the whole system will not transform radically, but rather return to a previous equilibrium. The opposite is also true, namely if meaning is lost human systems seem unable to recover." (Gunderson et al 2002 - adapted by P. Bunnell)

This notion addresses the importance of Traditional Ecological Knowledge (TEK) and cultural perceptions or worldviews in the process of creating or maintaining a resilient socio-ecological system. Beside this the importance of the effects arising out of the interaction of different levels with each other is shown. The organization of natural systems in a hierarchical way and the interactions between different levels are the subject of the next paragraph.

Holons, Holarchies and Panarchy

The notion of holon and holarchies was developed by Arthur Koestler (1967) to describe a model-component with a "*Janus-Face*" - one side looking "*down*" and acting as an autonomous system giving directions to "lower" components. The other side looking "*up*" and serving as a part of a "*higher*" holon. Holling (2002) developed the notion of panarchy. It integrates the adaptive cycle into a hierarchic (in the sense of Koestler) worldview.

Holons and Holarchies

Natural systems (i.e. biological and human systems) are usually organized in different hierarchies. A human being is made up of organs, these are composed of cells, and cells contain organelles and so on. In the other direction the human can be part of a family, a society, an ecosystem. Each level can be referred to as a holon: "*A holon is a whole made up of smaller parts and at the same times forms a part of a larger whole*." (Giampietro 2004 p32) A system made up of holons can be called a holarchy e.g. a certain ecosystem. (Koestler 1969).

The organization of the real world in nested systems composed of holons seems quite obvious but brings some difficulties due to the dualistic nature of the objects/systems under observation. A certain level of interest / holarchy (e.g. a socio-ecological system) is made up of smaller parts with different scales and different paces of change, and at the same time connected to and influenced by the higher levels.

Mario Giampietro (2004) formulates three "*Subjects that are taboo in the scientific arena*", which reflect these difficulties:

The existence of impredicative loops - chicken-egg processes defining the identity of living systems require the consideration of self entailing processes across levels and scales [...]. That is there are situations in which identities of the parts are defining the identity of the whole and the identity of the whole is defining the identity of the parts in a mechanism that escapes conventional modeling.

The coexistence of multiple identities - We should aspect to find different boundaries for the same system when looking at different relevant aspects of its behavior. Considering different relevant dynamics on different scales requires the adoption of a set of nonreducible assumptions about what should be considered the system and the environment, and therefore, this requires the simultaneous use of nonreducible models.

The existence of complex time - complex time implies acknowledging that (1) the observed system changes its identity in time, (2) the observed system has multiple identities on different scales that are changing in time but at different paces (3) the observed system is not the only element of the process of observation that is changing its identity in time. Also the observer does change in time.

Examples of Hierarchies in Social and Ecological Systems:

Social system (Westley 1995):

Social action is predicted on a hierarchy of three structures: slowly developed myths (structure of signification), faster rules and norms (structure of legitimation), and faster processes to allocate resources (structure of domination) (Figure 9 right).

“The attributes of the slower levels emerge from experience of the faster. As long as the transfer from one level to the other is maintained, the interactions within the levels themselves can be transformed, or the variables changed without the whole system losing its integrity. As a consequence, this structure allows wide latitude for experimentation within levels, thereby greatly increasing the speed of evolution.” (Gunderson et al 2002 adapted by P. Bunnell)

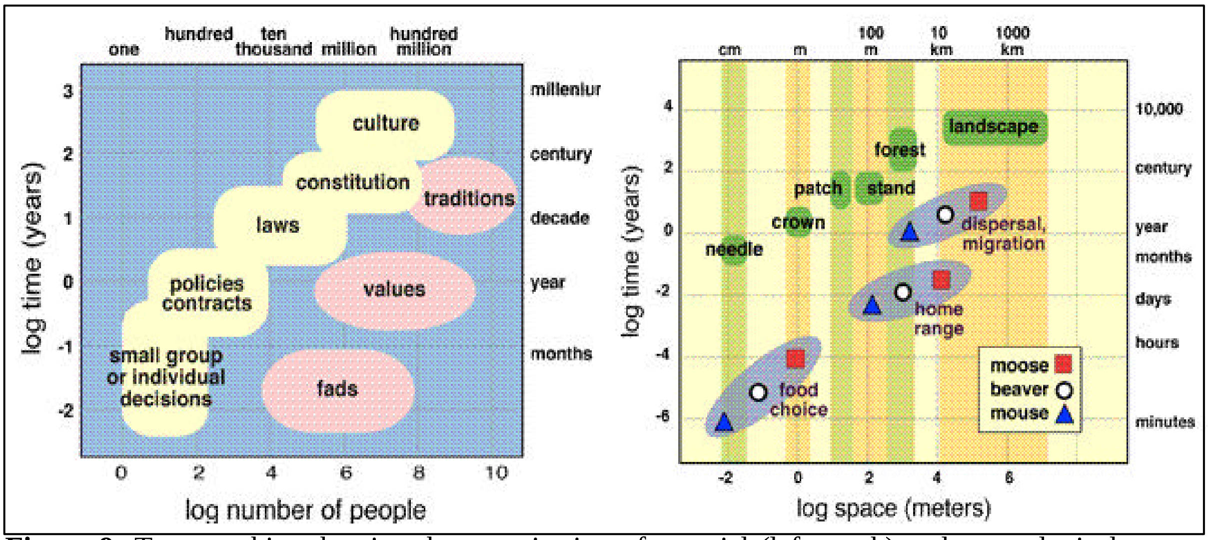


Figure 9: Two graphics showing the organization of a social (left graph) and an ecological system (right graph) in different hierarchies with different spatial and temporal scales.

In ecosystems the decision hierarchies of different species match the hierarchies found in the ecosystem/landscape level (Holling 1992). Figure 9 (right) shows three different species of three different body mass lump categories. The actions or choices of the animals also span different hierarchies in the ecosystem. A deer mouse establishes home ranges over tens of meters, a beaver over kilometers, and a moose over tens of kilometers.

Panarchies and Nested Cycles

The word "*panarchy*" was created to contrast the *"rigid, top-down nature […] of the common meaning of hierarchy”* (Gunderson et al 2002). The suffix "*pan-*" is an attribute to the Greek god Pan – the "*controller and arranger of the four elements*" (Gunderson et al 2002) and his role as creator, destabilizer and destroyer.

The main concern of the panarchy concept is to make clear that the different hierarchies of a system are not organized in a static top-down order. Each hierarchal level is represented by an adaptive cycle (Figure 10) and interacts with the lower (faster) levels and the higher (slower) levels. Two kinds of interaction between levels/phases are seen to be critical for the meaning of sustainability:

The first is termed revolt and describes the interaction between a small and fast cycle and a bigger slower one. When the smaller cycle enters the O-phase (creative destruction) and experiences a collapse, the effects of this collapse can cascade up to the next larger and slower level and trigger a crisis especially when this system is in the K-phase with low resilience.

The second is the interaction of larger slower level with a smaller and faster one. It is called remember. It indicates that the reorganization (a-phase) of cycle is influenced by the K-phase of the next higher and slower level.

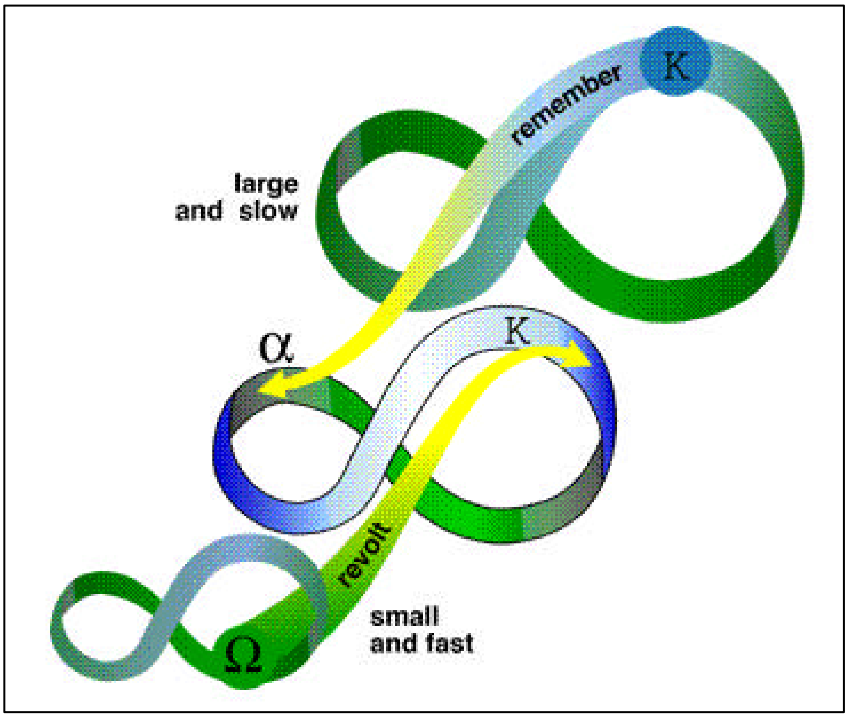


Figure 10: Panarchical connections. Three selected levels of a panarchy are illustrated, to emphasize the two connections that are critical in creating and sustaining the adaptive capacity. (Gunderson et al 2002 p75)

Panarchy and Sustainability

Viewing sustainability respectively sustainable development under the light of the resilience and panarchy concepts emphasis the role of adaptation and response to changing conditions. On the homepage of the ´Resilience Alliance´ following description of sustainability and sustainable development is given:

"In a healthy society each level is allowed to operate at its own pace, protected from above by slower, larger levels but invigorated from below by faster, smaller cycles of innovation. This summarizes succinctly the heart of what we define as sustainability. The fast levels invent, experiment and test; the slower levels stabilize and conserve accumulated memory of past successful, surviving experiments. The whole panarchy is both creative and conserving. The interactions between cycles in a panarchy combines learning with continuity. This clarifies the meaning of sustainable development. Sustainability is the capacity to create, test and maintain adaptive capability. Development is the process of creating, testing and maintaining opportunity. The phrase that combines the two, sustainable development, is therefore not an oxymoron but represents a logical partnership." (Resilience Alliance [Url. 1])

If sustainability is seen as the capacity to create, test and maintain adaptive capability and development is seen as the process of creating, testing and maintaining opportunity (Gunderson et al.2002), then the concept of panarchy gives a useful tool for combing both creative and conserving processes to describe what then is termed sustainable development.

The concept of panarchy is an attempt to contribute to theory making it possible to create models of human – nature interactions across scales and time

Resilience Analysis and Adaptive Management

Interlinking Research and Management

Considering the complexity of social-ecological systems discussed above the attempt to study (describe in a meaningful way) or manage these systems into a certain direction (e.g. "sustainability") seems difficult, forecasting the future developments nearly impossible.

Brian Walker et al (2002) give a short summary of reasons, which limit the usability of traditional scientific forecasting methods:

- Key drivers, such as climate and technological change, are unpredictable. Many change non-linearly.
- Human action in response to forecasts is reflexive. If important ecological or economic predictions are taken seriously, people will react in ways that will change the future, and perhaps cause the predictions to be incorrect.
- The system may change faster than the forecasting models can be recalibrated, particularly during turbulent periods of transition, so forecasts are most unreliable in precisely the situations where they are most wanted.

Brian Walker et al (2002) suggest two general possibilities of dealing with these difficulties:

(1). Concentrating on a larger perspective of the system – ignoring such details as agents and variables. This can be obtained by using the concept originated from dynamic system theory as for example the adaptive cycle (Holling 2002), which classifies four typical repeating phases in the development of a system over time.

(2). Leaving the uncertain area of predicting the future of socio-ecological systems and concentrate on "*maintaining the capacity of the system to cope with what ever the future will bring without changing the system in a undesirable way*." Or in other words learn to live within the system rather then controlling it.

Keeping the resilience high as suggested in (2) is not an easy task though. It implies knowledge about the biophysical and social components and the processes mentioned in (1) and an involvement of all actors including the scientists or managers (critical self reflection, e.g. considering design features due to the constrains of found raising) with the aim to foster co-discovery and enhance the knowledge of stakeholders on how to maintain the system. This procedure requires a two-way dialog between scientist and society, which is reflected in the principles of adaptive management approaches or concepts of postnormal science (e.g. Giampietro 2004.).

The adaptive management process as described by the Resilience Alliance seeks to identify major uncertainties in the system and then establishes methodologies to test hypotheses relating to those uncertainties. Management interventions are not only thought of as a tool to change the system but are also used to study the system. Vital components of an adaptive management approach are therefore both scientific and social processes like:

- Management is linked to appropriate temporal and spatial scales
- Management retains a focus on statistical power and controls
- Use of computer models to build synthesis and an embodied ecological consensus
- Use embodied ecological consensus to evaluate strategic alternatives
- Communicate alternatives to political arena for negotiation of a selection

(Resilience Alliance: Homepage)

An adaptive management process requires "*an open management process which seeks to include past present and future stakeholders*" (Resilience Alliance Homepage). One core of the adaptive management process is to use or create political and institutional openness and flexibility.

In the following two criteria, one derived from a more resilience – oriented group and one more concerned with Multi Decision Analysis – are shortly presented. Both are based on a system dynamics approach and concepts of adaptive management.

Analyzing Social-Ecological Resilience & the Procedural Approach

Brian Walker et al (2002) state that what is needed is a "*process that stimulates creative thinking about future and allows both stakeholders and researchers to compare maps of various pathways to the future*." They propose a framework composed of four steps for the analysis of social ecological resilience:

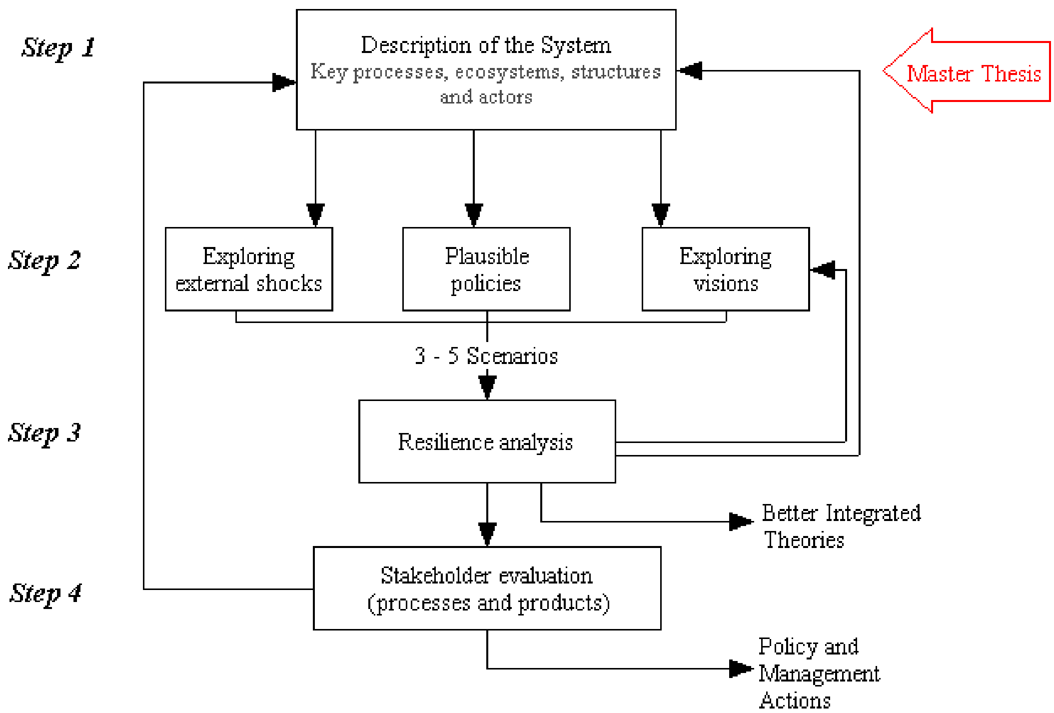


Figure 11: A framework for the analysis of resilience in social-ecological systems. The arrow points out the position this work would have in the analysis of the social-ecological resilience as suggested by Walker (2002).

The first step is the development of a conceptual model of the Social-ecological system. Ideally based strongly on stakeholder inputs.

The second step looks for the influences or drivers (e.g. policy drivers and stakeholder actions) that affect the behavior of the system. The aim is to produce a limited set of possible scenarios.

Walker proposes three different kinds of drivers to be considered:

1. external shocks and disturbances (physical, social, and economic);
2. the visions, hopes, and fears that people have for the future;
3. a set of possible policies that might conceivably be imposed.

Creating scenarios with the above in mind gives the opportunity to connect the visions the people have of their future with the constraints put on them from external drivers. Ideally the scenarios will provide a framework to discover pathways towards the aims of the people either by adapting to possible external forces or by bypassing them (another option would be that the aims and visions of the people become different during the processes.)

In the third step the visions of the stakeholders (step 2) are put together with the information collected in step 1. The focus is on the interactions of these two realms, that is how the system will react to drivers of change. Walker et al suggest using both modeling and non-modeling methods.

The process of managing a system towards a high resilience involves a stakeholder evaluation of the whole process and a consideration of the "*emerging understanding*" of the system by the actors. This should identify actions that can either enhance or reduce the resilience of the system.

An alternative, though similar approach is a multi-criteria approach based on the Soft Systems Methodology of Checkland (**Figure 12**), as described by Allen and Hoekstra[7] (1992) and by Giampietro (2004 p115). This approach also takes into account characteristic features of living systems as described by Giampietro (2004) and also exhibits similarities with the approach presented by Walker et al (2002).

The procedural approach starts with the recognition that there is a problem – even if it is not directly expressed. According to Checkland (1990) the first step is not as trivial as it may sound. He argues that even reaching an agreement over a problem definition can be quite difficult as different stakeholders have different perceptions of reality.

Checkland describes the second step of the approach as "*painting a rich picture*". The aim is not to build one model, which fits a particular view, but to create as many as possible

[7] Mario Giampietro states two reasons for using the narrative of Allen & Hoekstra (1992): (1) They propose an epistemology framed within complex systems theory. (2) They use the approach in the context of sustainability, multiple land use and ecological compatibility.

reflecting different views of the situation. These views are reduced again in the next step to find workable solutions (= finding root definitions). Mario Giampietro states that the analyst now should seek to answer following questions: What is the system of interest? What is the system doing? Why is this relevant? Relevant for whom? What are the criteria used to decide that? What are the system attributes that produce the conflicts and the unease that generated the willingness to get into the first step of the process? (Giampietro 2004).
Different models are needed for different root definitions. They should identify the constraints exposed on the system and the crucial mechanisms, which affect the general behavior of the system.

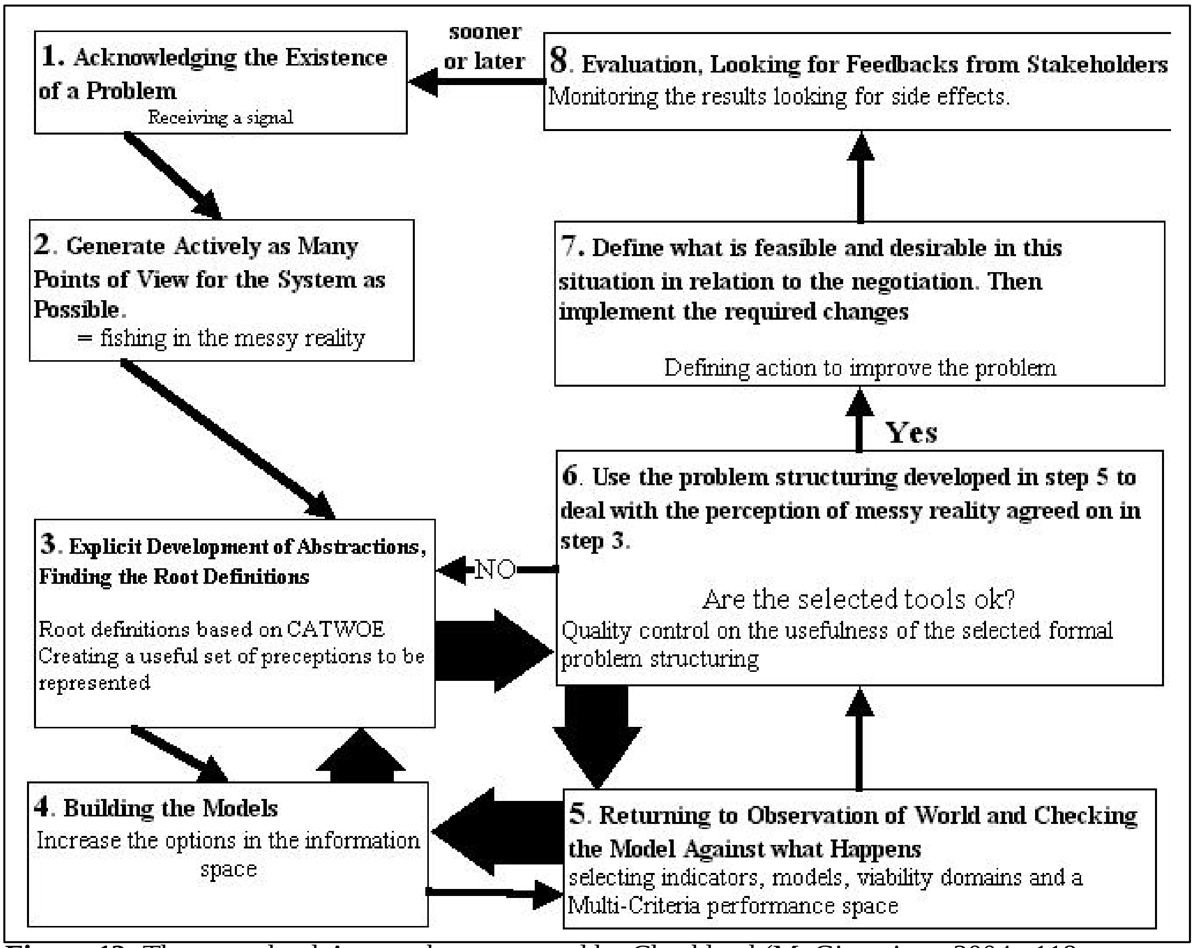


Figure 12: The procedural Approach as proposed by Checkland (M. Giampietro 2004 p118 (Modified))

The two approaches were described here to make clear three points:
First to show what implications the theoretical ideas about uncertainty in social-ecological systems, as presented in the beginning of this chapter, have in practical, management issues. Second it is interesting to note that both approaches although developed out of quite different disciplinary backgrounds and traditions suggest a similar handling of the respective problem.

This is in line with the statement that a system theoretic approach could have the possibility to help close interdisciplinary gaps.

The third reason is the attempt to position this thesis in a wider context and point out how a work like this could contribute to a process of sustainable development. A (still incomplete) description of Trinket Island is given, considering different types of systems (in terms of scale, rate of change, properties) and their interactions. Information of different sources is integrated with the aim of creating a flexible and open model of processes on Trinket Island. This is in line with step one of the framework suggested by Walker et al (2002), as pointed out in

Figure 11, and with step two of the procedural approach (Figure 12).

In the following chapter the role of modeling when considering an adaptive management or other similar approaches is discussed.

The Role of Modeling in a Complex Reality

In both approaches presented above modeling the social-ecological system under observation plays an important role (e.g.: see vital components of adaptive management). Checkland wrote:

"Models are only means to an end which is to have a well structured and shared representation of the perception of a problem situation to be used in the debate about how to improve it. That debate is structured by using the models based on a range of worldviews to question perceptions of the situation." Checkland (1990)

Checkland speaks of models in a very general term, e.g. either conceptual or mental models and mathematically or computable models (simulation models) may be seen able to fulfill the claim made above.

Focusing on computable simulation models used for resilience analysis is a statement made by the Resilience Alliance:

"Models play an important role in the analysis of resilience of social-ecological systems. A reason for this is that the concept of resilience is originally formulated mathematically on systems with multiple stable attractors. In the real world it is impossible to measure directly when a system flip from one domain of attraction to another one. However, by the use of models we can study resilience of social-ecological systems theoretically, and models can be used to formulate indicators that provide indirect but reasonable indicators for different stability domains. Furthermore, models can be used to explore the behavior of a system in new situations based on existing knowledge, and may therefore provide indications of possible costs and benefits of expected future developments in social-ecological systems.

Finally, models help to describe concepts and theories which make them tools for communication between disciplines and tools for education.” (Resilience Alliance, Homepage)

Different Approaches and Concepts of Modeling

Introduction

Modeling is employed by numerous different disciplines ranging from theoretical physics to the social sciences. The terms and definitions used differ from community to community. The following classifications are by no means complete. The examples described were all taken from ecological respectively social (or interdisciplinary) literature, as these are seen to be the most relevant for this work.

Before discussing different approaches in modeling one should recognize that the distinctions between different types of models can be made at several levels. First, there are various different basic technical approaches that have different capabilities in handling certain phenomena (see Appendix I for a short Introduction). Secondly there are applications based on some software, which utilize one or several of these technical approaches. Then there are different methodological approaches concerned either with the different stages of the modeling process or with the whole modeling process. Also the benefits of modeling can be classified by grouping them into hard and soft benefits (Table 2).

Hard Benefits	**Soft Benefits**
• Insight into and prediction of the behavior of the target system • Leading to scientific advance, policy guidance etc.	• Checking coherence of stated theory • Exposing ignorance and ambiguity Provoking collection of data • Enhancing communication and provoking discussion • Education / Entertainment • Generating interesting technical problems

Table 2: The Hard and Soft Benefits of (agent-based) modeling. Doran (2001b)

Mental Models vs. Computer Models

Mental Models

Mental models are what we use to live our daily life. They are representations of the reality, they are filters through which we interpret our experiences and chose our actions. Every “thing” that explains something about how the world is organized (sciences, religions, worldviews, etc.) can be seen as a mental model of a reality we never will be able to totally grasp. The problem with mental models is that they are often not easily shared among individuals; they are often complicated and based on assumptions difficult to examine. The second point is that our mental models may guide our decisions but they are also strongly influenced by authority relations, organizational context, peer pressure and cognitive abilities. This results in difficulties constructing and using even our own mental models for decision-making. (Sterman 1991)

Computer Models

Sterman (1991) gives following advantages computer models can have over mental models:

- They are explicit; their assumptions are stated in the written documentation and open for all to review.
- They infallibly compute the logical consequences of the modeler's assumptions.
- They are comprehensive and able to interrelate many factors simultaneously.

The important point to make is that these are the advantages computer models have in <u>theory</u>. In reality they often are:

Poorly documented and so complex that:

- No one can examine there assumptions.
- They act as black boxes and there can be no assurance in the reliability or accuracy of the assumptions.
- They are often unable to deal with relationships and factors that are difficult to quantify, for which no numerical data exists, or lie outside the expertise of the specialist who build the model.

Muetzelfeldt (2003) gives some more practical shortcomings of models implemented as computer programs:

- Research grade models often run into thousands of lines of code, requiring specialist programming skills and becoming expensive.
- Debugging is difficult.
- Re-use of models, sub-models and model support tools is difficult and thus rare.
- It can be very hard for others to understand the model based on the lines of the program used to implement it.
- There is no enforced correspondence between a model-as-program and the documentation (e.g. metadata, comment blocks or journal paper) that describes the model. Variables cannot have metadata attached to them.

- An equation in a conventional programming language is actually an assignment statement. This means that, while it is possible to write principled programs to implement a model, the language does not enforce this.
- There is a considerable conceptual gap between the constructs provided by a programming language, and those in the head of modelers when they design a model

Another danger or shortcoming is not due to the computer model itself but to its use as tool when it is relied on as the “holy gral” of truth finding / problem solving / future predicting machine.

Anyway creating computable models has been a scientific method in several disciplines since a long time now and has contributed to our understanding of processes in various fields.

In the following the focus will be on computable models (which of course always evolve out of mental models).

Computational Modeling Approaches I (technical section)

There are several different classifications of modeling techniques ranging from more technical to more applied concepts. A quite technical classification is based on the general structure of the model. Cellular Automata, Genetic Algorithms and Neural Networks are very basic concepts and often used together (hybrids) and used together in modeling a certain system. The discussion of the different methodologies is usually a realm of computer scientists or technicians. Appendix I gives a short overview over Cellular Automata, Genetic Algorithms and Neural Networks.

Visual Modeling Environments

These environments are usually based on the System Dynamics Paradigm (Forrester, 1971). In system dynamics the real world is modeled in terms of compartments (stocks), flows and variables that can be connected with influence arrows to stocks, flows or other variables. Common visual modeling environments are Stella, Vensim or Powersim[8]. They provide an intuitive way of modeling systems with differential or difference equations. Additionally they often also provide possibilities of using standard mathematical operators and functions,

[8] For information and downloads see “internet-resources” in Chapter IX.

Boolean operators (e.g.: and; or; not; and not)[9], conditional statements (e.g.: if…then…elsif…then…else)[10]. Visual modeling is mainly used for whole systems modeling. The system is mapped using the system dynamics elements, which results in a model with 2-dimensional structure.

Modular Modeling, Component Based Approaches

These types of modeling frameworks are all based on some notion of modularity. The component-based approach is a way of organizing modeling efforts in larger projects. The single components can either be different parts of a decision-support-system (the parts being e.g. the model, the user-interface, the data management, the GIS) or represent different parts of one model (e.g. in a cropping model: a crop growth model, a soil-water model and an insect pest model). In both cases the components are independent software objects, which communicate with each other through some interfaces.

Another approach of modeling, which deals with modularity, are various models programmed in object oriented languages (e.g. in C++, JAVA, Smalltalk). All agent-based models (ABMs) fall in this category. This approach has "*benefits for ecological modeling, including the analogy between composition and inheritance hierarchies in nature (a sheep has legs; a sheep is a type of mammal), and analogous constructs in object-oriented software design.*" (Muetzelfeldt 2004 p11)

Agent Based Modeling: Platforms and Methods

Synonyms for ABMs are: Individual Based Modeling (IBM); Object Oriented Modeling (OOM); Multi Agent Systems (MAS)[= systems with more then one agent, interacting with each other.]

ABMs can be used to simulated or model complex systems / complex adaptive systems with emergent properties. Agent Based Models simulate the behavior of agents (e.g. humans in a resource use model, trees in a forest model, individuals in a population model). The basic components of an ABM are the agent (or agents) and the environment. "*An agent is a*

[9] Boolean operators are commonly known from there use in search machines. You can state what keywords you want to include or exclude. In modeling they are often used to link conditional statements.
[10] With conditional statements you can specify under what conditions something will be changed. e.g. the statement : if pigage >= 5 then m==1 would mean that when the variable pigage (determining the age of the pig) turns 5 (the model-pig becomes 5 years old) the mortality-rate (m) will change to 1 i.e. the pig dies.

computer system that is situated in some environment, and that is capable of autonomous action in this environment" (Woolridge 1999 p29).

The system is modeled as a collection of autonomous decision-making entities or agents. Each agent individually assesses its situation and makes decisions on the basis of a set of rules. Agents can be defined as: "*autonomous, computational entities that can be viewed as perceiving their environment through sensors and acting upon their environment through effectors*." (Weiss, 1999)

ABM has been used in several fields e.g.: *Archaeology*: Anasszi settlement dynamics (Timothy et al 2000), Mesolithic foraging (Lake 2000), *Ecology*: forest dynamics, behavioral ecology (Boekhorst et al 2000), population dynamics, *Conservation Biology*: lake pollution (Carpenter et al 1999), resource use management, *Anthropology*: artificial societies (Doran 2000a; Lansing 2000), *Economics, Organizational Science*

The Advantages of the ABM approach (DeAngelis et al. 1992):

- A variety of types of differences among individuals in the population can be accommodated;
- Complex decision making by an individual can be simulated
- Local interactions in space and the effects of stochastic temporal and spatial variability are easily handled.
- The ability of agent-based models to handle heterogeneity and beliefs is important especially in systems containing humans.
- Agent based models can handle qualitative (ordinal or categorical, relational) and quantitative (age, size of organization) data.

Numerous approaches exist to represent the decision / reasoning process of human agents most of them are derived from psychological or economic theories. The technological repertoire for building the agent-structure can be derived from a number of modeling techniques including artificial neural networks and cellular automata. There are numerous agent types broadly distinguished due to their structure, the decision rules they use or the number of levels they posses (Weiss 1999).

Agent Based Models are usually implemented in conventional object oriented programming language (e.g. C++, JAVA, Smalltalk). There is little consensus about the best langue. Gilbert (2002) state that in a quick survey of 18 articles published in the Journal of Artificial Societies and Social Simulation in 1998 and 1999 no one language was used by more then one of the 18

papers describing a computational model. The problems that arise out of the use of general-purpose computer languages for modeling are generally the ones already discussed above.
As reaction to the struggle associated with the common modeling praxis several standardized libraries have emerged. One of the first and possibly one of the best know is SWARM (other libraries include ASCAPE or REPAST (for homepages and downloads see “Internet Resources” in chapter IX). Although these libraries have advantages in making some models easier to program they still require a good working knowledge in the respective programming langue (C++; JAVA). Beside this they often have build in assumptions, which can hinder the use of other approaches as those used by the developers (Gilbert et al 2002). The development of software packages could be a way to evade some of the disadvantages arising through the use of general purpose modeling languages. CORMAS or SDML (for homepages and downloads see “Internet Resources” in chapter IX) are examples for this kind of software packages. These packages do not demand that the user is fluent in any computer language. However they still have a very complex user-interface, which can take a considerable time to learn.

Modeling Approaches II

Beside the techniques used for creating a model there are also different approaches concerning the process of modeling including the purposes, the goals or the use of the model. Searching the Literature reveals that there usually is a distinction between two “opposite” ways of modeling.
Distinctions in modeling approaches (this is only a sample and no exhaustive list):

- Simulation vs. Optimization (Sterman 1991)
- Procedural vs. Declarative (Muetzelfeldt 2003 & 2004)
- Emphasis on Soft vs. Hard Benefits (Doran 2001b)
- Linear vs. Non-linear Modeling Culture (Richerdson 2002)
- Focus on Model vs. Focus on Process (Walters 1997)

The distinctions made by Sterman (1991) and Muetzelfeldt (2003) are more technical but also address fundamental differences in the approach towards modeling. The last three classifications (Doran, Richerdson, Walters) basically draw the same line of distinction between the different approaches and will therefore be discussed together. The formulation of Walters (focus on model vs. focus on process) might be the most straightforward one of them.

Optimization vs. Simulation Modeling

Optimization Modeling

"Optimization models do not tell you what will happen in a certain situation. Instead they tell you what to do in order to make best of the situation; they are normative or prescriptive models."(Sterman 1991)

An optimization model usually includes three parts:

(1) The objective function specifying the goal or objective. (2) The decision variables specifying the possible choices and (3) the constraints, which restrict the choices of the decision variable to those that are acceptable.

The main problems and limitations of optimization models are: (1) difficulties with the specification of the objective function (highly depended on personal perspectives / values), (2) unrealistic linearity, (3) lack of feedback, and (4) lack of dynamics (Sterman 1991).

Optimization models should be used when the problem is to choose the best of a well-defined set of alternatives with the meaning of "best" also well defined. Additionally the system to be optimized should be relatively static and free of feedback. These conditions do hardly meet any socio – ecological systems and their management questions.

Simulation Modeling

"The purpose of a simulation model is to mimic the real system so that its behavior can be studied. The model is a laboratory replica of the real system, a microworld. By creating a representation of the system in the laboratory, a modeler can perform experiments that are impossible, unethical, or prohibitively expensive in the real world." (Sterman 1991)

Simulation models are descriptive; they do not calculate what should be done but show what happens if something is done in a certain situation. Sterman (1991) proposes either foresight (predicting how systems might behave in the future under assumed conditions) or policy design (designing new decision-making strategies or organizational structures and evaluating their effects on the behavior of the system) as the purposes of simulation modeling.

Sterman (1991) finds two main components of a simulation model:

(1) The representation of the physical world (environment) relevant to the problem under study. E.g.: physical components, stocks, population attributes or flows (people, money, energy).

(2) A behavioral component defining in which way people will respond to different situations, how they make decisions.

In the simulation both components interact with each other (e.g. some choices depend on the status of certain resources). The output will be a description of expected decisions.

Simulation models are in principle able to deal with non-linearity, feedback effects and dynamics. There limitations are the assumptions made about the physical and behavioral components. Although Sterman (1991) states that the adequate representation of the physical environment is not such a problem *("the physical environment can be portrayed with whatever detail and accuracy is needed for the model purpose."* Sterman 1991) asking an ecologist aware of the complexity of the physical environment may give a different story (e.g. see Walker 2002). Never the less finding accurate decision rules for the actors in the model so that they respond to change like the real world actors would is also hard (if not even impossible). The use of "*soft Variables*" (descriptive, qualitative, difficult to quantify, not recorded) is often crucial for understanding and modeling complex systems, which brings problems in testing the accuracy of data. Another problem can arise when choosing too narrow system boundaries (spatial or time) and therefore ignoring important feedbacks.

Declarative vs. Procedural Modeling (Robert Muetzelfeldt)

"The key to realizing the vision for environmental modeling is this: to think of a model as a design to be represented and processed rather than as a program to be run. This is the essence of the declarative modeling approach." (Muetzelfeldt 2004)

The distinction between declarative vs. procedural modeling was drawn by Muetzelfeldt (2004) how is also involved in the development of the simulation software (SIMILE) used in this work. The distinction between procedural vs. declarative can be described as the distinction between "knowing that" and "knowing how". In terms of computing this distinction refers closely to the distinction between data and program. Data describes what is the program describes how to process the data (Muetzelfeldt 2004). The boundary between declarative and procedural is not a fixed one e.g. any given procedural program can be replaced by a set of data and a more generic procedural program.

The procedural (or imperative) modeling approach usually utilizes models implemented as computer programs, written in conventional programming languages like C++, Fortaran, JAVA. These programs specify a set of procedures to execute or (equivalently) specify a set of instructions to follow.

Muetzelfeldt (2003 & 2004) and others see a range of major problems in this approach, the most frequent being:

- Lack of re-use or share ability of model components
- Time taken to build models
- Difficulty of people to understand other peoples models
- Mismatch between model documentation and the implemented model
- Effort wasted in producing user-interfaces and input/output utilities for individual models

Declarative modeling is based on the principle that:

"Models should be represented on the computer as a specification of the conceptual and mathematical structure of the model, not as a computer program instructing the computer to perform a set of calculations. The specification defines the objects and variables in the model, and the functional relationships between them." (Muetzelfeldt 2004 p6)

The procedural vs. the declarative distinction
The distinction between declarative knowledge (knowing that) and procedural knowledge (knowing how) has long been recognized in human cognition. *I know that a bicycle has two wheels; I know how to ride a bicycle.* This difference is even ascribed to different parts of the brain, with the bilateral temporal lobes being used for semantic/conceptual knowledge, and the left frontal/basal-ganglia part being used for cognitive and motor skills (Ullman: http://slate.lang.uiuc.edu/lectures01.html).

Consider an IKEA wardrobe. We can describe it as a design - on paper, or in a computer-aided design package such as AutoCAD. The design says what bits we have, their properties, and how they are connected together. Or we can have instructions on how to construct it. The former is declarative, the latter procedural. The design is what was produced originally, to meet some specifications (size, cost, appearance, etc). And knowing the design, we can infer many things about the wardrobe: how big it is, how much it weighs, even possible procedures for constructing it. The instructions, on the other hand, serve a particular purpose - to get the flatpack into a functioning wardrobe - and are not an effective method for indicating what the wardrobe is actually like. If you simply gave the text instructions to someone, they would have a hard job making a drawing of what the finished wardrobe would look like.

Textbox 2: Distinction between declarative and procedural knowledge when building an IKEA wardrobe (Muetzelfeldt 2004 p7).

The modeling can therefore be treated as a "*design process*". Creating the representation of the structure (the design) is separated from the processing (e.g. simulation) of the design. The objects, variables and equations specifying the model might be saved in a single file. This information is then used by different tools e.g. one for displaying the model in a certain way, one for simulating the behavior of the model, one for comparing the structure of two versions of the same model and so forth. This makes the development of different tools supporting various aspects of the modeling process possible.

Declarative modeling focuses on the process of modeling. Important are questions of how models are designed, presented, analyzed or transformed, the simulation process it self takes a back seat.

The benefits of declarative modeling:

1. It is closer to the way humans think about the world. Knowledge about the world (facts and rules) is separated from what we can do with that knowledge (reasoning).
2. It allows more flexibility. A declarative body of knowledge can be used in many different ways, to answer a wide range of different problems. (e.g. consider a rout description: it can be given as a description of how to walk from point A to B (go straight turn left at the first corner - procedural) or as a map. The map (and the brain as generic program) can not only be used to find the way from A to B but also for finding other points.)
3. It is easier to debug and less error-prone. Unlike a procedural document a declarative body of knowledge usually consists of independent components, each of which can be treated separately.

Declarative	**Procedural**
Use knowledge in multiple ways	Use knowledge one way
Low efficiency (though not necessarily true)	High efficiency
High modifiability	Low modifiability
High cognitive adequacy (close to the way we think)	Low cognitive adequacy (less intuitive way of thinking)
Higher level of abstraction	Lower level of abstraction
Independent collection of facts	A composite whole, difficult to decompose
Easy to validate	Hard to debug
Transparent	Black-box

Table 3: Relative merits of declarative and procedural approaches Muetzelfeldt (2004 p23)

Linear vs. Non-linear Modeling Culture; Focus on Model vs. Focus on Process

The points made by the different authors according to the classifications of different modeling processes are similar. To say it in a short way: the Non-linear modeling culture focuses on the process of modeling and aims to emphasis both the soft and hard benefits of modeling.

The appealing aspect of the Linear vs. Non-Linear Modeling Culture distinction (Richerdson 2002) is that it draws the attention to the fact that the structure of the model itself (linear or non-linear) can have little to do with its capability to handle non-linear processes in complex realities. This ability arises out of the whole process of modeling (and can therefore be seen as an emergent property arising from the interaction of different scales/levels –e.g.: model - modeler - real world – user). In the following the Linear vs. Non-Linear modeling culture distinction is presented.

The distinction between linear and non-linear models originally was used according to the abilities of the models to capture linear or non-linear phenomena (**Figure 13**).

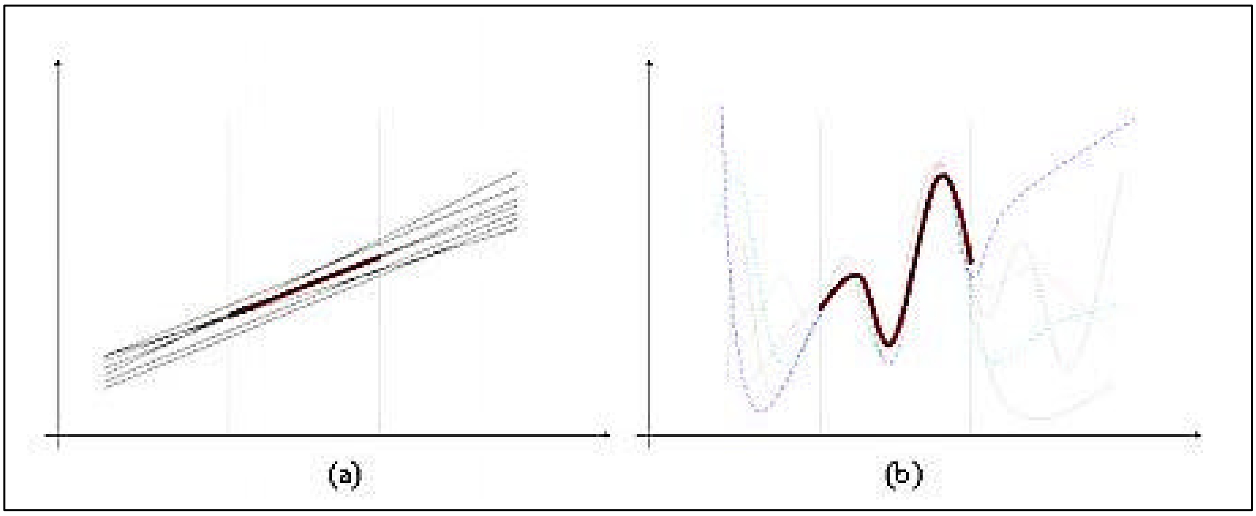


Figure 13. Linear models of a linear universe versus non-linear models of a non-linear universe. (For linear systems extrapolation from limited data is a trivial exercise, whereas for non-linear systems extrapolation from limited data is a highly problematic exercise (Richerdson 2002)

The basic concepts of complexity theory would suggest that linear models are quite useless for describing social-ecological systems, as these systems tend to show non-linear phenomena. Richerdson argues that linear and non-linear models often suffer from the same shortcomings when used to predict non-linear events. He suggests moving the focus on the modeling process:

"The linear culture takes a representationalist view of models in which aspects of reality really are considered to be captured by the model itself – the model becomes an accurate map of reality. Even if the model itself is non-linear its efficacy tends to be overestimated." (Richerdson 2002)

When focusing on the process even linear models can be used to deal with non-linear systems, if the persons using them change and adopt them to the changing system. The capability of the model to deal with non-linearity's comes with the (non-linear) thinking of the users and the modifications they create to fit the model to the observed system. Richerdson describes the non-linear modeling culture as follows:

"The non-linear culture takes a very much more pragmatic stance which recognizes the model as no more then a rough and ready caricature or metaphor of reality. As such the knowledge contained in the model should be regarded with a healthy skepticism, seeing it as a limited source of understanding. The (non linear) modeling process is regarded as an ongoing dialectic between stakeholders (modelers, users, customers, decision makers, etc.), the model, and the observed reality rather than a simple mapping exercise." (Richerdson 2002)

Non-linear approaches (in terms of the modeling culture) seem especially useful for dealing with all kinds of problems arising in the management of socio-ecological systems.

An example for applied "non-linear"-modeling culture is the Participatory Agent Based Social Simulation as described by Pahl-Wostl (2001).

Participatory Agent Based Social Simulation

Participatory agent based social simulation deviates in a number of ways from conventional modeling. The actors themselves whose behavior is represented in the model and who are supposed to later use the models for decision-making and strategic planning participate and contribute to the modeling process. This guarantees that the model captures issues and subjective perceptions and expectations that are of relevance to the actors involved.

This way of modeling can be seen as rout to build dialog and a means for a co-production of knowledge and social learning rather than a means to develop a predictive forecast.

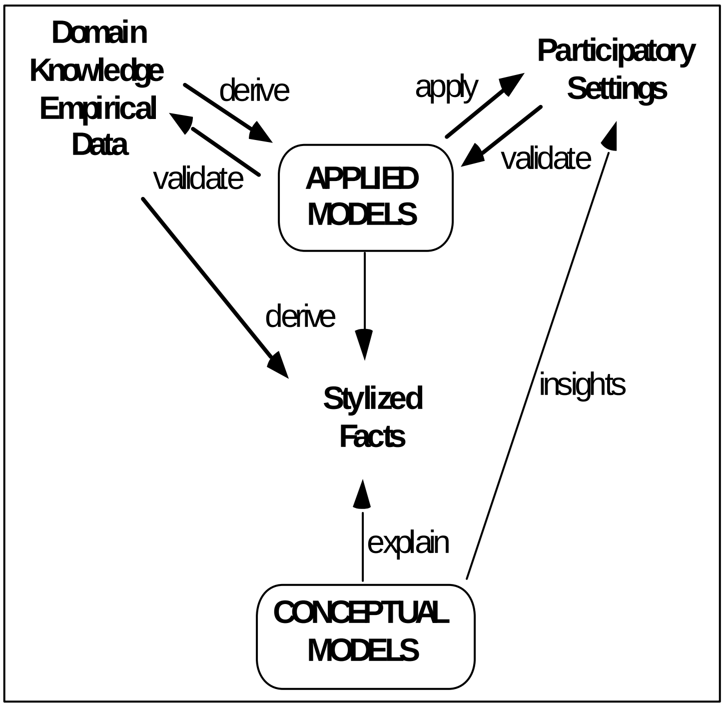


Figure 14: Suggested relationships between different activities of research and different types of models to derive a new research agenda for improving the understanding of human-environment systems and for approaches to joint problem solving in participatory settings. (Pahl-Wostl 2001)

IV.
Methods and Data

Data

In the process of creating Trinket Island Model (TIM) the Data of previous field trips to Trinket was utilized. Some of this data was originally collected to conduct a Material and Energy Flow Analysis to describe the biophysical metabolism of the society on Trinket (Singh et al 2001). This data was in ways very useful for modeling because it outlined important stocks and also the major flows of energy in the Trinket Island system. The shortcomings of this data were the missing indications of what processes controlled these flows. Information about "soft"-variables was gathered through talks and interviews with Simron Singh, who is a leading expert concerning the Nicobars. The work and data presented in his book "In the Sea of Influence – A World System Perspective of the Nicobar Islands" was one of the main sources of information.

Through the creation-process of TIM missing but useful data for modeling the human – nature interactions could be specified. During the last field trip to the Nicobars (2004) this was already taken into account and some spidergrams were constructed.

Spidergrams

Beside "hard"-data (measurable and quantifiable) soft data plays a vital role in the simulation of complex human systems (Sterman 1991). In the search for an appropriate tool for collecting information about the local knowledge, the perceptions and values of the people and their understanding of processes etc. the use of spidergrams as suggested by Lyman (1999 and 2002) was adopted. Beside of being able to capture information of different levels the spidergrams also allow a participative process and were already used for adaptive management processes (Lynam et al 2002).

Two spidergrams of key-informants were conducted proving the usefulness of this approach for creating a model of the Trinket socio-ecological system.

Spidergram Manual

Following manual, based on descriptions given by Lynam (1999), was used to conduct the interviews:

It seems useful to work with a group of people, so that there can be a discussion about the answers given and a more complete network is obtained. To form the groups there are two possibilities: first different homogenous groups each representing a certain class of people/household type. E.g.: young, old, traditional, modern, men, and women. This would result in (different?) spidergrams reflecting the preferences and needs of the respective group. The second possibility is to form heterogeneous groups from the beginning to get a complete picture of the situation in one spidergram.

A spidergram starts with a central question (e.g. What does an average family need to live?) This question can be written on a large enough sheet of paper or represented by a symbol on the ground. The participants are now asked to discuss this question. The answers they give are placed around the central question, and connected with a line (= leg of the spider).

In the second step the participants are asked to weigh the answers e.g. according to their importance. You start with the question: What is considered least important? The least important "spider-leg" receives one point. Other components are scored in relation to the least important e.g.: Component is considered five times as important => it receives five points.

In the third step you start with the highest scored leg and ask a new question. In this way this element becomes the center of a new "spider". This can be exceeded as long as the researcher and the participants are willing.

Only two spidergrams were conducted. This two were mainly concerned with the use and value of different land types, there information could not be included into the current model. See Appendix III for a graphic representation of a spidergram with the central-question: *"What does an average household on Trinket need to live?"*
See Appendix II for the results of two interviews conducted with this method.

Defining Levels

Cross scale linking between different levels e.g. physical-chemical and ecological processes has been found to be one of the most difficult technical issues in simulation modeling (Walters 1997; Bengston et al 2002). The problems in choosing appropriate levels and collection of processes are rooted in a lack of understanding of interaction processes partially due to the spatial and time scales involved (see also chapter– Hierarchies Holons Panarchies).

Walters (1997) gives three reasons why it can be difficult to model cross-scale linkages:

(1) Critical interactions or events can be highly concentrated in space and time at scales/locations/times that we have ignored, or over which we have incorrectly assumed a simple averaging process.

(2) Adding more detail adds more parameters to the model structure, yet each of these parameters is likely to be less well supported by field data; this "overparameterization" can degrade the predictions of a mechanistic model in exactly the same way that it can cause statistical prediction models to fail.

(3) Some ecological interactions result in positive feedbacks that can propagate effects of localized events across scales to produce highly variable, unpredictable spatial patterns at much larger scales (Holling 1992)

Choosing the levels represented in a simulation model is therefore always a trade-off between the mental models of the modeler, effected by his or her background, the available scientific knowledge about processes in the levels of interest, the available traditional / local knowledge and the collection of available local data.

A quote of Walters accurately describes the problem:

“Although we may be able to predict the occurrence of such cross-scale propagation events, we seldom have accurate enough data on process rates and initial spatial pattern to accurately simulate where the propagation of each event will lead.” (Walters 1997)

Besides these technical problems concerned with the modeling process itself there are also some methodological ones already appearing when describing different levels. To deal with the different levels of a social-ecological system Mario Giampietro (2004) suggests the method of Triadic Reading. In the process of triadic reading the scientist chooses levels of interest within a set of nested hierarchical levels.

Triadic Reading – Filtering the Pace of changes in the representation	
Higher Level (n + 1) (e.g. community)	boundary conditions, definition of function for the whole on level n, constraints imposed on level n, possible channels of influence from n to n+1
Focal Level (n) (e.g. household)	Relevant behavior of the whole
Lower Level (n – 1) (e.g. individuals)	Initiating conditions, definitions of structural stability of elements of the whole, constraints imposed on n

Table 4: Triadic reading (Giampietro 2003 – modified)

Some problems can arise though when there is uncertainty on what the next higher level is. This is especially the case when dealing with socio-ecological systems. If the focus is e.g. on the household or family level one has to ask the question if the next level is the ecosystem or the society respectively is the "cultural"-level nested in the ecological or vice versa?

One way of dealing with this would be to separate biophysical from social processes on the cost of loosing information on the interaction between them. Figure 15 tries to illustrate the problem of defining certain levels, when boundaries are partially unclear, and each level itself is made up of nested processes and emergent properties.

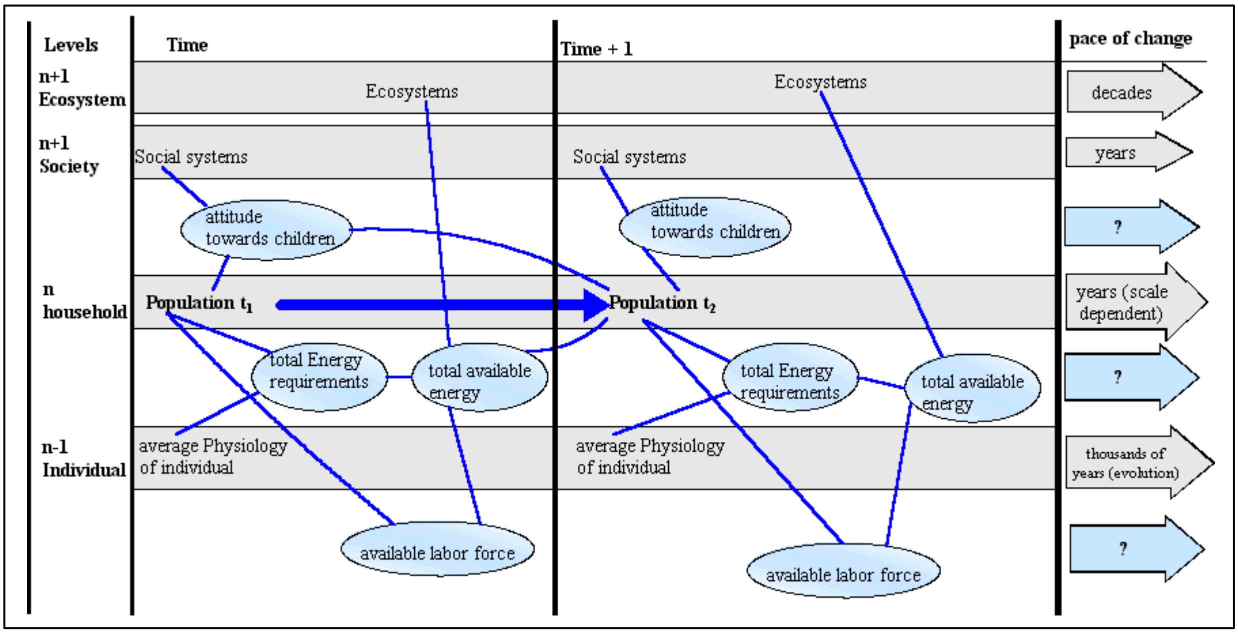


Figure 15: The gray lines represent levels. Level n is nested in the levels n+1, level n-1 is nested in n. Inside the levels are the properties of the level (e.g. the *average Physiology of an individual* is one part of the individual (average) agent) the different properties of the levels can interact with each over and this creates driving forces which influence the properties in the next time step. The figure shows some possible forces, which could be considered for forecasting the population development. In this case it is assumed that the next population (t_2) is influenced by the "attitude towards children" and the possibility to meet the energy requirements for the population. The arrows on the right indicate the time-ranges in which major changes can be expected to occur in the different levels. Note that the times given are only rough estimates basically used to illustrate that processes on different levels do change at different paces.

The focus level of this study was defined to be the social-ecological system of Trinket Island. The other levels and sub-levels were chosen during the process of modeling.

The Modeling Software: SIMILE v3.3

"The modeling world divides into those whose models are based on differential/difference equations (with or without disaggregation); and those who subscribe to an approach based on collections of objects (variously called object-oriented, individual-based or agent-based modeling)." (Simile Homepage)

The Basic Features of SIMILE v3.3

A particular strength of SIMILE is to enable a combination of both "*modeling worlds*" in a very easy way. The modeling software used to create the TIM was developed by Muetzelfeldt as a prove of concept for the advantages of declarative modeling. Simile is characterized by the following main features:

System Dynamics modeling
System Dynamics is a diagrammatic notation for representing systems of DAEs (differential algebraic equations), based on a concept of compartments (stocks, levels) and flows (processes) (Forrester 1971). The compartments represent mathematical state variables, and the flows contribute to the rate-of-change term for each state variable. Additionally, System Dynamics includes the concept of influence, intermediate variable and parameter. Influences arrows show which quantities are used to calculate which other quantities. Intermediate variables hold intermediate quantities. Parameters hold values, which are constant during a simulation run.

Disaggregation
Simile allows the modeler to express many forms of disaggregation: e.g. age/ size/ sex/ species classes. This is done by defining how one class behaves, then specifying that there are many such classes.

Object-based modeling
Simile allows a population of objects to be modeled. As with disaggregation, you define how one member behaves, then specify that there are many such members. In this case, however, the model designer can add in symbols denoting the rules for creating new members of the population, and killing off existing members. Individual members of the population can interact with others.

Spatial modeling
Spatial modeling, in Simile, is simply one form of disaggregation. One spatial unit (e.g. grid square, hexagon, polygon.) is modeled, and then many such units are specified. Each spatial unit can be given spatial attributes (area, location), and interactions between spatial units can be represented (Muetzelfeldt and Duckham, in press).

Modular modeling
Simile allows any model to be inserted as a submodel into another model. Having done this, the modeler can then manually make the links between variables in the two components (in the case where the submodel was not designed to plug into the main model); or links can be made automatically, giving a 'plug-and-play' capability. Conversely, any submodel can be

extracted and run as a stand-alone model ('unplug-and-play'), greatly facilitating the testing of the submodels of a complex model.

Efficient computation
Models can be run as compiled C++[11] programs. In many cases, these will run at speeds comparable to a hand-coded program, enabling Simile to cope with complex models (100s equations; 1000s object instances).

Customizable output displays and input tools

Simile users can design and implement their own input/output procedures, independently of the Simile developers. Thus, users can develop displays for model output that are specific to their requirements. Once developed, these can be shared with others in the research community.

Declarative representation of model structure

A Simile model is saved in an open format as a text file (in Prolog syntax). This means that anyone can develop tools for processing Simile models in novel ways. For example, one group may develop a new way of reporting on model structure, while another may wish to undertake automatic comparison of the structure of two similar models. It also opens the way for the efficient of models across the internet (as XML files), and for the sharing of models between different modeling environments.
(Muetzelfeldt 2002)

For a description of the basic components of the SIMILIE v3.3 software see **Appendix III**.

Why SIMILE was used

There were several reasons why SIMILE v3.3 was used for creating the model:

- Easy and quick to learn, no requirement to be fluent in any conventional programming language.
- Appealing design, allowing intuitive modeling.
- Combination of different modeling approaches like: System Dynamics, Spatial, and Object Based modeling. Making it easier to integrate ideas of already existing models of different types.
- Even large models run at a considerable speed due to the possibility of converting them into c++ programs. This is especially important when only limited computer resources are available.

For more information on SIMILE and a download of free trial software see: Internet resources in **Chapter IX**.

[11] C++ is a commonly used object-oriented programming langue.

V.

Pigs for the Ancestors or for Driving Down the Hypercyle? – A Review

In the following some models interpreting the effects of ritual resource use are presented. Most of them describe the ritual-cycle of the Tsembaga, a Maring-Tribe on Papua New Guinea. These tribes also regard pigs as high status animals and are involved in a ritual cycle, which climaxes in a pig-festival (Kaiko), when nearly the whole pig-population is slaughtered. The first one to describe this ritual-cycle from an ecosystematic point of view was Roy Rappaport in his influential book “Pigs for the Ancestors” (1968). The debate and consecutive statements and models interpreting the functionality of the ritual cycle that followed his work are addressed. First a short description of the Tsembaga and their ritual-cycle is given then the different interpretations on the functions of the cycle are discussed.
More in line with the resilience approach as presented in chapter II, is the work of Tropser (2002) describing the potlatch system of the pre-contact Indians of the North West Pacific coast of North America. He argues that the potlatch system and the associated property right and governance institutions had the probability of increasing the resilience of the socio-ecological system.

The Ritual-Cycle of the Tsembaga

The description of the Tsembaga and their ritual-cycle basically draws on the description given by Rappaport in his work “Pigs for the Ancestors”, based on his 14 months of fieldwork during the year 1963.
The Tsembaga belong to the Maring-group of people. They inhabit the Simbai and Jimi valley in the Bismarck-Range of Papua New Guinea. First contact was established 1954, they remained uncontrolled until 1962. The social organization is, similar to the Nicobars, egalitarian with a “big-man” system. The Tsembaga practice slash and burn shifting cultivation the main livestock are pigs. The fields can be cultivated for about two years then

they should remain fallow for eight to ten years to regain there productiveness. Beside that the Tsembaga are also engaged in hunting and gathering.

The pigs play an important role in the live of these people. They are solely consumed for ritual purpose (e.g. for healing-rituals) or festivities. In addition Rappaport also mentions that they enhance the quality of the fields by ploughing it and also are useful as "waste disposal units".

A Cycle of War and Peace

The Tsembagas and their neighboring groups are engaged in a ritual-cycle, which determines time of piece and time of war with neighboring groups. The cycle repeats itself about every ten years.

The planting of the Rumbim (*Carclyline fruticosa*) is the sign for the ending of the "*time of war*". The ancestors are invoked and all adult pigs are slaughtered and scarified. The local residents consume a smaller amount of the pig meat; the larger part is donated to the allies, which assisted in the previous fighting. Some taboos are released others enforced. The group is still indebted to its ancestors who also assisted in the fighting. This phase is called the "*time of the fighting stones*" and is seen as a time of danger. The contact to the former enemies has to be avoided and there land shunned. It is not allowed to attack other groups. This time lasts until the Rumbim is uprooted at the Kaiko-festival for which a sufficient number of pigs are needed. This festival takes place when the woman start complaining about the extra workload exposed on them due to the grown pig herds. Furthermore the pigs' cause increasingly troubles and conflicts as they start ravaging the gardens. The time the pig population needs to grow to such a size varies between five (good place) to ten (bad place) years. Rappaport describes this situation as a shift of the relationship between pigs and human from mutualism to parasitism. The state of Kaiko remains for about one year. In this time friendly tribes are invited for dance using the same channels that are later used for calling the allies for fighting. The Kaiko ends with a major pig slaughtering. Rappaport reports that about 2000 – 3000 people attended the Kaiko during his fieldwork. After the Kaiko the "fighting stones" are removed again and fighting between groups is no longer taboo. Conflicts between neighboring groups now often escalate in war. The fights between groups are ritualized and accomplished by several specific taboos. The men consume heavily salted pig meat and fat during the periods of fighting. Sporadic fighting can last for several weeks, with some deaths on each side. Only when one side is much weaker then the other (usually due to a not functioning net of allies) raids and turnouts occur. The ending of the period of war is again indicated through the planting of the Rumbim.

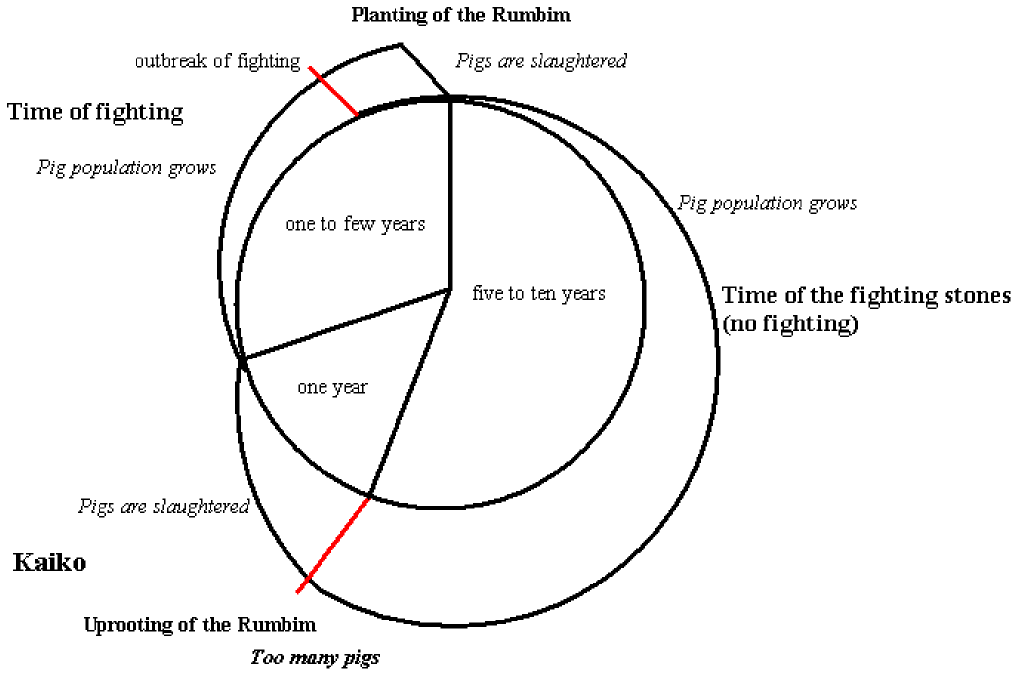


Figure 16: The Ritual-cycle of the Tsembaga. The thickness of the outer circle indicates the size of the pig population.

Rappaports Interpretation of the Tsembaga Ritual Cycle

Rappaport conducted energy and material flow analysis. He concluded that the ritual cycle not only had a function in regulating the relation between the Tsembaga and the spirits but also in regulating their relation to the natural environment [local subsystem] and other human groups [regional subsystem]. He regards the ritual cycle as: "[…] *a complex homeostatic mechanism, operating to maintain the values of a number of variables within "goal ranges*[12]" (Rappaport 1984 p224). Besides that he also sees the ritual-cycle as a transducer "*translating changes in the state of one subsystem into information and energy that can produce changes in the second subsystem*" (Rappaport 1984 p229). He assigns following effects to the ritual-cycle:

[12] Rappaport defines goal range as: "Ranges of values that permit the perpetuation of a system, as constituted, through indefinite periods of time."

- Regulates relationship between people, pigs and gardens. Ensures adequate cultivation-fallow ratios.
- Helps keeping the human population below the carrying capacity due to the deaths occurring during the war-time. The pigs are seen as trigger.
- Regulates the frequency of the fighting
- The Kaiko enhances trade
- Local abundance of pig meat is distributed
- Ritualized use of pig meat and fat makes sure that supply with high-quality protein is assured in times of need.

He assumes that land and therefore also (agricultural) food is a limited resource and that pigs and humans compete for nearly the same resources.

Shantzis and Behrens (1973) Dynamic model of the Tsembaga

In the process of creating the first “world model” (Meadows 1973) Shantzis and Behrens (1973) created a dynamic system model of the Tsembaga agricultural system, based on the data from Rappaport. They provide a formal, graphic and mathematical model of the human-ecosystem. (Shantzis et al 1973). They name four reasons for the creation of their model:

1. Clarify causal relationships in the system
2. Through an analysis of the robustness of the model to change, critical or important parameters can be identified.
3. New questions can be discussed; knowledge gaps can be identified.
4. The model analysis can yield information about relationships outside of the observed parameter space.

They basically draw the same conclusions as Rappaport.

The pig herds function as indicator. The fighting is an automatic birth-control device, reducing dangerous overpopulation and at the same time also keeps the cycle going. They emphasizes that the fighting/population control mechanism is discontinuous and only takes a small toll. As soon as the population rises the frequency of the fighting events will rise and not the intensity. They identify following important parameters:

Rate of population change

The extraction of the people and the consumption of the pigs both affect the fertility of the land. If the food becomes lean a negative feedback loop puts pressure on the society (but not effective enough to control population growth).

Rate of pig population change

Three factors control the pig population development: (1) value of pigs as status symbol, (2) ritual pig sacrifices by misfortune, (3) working time and land necessary for maintaining the pigs.

The pig population itself has two effects: (1) Enhances the quality of the land. (2) Together with the human population it acts as trigger for feasts.

The pig slaughtering at the feats and the size of the pig population that acts as trigger for the feasts influences the protein content in the food of the people.

Keeps number of people and pigs below the carrying capacity. A festival reduces the pig population at 85%.

Death rate in war

The human death rate increases to 12% after the festival (time of war) then drops to 5% in the consecutive year. In the third and fourth year it drops back to the "normal" value of 2%.

The model was created with the Dynamo modeling language in a system dynamics modeling approach. Shantzis and Behrens (1973) characterize the Tsembaga system as extraordinary inflexible and sensitive to outside influence. In their model even small changes in the parameters can "*destroy the dynamic balance of the variables determining the ritual cycle*" (Shantzis et al 1973). Further they state that the high status of the pigs in the Tsembaga society is crucial for the functioning of the system.

Critique and Alternative Models.

The work of Rappaport (1984) on the ritual cycle of the Tsembaga has released discussion and critic. Many of the points made against Rappaport can also be made against the model of Shantzis and Behrens (1973):

- Ignoring any form of historical development – Salisbury (1975) argues that the Tsembaga have been far too short in place (maybe 200 years) for such a fine-tuned system to evolve.

- Ignoring the role of the individual – emphasizing group selection. It is not clear how such a system could have evolved (Bates and Lee 1979).
- Evidences that the Tsembaga are not very well nourished are not in line with the hypothesis that the population is kept below carrying capacity (MacArthur 1974; Buchbinder 1977 in Foin et al 1987).
- Too much focus on a certain equilibrium stage (Foin et al 1987).

Concerning the Dynamo model of Shantzis and Behrens it was also criticized that the model reacts very sensitive to parameter choice. Foin and Davis (1984) tested the model with more accurate data (especially concerning the death rates during warfare) with the result that the ritual cycle did not act stabilizing.

Other authors proposed different mechanism responsible for controlling the population size of the Maring tribes for example interaction between malnutrition and diseases like malaria (Buchbinder 1977). Buchbinder suggests that each local group moves through a development cycle in which population density varies over time. In the first stages the nutritional status and the quality of the environment is high. In the phase of high human density the environment is degraded and the nutritional status is poor. This malnutrition results in a higher death rate due to malaria and other diseases (Buchbinder 1977 in Foin et al 1987).

Foin and Davis characterize both Rappaports (1984) and Buchbinders (1977) model as *"Local equilibrium models"*. As both of them propose that the local population (the tribe e.g. the Tsembaga) are in an equilibrium state.

They oppose two other principle types of models: The *"Regional Stability Local Instability"* models and the *"Disequilibrium"* models. Proponents of the former are e.g. Moylan (1973) and Lowman (1980). These models are based on the notion that the local populations are unstable (neither point stable nor subject to a limit cycle (Foin et al 1987 p12)) but the regional populations persist in time and space. Local population can become extinct but their patches are re-colonized through other parts of the regional population. In ecology this relates to the concept of meta-populations. Lowmans model (1980) suggests a development cycle similar to Buchbinder (1977), with the difference that the local population becomes extinct respectively emigrates to neighboring groups.

The Disequilibrium models argue that equilibrium may exist (in contrast to a non-equilibrium approach) but that the system seldom or never reaches that state. Salisbury (1975) argues that cultural rules and environmental reality can be seriously out of phase. Therefore cultural stability does not necessarily imply population stability. At the heart of his model is that exogenous [or emergent] inputs, typically new technologies for food production or more efficient organization, can be expected at a frequency such that the resource limitation is rarely a serious factor (Foin et al 1987). An example for this is the introduction of the sweet potato, which had a dramatic and lasting impact on the Maring (Golson 1982 & Boyd 2001).

Foin and Davis compare the different model-types/theories by testing them on a mathematical model of the Maring ecosystem. The main source for their model was the simulation model of Schantzis and Behrens presented above. Important differences include:

(1) The population sector has specific loops for malaria effects. The effects of malaria on the mortality depend on the nutritional status of the population. Malaria also reduces fertility and increases infant mortality.

(2) The forest sector was completely reconstructed. Shantzis and Behrens built in a strong sensitivity to overuse of the forest (occurs when the follow period is too short). Overuse leads to the unavoidable collapse of the forest. In the model of Foin and Davis overuse affects the recovery (both qualitatively and quantitatively) of the forest but does not lead to irreversible forest destruction.

(3) The forest succession and cutting sector features explicit decision-making behavior. The behavioral variables include a preference function for forest type and age; limits on per capita ability to clear forest; adjustment of cutting rate as a function of dietary quality; and control over swidden retention and follow period intervals.

(4) The ritual festival sector does not follow Shantzis and Behrens (1973) how referred to the work of Rappaport (1968). Rappaport states that the human/pig ratio and the number of incidents of pigs raiding the gardens trigger the festival. In the model of Foin and Davis, (in line with Salisbury 1975; Peoples 1982; Boyd 1985) the festival is triggered when a sufficient number of pigs are available to support an adequate festival. The warfare period is essentially the same in both models, with differing mortality rates per episode.

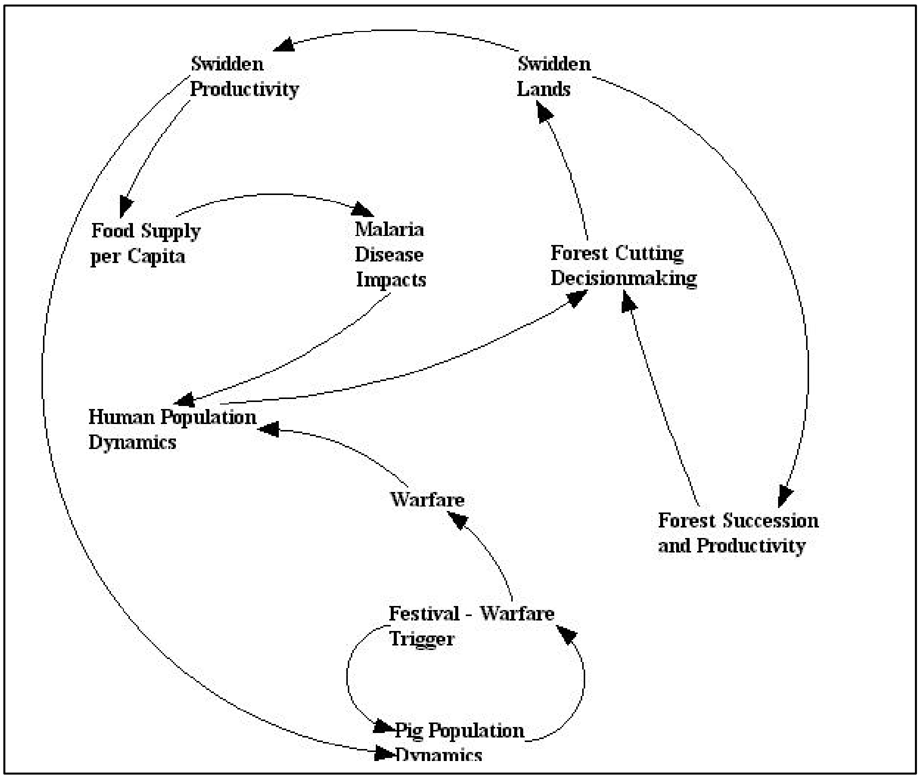


Figure 17: The principle causal loops of the Foin & Davis simulation model. The arrows indicate the major causal flows in the model. By convention, the variable at the tail of the arrow has one or more specific impacts upon the variable at the head of the arrow. (Foin et al 1987 p15)

Simulation strategy

All runs were carried out by using a period of 400 years, with integration step size of 1 year and print/plot intervals of 10 years. The debugged and verified version of the model was used to produce a baseline output. This output was then compared to the outputs derived when changing the model.

The baseline model shows a stable behavior, with the population reaching "equilibrium" in about 170 years. All vegetation types reach steady state in less then 50 years. (Foin et al 1987 p19).

Foin and Daivs state that the results of the model suggest that the local equilibrium approach is a reasonable model for describing the Maring – ecosystem. Comparing the two models utilizing a local-equilibrium approach (Rappaport 1984; Buchbinder 1977) the model supports the feasibility of a malaria control agent and rejects Rappaports ritual-cycle model. This is due to the fact that the disease mortality outnumbers the war mortality about ten fold. In the simulation war mortality becomes important only under extreme conditions.

For testing the regional stability – local instability theory (Lowman 1980) four identical groups were linked using simple migration rules. Nevertheless the simulation model fails to produce local disequilibria.

To check the disequilibria based models Foin and Davis estimate the return times for selected variables (human population size; standing mature secondary forest). Long return times indicate that the system hardly or even never reaches its equilibrium state. The return times for the human population show that even small losses (5% ~ estimated loss in a war campaign) need about 80 years for recovery. Let alone the much higher losses from diseases (a 20% loss has a recovery time of approximately 200 years).

Concerning the recovery times Foin and Davis make two points:

(1) The recovery times are not linearly related to the size of perturbation imposed.
(2) Even small changes in population require long recovery times.

They conclude that if such disturbances are realistic for the Maring – ecosystems, the disequilibria model is the one that provides the best description of the system. Further conclusions are:

"(1) The Maring populations are equilibrium seeking; (2) with limited rates of change and sensitivity to disturbance, the Maring are most often moving transititionally from some displacement to some equilibrium; and (3) it is extremely difficult empirically to detect equilibrium under these conditions. Long recovery times render it likely that significant perturbations will occur in the interval." (Foin and Davis 1987 p28)

As an implication arising out of these conclusions Foin and Davis argue for the possibility that the equilibrium state changes itself over time due to exogenous factors. They propose "*if this is true, empirical studies on population regulation should attempt to define the regulation mechanism in force at time, with less emphasis on the equilibrium-disequilibrium issue*." (Foin and Davis 1987 p 2).

The notion of a changing equilibrium state makes clear the difficulties when using equilibrium centered concepts for describing adaptive dynamic systems.

Anderies: Culture and agro-ecosystem dynamic of the Tsembaga

In his article "Cultural and Human Agro-ecosystem Dynamics: the Tsembaga of New Guinea" (1997) Anderies develops a "*much simpler dynamical system models* [as Shantzis et al 1973 and Foin et al 1984 & 1987]" for the slash and burn agricultural system of the Tsembagas. He seeks to identify possible sources of instability and possible stabilizing mechanisms. Reacting to some of the critic brought up against Rappaport he states that he is not focusing on how the system developed in time but on the "*rather more general question of how behavioral plasticity (i.e. the very presence of humans) and associated cultural practices affect the structure and dynamics of the agro-ecosystem*." (Anderies 1998 p516). Anyway he also gives an argument supporting a group selection as would be necessary for the evolving of a ritual cycle[13].

He develops his model in three steps:

(1) A simple physical model of the human agro-ecosystem is developed. The behavior (i.e. working time) is fixed. The focus is on the importance of the food production sector and associated feedbacks on the dynamics of the physical system.

In this stage the model shows a locally stable fixed point. The feedbacks from the agricultural system (nutritional status) keep the human population in check. The stabilizing mechanism is the "*intraspecific competition for food resources, i.e. malnutrition and diseases*". (Anderies 1998 p516). This is in line to the model proposed by Buchbinder (1977).

(2) The model is altered to allow for a changing work effort based on the needs of the human and pig populations.

As soon as the population is allowed to modify its work effort to meet its nutritional needs the stabilizing mechanism of malnutrition and disease is lost. This is true when the "*marginal productivity of labor (in the short run) is higher than that of soil (probably reasonable) then the destabilizing effect of behavioral plasticity can be so strong as to nullify the stabilizing effect of malnutrition and diseases […] opening up the possibility of temporally violent oscillations in population numbers.*" In other words if the food gets lean the people invest more work in the agricultural sector which will increase the nutrients extracted. This exerts an additional pressure on the soil-systems causing a decrease of the per hectare harvest. This decrease can be compensated in the short run by investing even more work but in the end unavoidably leads to the collapse of the system.

[13] If expected lifetime reproductivity is higher for individuals who participate in the cultural system into which they were born than for those who chose not to (if this were possible!), then a group phenomenon like the ritual cycle that prevents ecosystem degradation could be adaptive at the individual level.

(3) The ritual-cycle is added to the model.

The ritual-cycle is built into the model in two stages. First the pigs and then the actual ritual-cycle are included.

The first observation Anderies makes is that just adding pigs to the model helps stabilize the whole system. This is due to the human labor force bounded to activities concerning pig rising. If the human population can utilize all the fruits of its agricultural efforts just for itself, it will grow, and produce a larger labor force keeping the per-capita work-level constant. If the population holds pigs, and the pigs increase relative to the humans, then the per-capita work level increases. This stability admittedly only occurs when, like in the model of Anderies, the food is first fed to the pigs and the remainders to the human population. Anderies states that this is not what happens in reality and therefore the stabilizing effects of the ritual cycle are needed.

The ritual-cycle

The Kaiko is triggered by a critical pig/human ratio (2-3 pigs per woman). After the Kaiko the pig harvest remains high for about one year until the pig population is significantly reduced. The fighting break out, the human dead rate increases. The people to pigs ratio therefore begins to decrease and with that the human work level increases. This indicates that it is time plant the Rumbim and put a truce in place. With this the cycle begins from new.

The Dynamics of the whole system

A critical parameter in the models discussed above is the mortality rate in times of warfare. Due to a lack of data estimates range between 2 and 12% (Foin et al 1984). Anderies points out that the actual mortality rate is not that important for stabilizing the system. He assumes that the number of deaths due to warfare increases nonlinearly with the human population size[14]. If this is true then the ritual-cycle has the ability to stabilize the system.

With his focus on the behavioral plasticity of humans Anderies provides a model supporting Rappaports claims on the regulating capability of the ritual-cycle. His notion that adding the pigs alone might stabilize the system already is an interesting aspect of its own.

We will now leave the Tsembagas in the Papua New Guinea highlands and also the system dynamics modeling approach. The next section deals with a case study that applies the concepts developed around the Resilience Alliance to investigate the Potlach system found in

[14] Anderies 1998 p528: Rappaport actually indicated that this was the case. As there are more pigs, people and gardens there are more possibilities for the pigs to invade the gardens and cause conflict, increasing the number of required blood revenge deaths during an active period of warfare. The number ways a pig may invade a garden rises much faster than linearly with increase in pig and garden numbers."

the pre-contact Indian cultures of the Pacific Northwest (PNW) Coast. The Potlach system is among other things characterized by the ritual destruction of resources.

The Potlach and its influence on Resilience

Trosper (2003) inspects the socio-ecological system of the Indian tribes populating the Pacific Northwest coast of North America. He argues that the Potlach and related cultural activities and institutions of these tribes have helped to shape a system with high resilience. The resilience concept as developed by the Resilience Alliance is adopted: A socio-ecological system requires three characteristics to be resilient: (1) the ability to buffer (2) the ability to self-organize (3) the ability to learn.

As proof for the high resilience of this socio-ecological system he cities that there are evidences that the Potlach system may have been in place from about AD 200/500 to AD 1775 (Ames et al 1999 in Trosper 2003). He suggests that the characteristics of the Potlach system "*namely property rights, environmental ethics, rules of earning and holding titles, public accountability, and the reciprocal exchange system*" (Trosper 2003, p1) provide all three required characteristics for a resilient system.

Different authors have suggested different theoretical views of the potlatch system (Trosper 2003 p3). Trosper follows a notion of Mauss (1967): *potlach ceremonies organize a system, but the system also includes nature.*

Trosper describes the ecological setting of the region (according to Suttles 1987, 1990) as follows:

"The region has large rivers, such as the Fraser and Skeena, which present different conditions in the headwaters and near the mouth. Some areas have large amounts of land in the drainage of the tributaries; people relied on these areas for hunting and gathering. Along the cost some societies could gain considerable resources, including whales, from the sea to supplement the bountiful salmon rushes in the much shorter rivers. The ecosystem provided considerable variability, a challenge for the societies´ coping abilities." (Trosper 2003, p2).

The North West societies all consisted of "*houses*": corporate groups with proprietorship in specific lands and fishing sites. The houses consist of a head (*titleholder*), lesser titleholders, commoners and slaves. The rank of the titleholder is inherited through a kinship system. Trosper describes the social-organization as follows:

"The head title holder was in charge of land management, no one could use the land without permission. Even being present on the land required an approval; trespass was a capital offence that would be enforced usually after a warning. […]. The titleholders of the house were the proprietors of the lands with the ability to exclude others, manage, harvest, and bequest the lands and resources. Sale was not a possibility; a market for land did not exist. Hence the houses were not "owners", as the term is commonly used. […]. After the death of a head titleholder, the successor would organize a major ceremony in order to obtain recognition of the right to inherit the title and to take charge of the lands of a house. Head titleholders of other houses, by accepting the gifts of the host, recognized the hosts claim. […] the new titleholder raises a totem pole to honor the previous titleholders and recounted the origin story for the house." (Trosper 2003 p3)

The titleholder had the duty to host feasts and distribute wealth to other titleholders. At these feasts the titleholders could express their opinions on any issue they wanted. Aim was the reaching of joint agreements. (This governing aspect of the potlach is e.g. stressed by the Nisga´a Tribal Council (1995) and McNeary (1994 in Trosper 2003).)

The people of the North West Pacific cost believe that human and animal souls are both involved in cycles of reincarnation. One purpose of the potlach was to symbolically allow the cycling of food. Failure to hold adequate feasts and to distribute wealth would interfere with the reincarnation of salmon and other nonhumans and so destroy the base of this wealth. Trosper now relates certain characteristics of the potlach system to the three criterions of a resilient system.

Ability to buffer

- Reciprocal exchanges:

  On a large scale: Social insurance against variation in harvest abundance (Wayne Suttles 1960, 1987). Through kin-bounds people of different areas provide help to each other. (Obtained assistance had to be repaid at a later date)

  On a smaller scale: problem of interdependence of harvest. The knowledge that neighbors would share their surplus through the potlach system provided a solution to the "prisoner's dilemma" of a common pool resource (Trosper 2003 p4).

  - The ceremonies had integrated elements, containing methods to find joint agreements.
  - Control of the titleholder:
    - The successor of the head titleholder had to organize the house in a way that it would generate sufficient surplus to satisfy the other titleholders. The other titleholders indicated their acceptance by accepting the gifts at the potlach. In this way the claimant had to prove his ability to manage the resources of his house properly.

- The commoners had the possibility to leave the house to join another house to which they were connected through kinship ties. Thus the commoners had the possibility to live in the house that managed best.
- If the head titleholder was captured during an armed conflict, his followers could decide if whether or not to buy the titleholder back. In some areas the failure of resources would even lead to a killing of the titleholder as the members of a house would believe that the titleholder had lost his spiritual power.

- The institution of potlach possibly averted the creation of chiefdoms or other large state structures – which would have been a major disturbance for the system.

Trosper describes this process as follows:

"Upon taking a neighbor's titleholders land, the property system required that other titleholders recognize title by accepting gifts at feasts. A coalition of all other titleholders refusing the gifts would be a first step into their resistance. According to sacred believes, failure to successfully feats and share output would potentially threaten salmon run, and thus lead to doubt among the aggrandizing titleholder's followers regarding his long-term success. […]. The competition caused by conflict among titleholders, by leading to excessive harvest, would simultaneously threaten all of their positions, although the upstart would be more vulnerable because of the inability to give away his wealth." (Trosper 2003, p5)

Ability to self organize

The possibility to self organize is important in the case the buffering mechanisms described above fail. A self-organizing process establishes its self without external guidance and direction. Troper describes three major sources that could provide disturbances to the socio-ecological system of the Indians:

(1) Military conquest through a neighbor.

When the buffering mechanisms preventing military conquest, described above, failed a whole population could be driven out of a watershed. To become accepted as new titleholder by the neighboring titleholders these had to agree to join a ceremony and accept the gifts. This was a substitute for violent conflict and provided the possibility for other titleholders to ratify the consequences of violent conflict.

(2) Technological change

When some Indians discovered ways of utilizing whales this was a major technological change. Trosper describes this process according to the oral history of the Nu-chah-nulth. In the beginning the titleholders opposed the new way of obtaining meat and killed their reveals.

The conflict was solved two generations later through their grandchildren and the community began to harvest whales.

(3) Declines in food/salmon abundance.

Tropser argues that the people of the North West Pacific coast affected the timing of the runs and the size of the fish through barricades and size-selection when harvesting. “Humans thus were a keystone species supporting monitoring of the ecosystem structure through management of salmon and other resources; humans became a force in co-evolution” (Trosper 2003 p6). He argues that such type of control could be used to adjust for changed ocean conditions, which influence the abundance of the salmon.

Another point already described above is the monitoring activities of the lesser titleholders and commoners according the capabilities of the head-titleholder to manage the land. Many forms of self-organization rely on system memory. The ritual that every succeeding titleholder had to retell the stories of the funding of the house and subsequent events helped to create this system memory. How this system memory is attained is described in the consecutive chapter dealing with the aspects of social learning.

Social learning

Tropser states that the oral history of the house contains the knowledgebase the society has collected about nature and ecosystem management. This knowledge was and continuously is collected/modified through the observations and interpretations the humans make about their environment while living (dwelling) in the same. In this way slow processes in the socio-ecological system can be recognized. The titleholders were regarded as persons with special knowledge and spiritual power (Suttles 1960). By declaiming the oral history of the house in public the succeeding titleholder had to proof that he was knowledgeable about the events and the lessons learnt in the past.

Tropser argues that “*private knowledge*” held by the titleholders also helped them to underpin their position. The system of ethics in place also supported social and individual learning. The people believed in “*careful husbandry of the resource, and required the titleholders to show respect for the resources on which they depended. […]. The natural system was not separated from the human system; both were linked requiring proper human behavior in order to preserve the entire system. Such a system of thought would mean that the actions of humans had to be studied and their consequences understood.*” (Trosper 2003 p7)

Tropser concludes that all of the features found in the potlach system were "*rediscovered*" and suggested independently by scientists concerned with different environmental problems and ecosystem-management. These features are:

(1) Cooperative decision making
(2) Social learning
(3) Environmental ethics
(4) Contingent proprietorship
(5) Balanced reciprocity
(6) Public accountability

He argues that this is strong indication for the potlach system to have fulfilled a stabilizing function. He stresses the need of cross-cultural comparison to clarify which of these characteristics must be present and which can be present in other forms.

Driving the Hypercycle

After presenting some of the different approaches used to describe the socio-ecological system of the Tsembaga and the Tribes of the PNW-Coast the concept of the hypercycle is now introduced. This concept was suggested as one possibility for describing the stabilizing effects of the pig-system on Trinket (Giampietro p.c.). The concept of the hypercycle was first developed to describe autocatalytic chemical reactions (reactions that once started enforce themselves). It is regarded as an emergent property of interacting systems and is now also used to describe economic systems. Hypercycles in capitalistic-societies are seen as one major danger for the sustainable use of natural resources. After a short description of how a hypercycle can erode the natural-resource base it is argued that the pig-system on Trinket has features for "*driving down*"/controlling the hypercyle. These features can also be found in the Maring and NWP – coats socio-ecological system.

In the following a description of the hypercycle as it manifests itself in a capitalistic society is given:

" In the capitalist market economy, that institution of money/capital with interest on money and returns on capital as its primary mission sits on top of and feeds the physical process turning natural assets into monetary value and, by the same token, into further claims for natural assets.

The capital/resources feedback loop turns into a hypercycle through being linked to human needs. The (human!) agents of the system who, from their own experience, know intimately the psychological profile of its customers have the capacity to invent a never-ending stream of new needs and wants.

Moreover in a mature capitalist society there is a positive feedback loop connecting, on the one side, the gratification of essential human needs (for love, support and identity) with material *satisfiers* (impressive homes, cars, TV, clothes) and, on the other side, the deficits and needs that are created and sustained in the process. The cycle thus established displays classic features of addiction, maintaining and feeding on itself. The coldness of economic relationships creates an overwhelming craving for warmth - to which industry responds by offering an abundance of products promising to fulfill this need.

At the same time, value creation in the imaginary sector develops a momentum of its own. Unlike the satisfaction of physical needs, it is not limited by inevitable saturation.
A mechanism has thus been created that permits unlimited value creation in the imaginary or notional sphere - the sphere beyond basic needs. Imaginary needs, however, are not always satisfied with imaginary goods - quite the contrary: there is nothing imaginary about silk bed-linen, a fifth pair of shoes, or a holiday in the Caribbean. What is imaginary is their value - it is derived from fantasies, from symbolic meanings, from prestige. […]

People will always crave status symbols such as big cars, beautiful houses, classy dogs and horses or famous works of art, because an individual's underlying psychological ('imaginary') needs like a craving for security, recognition, love or identification can be fulfilled - or rather unfulfilled - in a million ways.

Zinn (1995) distinguishes needs into satisfiable ones, which include physical needs (e.g. hungry – food) and unsatisfiable ones, which include the 'imaginary' needs. The never-ending creation of new imaginary needs keeps the capitalistic rat-race going and has a big share on the unsustainable effects observed in capitalistic systems.

Linking status to pigs and devoting considerable time and resources in the creation of "*piginess*" results in a system where the imaginary needs (more pigs) depend on the same environment as the humans. This is also inline with the notion of controlling the "behavioral plasticity" (Anderies 1998).

Following the chronological development of this work some conceptual respectively theoretical models are developed in the next chapter. An additional description/analysis of the information provided in the first chapter (The Setting) is given and a mind-model of the social-ecological system on Trinket is developed.

VI.

The Socio-Ecological System of Trinket Island

"To describe a human ecosystem is to describe the roles that humans play in the maintenance or mutual regulation of relationships between themselves, other living species, and non-organic elements with which they interact." (Lees et al 1990 p248)

Introduction

This chapter wants to discusses the dynamic interactions in the social-ecological system of Trinket Island and clarifies some of the assumptions underlying the computable model TIM. Concepts and terminology as described in the previous chapters are used. First the boundaries and levels of the system are defined. Then single aspects of the interaction between these levels are discussed. Afterwards case studies dealing with similar human – nature interactions are reviewed. They all describe socio-ecological systems where the ritual destruction of resources or the uneconomical maintenance of livestock is an integral part. The most prominent being Roy Rappaports work, "Pigs for the Ancestors" (1984) on the ritual-cycle of the Maring on Papua New Guinea. Foin and Davis (1987) compare equilibrium and non-equilibrium models of the Maring Ecosystem and discus the different approaches. Anderies (1998) proposes a dynamic system model of the Tsembaga Ritual Cycle, outlining conditions under which the ritual cycle produces (local) stability. The last two approaches presented provide the basis of a more general explanation of the observed phenomena. The first describing the influence of the Potlach-system in pre-contact Pacific Northwest (PNW) (Trosper 2003) on the resilience of the system, the second the more general concept of "*driving down the hypercycle*" (Giampietro 2003 & Mayer 2004)

System Boundaries

The problem of defining system boundaries is well recognized and was often discussed (e.g. Ellen 1982). Following Singh (2001) the system includes Trinket Island together with its coastal area consisting of the surrounding coral reefs used for harvesting marine resources. In the model all variables lying outside the boundaries are also characterized by having no feedbacks from inside the system. They act as external forces on the system. When extending the model, over the whole group of islands the borders and external forces would have to be defined new.

System Levels

In the case of Trinket Island eight levels were found to be important. Note that not all of them are represented in the actual version of the computable model (TIM).

Level	Real World	Model
N+4	**World Economic** e.g. Demand and price for copra	Copra price can be manipulated in runtime
N+3	**National State: India** Influence of Central Government in India e.g. subsidies for copra, government shops with fixed rice prices, development projects (e.g. education, health care, introduction of new breeds…)	Rice price can be manipulated in runtime
N+2	**Nicobarese Archipelago & Society** Tribal Conceal, relations between islands, Trade Cooperatives…	Conversion of copra in to money, consumption of consume articles (cash-economy sub-model)
N+1	**Trinket Island System** Characteristics of the island ecosystems and the relations and interactions among them. Effects on this scale are influenced by the size of the island, the topography of the island, the distance to neighboring land.	Land-use-model Reef-system, interactions between different sub-models (e.g. reef – mangroves)
N	**Socio-ecological System of Trinket** The Ecosystems used, shaped, and perceived by humans in specific ways due to culture, lifestyle, history of the people (which are all part of this level) Interaction between different populations compromising the social-ecological system	Extraction processes out of the coconut-system sub-model and the reef sub-model (converted in the “harvest” sub-model). Distribution of coconuts between pigs – and use for copra. (Preferences pig vs. copra can be changed in run-time) Perception of the minimum pig / person ratio (can be changed in run-time) Number of feasts per time and amount of pigs slaughtered
N-1	**Population** Dynamics of single population due to age / sex composition, carrying capacities, etc. Note that the human-reproduction rate is driven by influences of higher levels	Human-population, pig-population and the coconut palms are modeled as individual-based Populations. The Reproduction-rate of the human-population can be changed in run-time.
N-2	**Individual Agent** Single human actor (Household could also be considered)	
N-3	**Physiological Parameters** Energy requirements, nutrition-requirements, weight gain	Energy requirements of human, energy requirements and weight gain in pigs.

Table 5: Different levels on Trinket Island.

The External Levels

The events in the two highest levels (N+4; N+3) can be treated as external variables. "External Variables" are events that have affect on the Systems of the island, but are not influenced by the events they cause - i.e. there is no feedback.

These events can include:

- Weather, natural catastrophes; in the case of Trinket e.g. cyclones, earthquakes or Tsunamis (Ortiz et al 2003).
- Performance of world market according to important cash crops of society (e.g. copra)
- Institutional or national decisions that can not be influenced by the affected people
- Changes in nearby societies with which exchange of goods exist.

Historic examples, concerning the Nicobars, would be the influence of the World War I (Singh 2003 p) or the fall of copra price in 1935 (Singh 2003).

Nicobarese Archipelago & Society

The level N+2 deals with the processes and interactions between different islands of the archipelago. Ecological effects on this scale would be re-colonization of extinct species or the diffusion of invasive species.

As mentioned earlier a ritualized trade relation organized around fetish objects between the islands existed. Today this traditional trade relations and fetish are replaced by cash economy and modern fetish objects e.g. TV (Singh 2003). Nevertheless the inter-island relations have remained enthralling. The shops were the people of Trinket purchase their commodities are associated to the government-employees settlement on Katchal Island and are run by mainland Indians. The money spend in this shops is received through the selling of copra to local cooperatives installed on other islands of the archipelago. A Tribal Council influences the politics concerning the Nicobars. Although interesting and worth an investigation the interactions between the various stakeholders on this level were not subject of this work.

Pace of Change and Spatial Scales

In general it is difficult to appoint a certain speed (slow - fast) to all the Variables of this category. The speed of change can vary between slow e.g. natural influences (global warming) and fast e.g. world-market (copra prize). Besides natural systems tend to react hysteric - that means that after some long time of slow change the whole system can suddenly flip into another state.

The spatial scale for the external influences/disturbance is very big. For the two major natural disturbances on the Nicobars (earthquake/cyclone) the scales are global (e.g. earth-tectonic) or cover at least the whole region.
The effects of these events will influence the plant-cover on which the other parts of the system depend and stocks of society like buildings, boats and so on. The events themselves occur over varying time scales from short (earthquake) to long (draught).
The scale of the world-market is also global; the scale of institutions can be regional (district level) or national (India). Here the difficulty is a distinction between events influenced by the reaction of the affected people (feedback) and those how are not influenced or to such a less content or with such delay that it can be neglected.
If the external forces are very strong, changes in the parts of the system may not have any effect on the possible development pathways. Usually a society has certain coping strategies against this kind of disturbances. The more disturbance a society can cope with, without changing completely and without destroying the future options of the following generation, the higher is the resilience of its socio-ecological system.

The Socio-Ecological System on Trinket Island

The external influences were already discussed above. The interactions between the remaining levels, from N+1 "Trinket Island System" to N-3 "Physiological Parameters", will be discussed here. **Figure 18** gives a first picture of some possible interactions.
The problems with sticking to the same hierarchical levels as defined in **Table 5** when dealing with processes were already discussed earlier in chapter III.

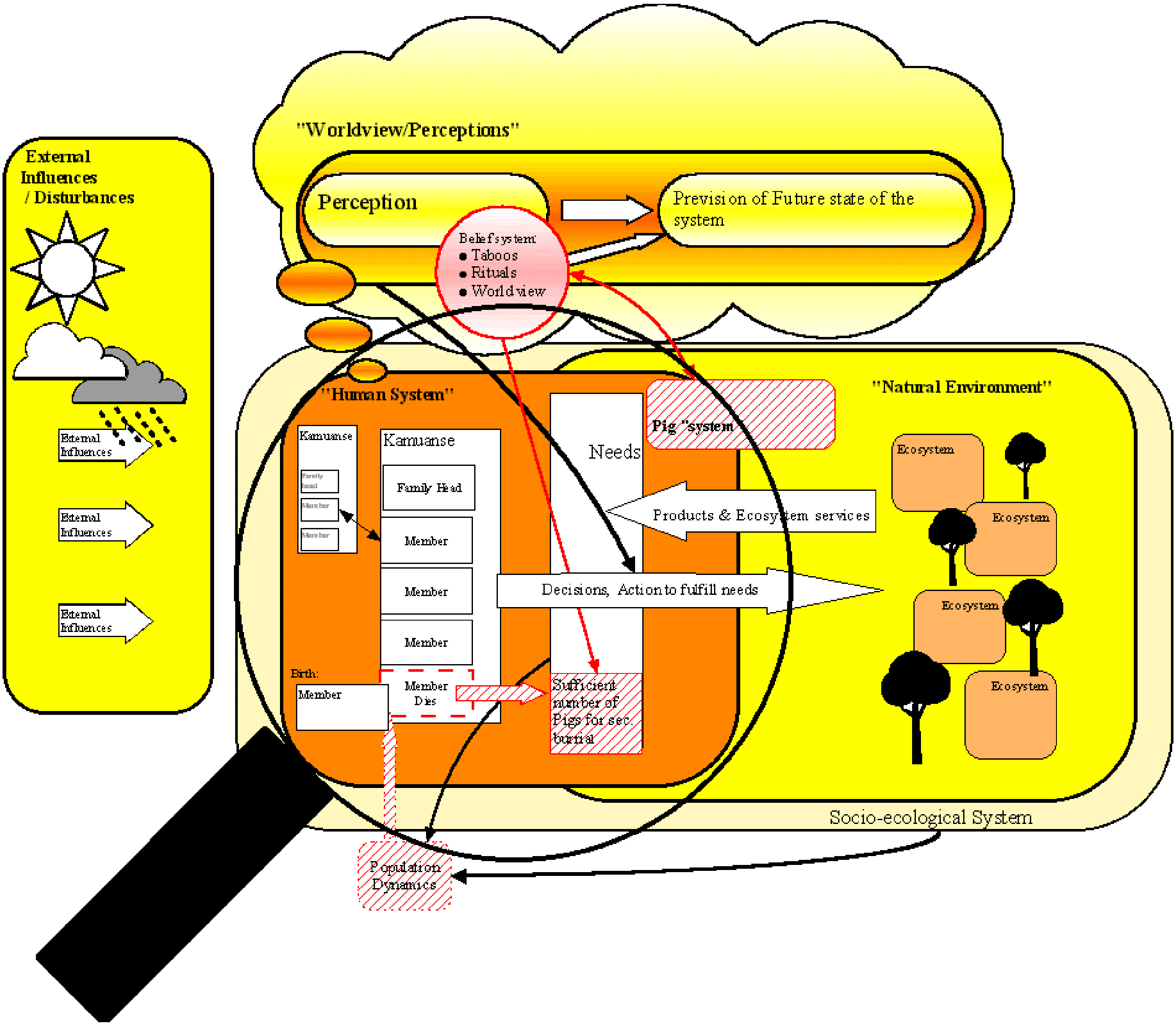


Figure 18: A conceptual model of interaction and driving forces in the socio-ecological system on Trinket Island. The symbolic magnifier indicates that the “human system” is not larger as the other parts of the “Natural Environment”. The “worldview/Perception” field is drawn as thought-bubble to indicate that has no physical manifestation and emerges out of the individual and collective thought. The red marked arrows and shapes all play a role for the celebration of the pig-festivals. The field “population dynamic” is an emergent non-physical property of the human population and therefore stands outside of the system and has a dotted borderline.

The World in our Head: Worldview & Perception

In a very general way the perceptions or worldviews we have are influenced by two factors: First the perceptual organs we posses only allow us to grasp certain aspects of the world. Second our brain interprets the raw signals of the world and fits them into some picture/model we already have (worldview). This mind-model of the world is influenced by the live history of the individual (system memory). Similar live histories will produce similar mind-models.

Scales and Nested Properties

Different nested hierarchies (or panarchies) play a role in determining the processes in this area. In the case of the Nicobars the biggest one would be the collective construct/worldview (culture) of the whole Nicobarese society. This means that similar features in the mind-models of the people can be found throughout the Nicobarese society. An example is the high status of pigs all over the Islands, or the former involvement in the ritualized inter-island trade. The next in itself more similar set would be found on a single Island or Island group. The single islands have distinct forms of social organization and organize their feasts and rituals in different ways. Still the similarity in mind-models between the islanders is bigger as to other societies e.g. the Shompen or mainland Indians. The smallest hierarchical level is the individual. Changes in the system are often triggered from some changes on this level whereas the higher levels often act stabilizing (Resilience Alliance).

The speed of change in the cultural field depends on the hierarchical scale. It can be quick in individuals and become slower the larger the group of people is who share a similar worldview. Here major changes often come with shifting generations. Conflicts in this realm arise when tradition and new worldviews imposed from outside have opposite features. How these conflicts are solved varies.

The worldview/perception field is important if the actions of the agents/humans are considered and future scenarios are developed. Regardless of the discussions how a worldview or perception of environment evolves in a society or in an individual it seems to be obvious that an existing worldview/belief system has greatest influence on the actions of the agents.

The worldview/perception influences:

- the needs of the people,
- the methods with which these needs are satisfied,
- the institutions which control e.g. the resource use / property rights etc.
- the attitude of the people against nature, which can help or hamper conservation strategies.

For a resource management perspectives following sub-fields are important:

Traditional/Local Knowledge

To act accordingly, the agent needs a certain minimum knowledge base about the local environment. This knowledge is actively obtained through living in (dwelling[15]) the environment and through the bequeathed experiences of former generations.

The more possible alternatives known, e.g. for food allocation, the higher the resilience when unexpected events occur as substitutes for lost resources can be utilized quickly.

In terms of ecosystem management the local knowledge can be compared with the scientific knowledge of the system. This may help to identify knowledge gaps on both sides and produce new insights.

Taboos concerning resource use

The concept of taboos, e.g. for using certain species at certain times, shows similarities to the western concepts of protected species or closed seasons on game. Colding et al (1997) compare 70 examples of specific-species taboos with lists of threatened species and keystone species. About 30% of these taboos prohibit the use of threatened species (as defined by the IUCN[16]).

Rituals/feasts with influence on resource flows

In some societies a significant amount of resources is set aside for rituals or feasts. Besides the social functions provided by these activities, several attempts have been made to find functional explanations for the regulation of bio-physical processes (e.g. Rappaport 1984). Pragmatically one can say that these activities often bind a significant amount of resources or time of the people so that changes in these patterns are likely to effect the whole system. As the effects of the Trinket pig-festival are at the core of this work this topic will be discussed more elaborately later on.

Concept of holy places

The concept of holy places provides (similar to the taboos) the possibility to set parts or whole ecosystems aside. Often places providing special ecosystem services (e.g. wells) are regarded as holy and special laws regarding their use are apposed on them.

---

[15] Ingold 2000

[16] World Conservation Union

How to Model Worldviews

There are some difficulties in modeling something like worldviews or perceptions due to diffuse boundaries and too many linked elements. Additionally, there is a weak understanding of all these processes. Though agent based modeling provides possibilities to incorporate the perceptions of the agents into the model, modeling the change of these perceptions and worldviews in a computational model is impossible. In the case of this work it seems convenient to treat this field as a kind of blackbox, only illuminating certain important elements and important connection points/triggers to the other fields. In the sense of declarative modeling and non-linear modeling culture some variables that are heavily influenced through this field have been defined as sliders. The user of the model (respectively his brain) replaces the program.

The Human and the Natural Environment System

The social-ecological system can be disjointed into a “human system” and a “natural environment system”. It is recognized that this separation is somehow artificial and that the borders are often hard to draw. In this case natural environment consists of all ecosystems not significantly altered/colonized by the human society. The activities of the humans in the “natural-environment systems” are hunting and gathering. Livestock, agriculture plantations etc. belong to the human-system.

The building blocks of the “natural-environment systems” are the ecosystems. The Human system can be seen as a special case ecosystem, with humans as key-species.

The human system contains the biophysical elements of the human society (humans themselves, stocks of society e.g.: buildings, livestock). These elements have to be maintained through the use of local extracted or imported resources. This links the human system to the “natural-environment systems”. The “natural environment systems” provide these resources respectively interact with the colonized (e.g. agricultural) elements of the human-system and provide essential ecosystem services. The requirements (“Needs”) of the humans to maintain themselves and the rest of their system are composed of the basic-needs (food, shelter) and other mostly cultural influenced needs.

The Human System

Humans are organized on different scales. They are part of a core-family, a household, a number of associated households etc. The form of social organization is influenced by the worldview/perception and by constraints imposed by the natural-environment system. These forms of organization are not static. They change over time. The decision if such changes are incorporated into a model depends on the anticipated speed with which these changes will occur and the possibility of forecasting them. As economic decisions on Trinket are taken at the level of the Kamuanse (Singh 2003), this level is highlighted in **Figure 18**.

The humans interact with the other systems when they try to fulfill their needs. The worldview/perception field influences what these needs will look like. When extracting resources out of the environment the humans also receive feedbacks. How these feedbacks are interpreted again largely depends on the worldview/perception of the people.

What People Want: Emerging Needs

The needs of a family/single person are roughly composed out of the need for:

Food for survival (sufficient number of calories, essential elements), additional food/special food (e.g. spices), status food, drugs, clothes, housing, feast/rituals other cultural activities, leisure articles, status symbols.

How these need manifest themselves is determined by society norms & traditions, environmental conditions (e.g. climate) and economic conditions.

Ranking	**List of products purchased by the Nicobarese**	
	Mark Paul	**Gladys**
1	Rice	Flour
2	Sugar/Tea	Rice
3	Tobacco	Sugar
4	Toiletries	Cloth
5	Kerosene (if village is not electrified)	Lentils
6	Flour, Lentils	Kerosene
7	Fishing gear	Suitcases
8	Footwear	Watches
9	Suitcase	Diesel
10	Radio/Tape-recorder	Tea
11	Liquor	TV
12		School books/bags
13		Radio/Tape recorder
14		Cooking utensils
15		Liquor
16		Footwear

Table 6: Two Interviews with key-informants (male & female) show the most important consume-articles bought by the Nicobarese (Singh 2004 p.c).

The model shown in Figure 18 assumes that the humans strive to satisfy these needs through a certain set of possible actions. These actions are imposed either on systems of the "natural-environment systems" (e.g. forest) or on sub-systems of the human-system (e.g. livestock or plantations). The action-space of the people is determined by the natural-environment and by the worldview/perception section.

To satisfy their needs a family living on Trinket basically has following possibilities:

Subsistence activities:

Food: fishing, coconuts, forest-products, garden, livestock, trade money against food

Cloth and housing out of local available resources (wood, fibers)

Economic activities:

Cash is obtained through the selling of copra. Copra is a product of the coconut-plantations, wood out of the forest (to dry the coconut-meat) and working time.

What People do: Action Choice of Agents

The choice of what activity is undertaken will be influenced by:

Most urgent need, e.g. food, is more important than nice clothing

Constraints e.g. Access to resources

Worldview/perceptions e.g. maintaining status, social obligations, respecting taboos

The conditions of the individual human (his inner environment) interact with the two higher levels (hierarchies) from which it is a smaller part. One is the "natural Environment" (e.g. climate, weather, resource availability) the other the human society (cultural environment). Out of the interactions of this three systems the needs as well as the actions undertaken to meet the needs emerge. Additionally creativity and foresight can strongly influence possible actions.

One manifestation of the human striving to fulfill their needs is the social metabolism of a society. Social Metabolism is the material or energetic throughput of a society.

The harvest of resources and the waste output of the human-system can affect the natural systems in many ways. In traditional societies like on Trinket the waste output is mainly organic and usually the natural or colonized agricultural systems can easily cope with it. What are more critical are changes in the amount or composition of extracted resources. Through an overexploitation or replacement of natural or near-natural system a breakdown of an ecosystem is more likely to happen. Changes in amount and quality of harvested resources can take place due to:

Population development (more people need more food)

Substitution through change in preferences

More effective harvesting methods e.g. motorboats

Declining abundance or extinction due to not sustainable harvest, natural cycles or external influences.

Vanishing of taboos, loss of local knowledge.

The Pig System

For the Nicobarese their pigs are the most important livestock both in terms of numbers respectively biomass and social status. They use them for ritual purpose or ceremonial food at feasts. The status of a family is strongly linked to their ability of providing a sufficient number of pigs. Due to this people are willing to invest more energy into pig keeping then they can gain out of this activity.

On the other hand, one can understand that a pig population of about 320 domestic pigs (16 pigs / 1km² forest) which find about 70% of their diet in the forest has an considerable influence on that ecosystem, especially as island-ecosystems are seen to be even more easily effected by a single species (Vitousek et al 1995).

The Influence of the Pig (Sus scorfa) on Tropical Island Systems

Pigs can have a considerable effect on the ecosystems they dwell. Digging and rooting activities of pigs in forest soil has the potential to increase decomposition of leaf litter and the rate at which nitrogen and other nutrients become available (and subsequently lost from soil through leaching.) (Singer et al. 1984). Due to the special conditions on islands (disharmony of species, e.g. missing functional groups, low species richness, high degree of specialization and endemism, short food webs, under saturated communities, lower competitive ability) these effect can be fortified.

Cushman (1995) gives two probabilistic rules for predicting if an organism has an ecosystem-level influence on an island ecosystem:

Rule 1.:
"In order to have ecosystem-level effects, a species must be abundant relative to other taxa in its functional group and exhibit an ecosystem-wide distribution."

Rule 2.:
"In order to have ecosystem level effects, a species must either (1) directly play a unique or under-represented role or (2) indirectly play such a role by significantly altering the abundance and/or the distribution (and there for influence) of other taxa that play unique or under represented functional roles." Cushman (1995)

In the case of the Trinket both rules apply for pigs. It can be assumed that pigs have played and still are playing an important role in altering the environment on Trinket. The island ecosystem would not look like it does today without the influence of the pigs.

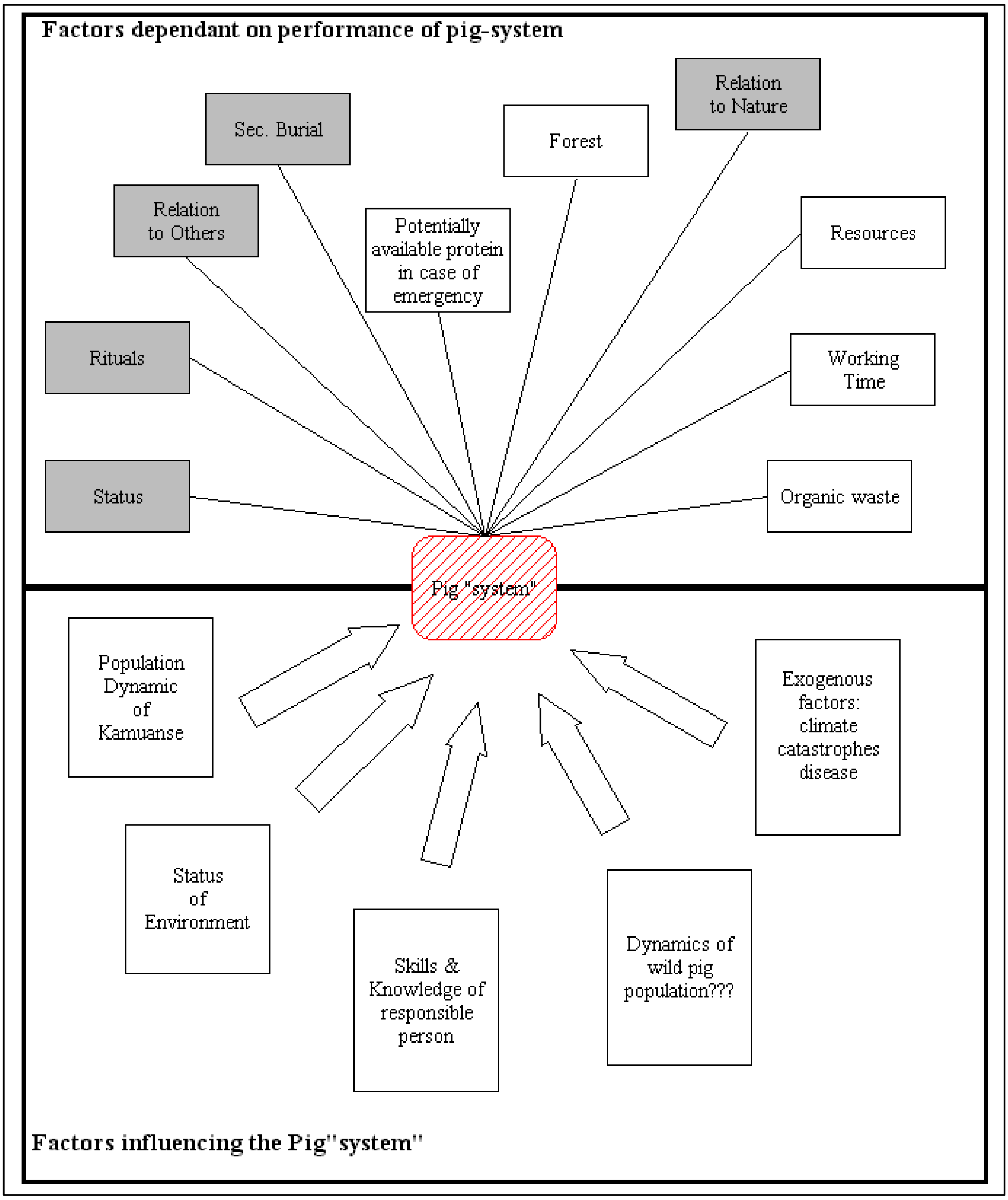


Figure 19: Linking the pig-system to other components of the system.

Linking the Pigs

The special case in this system is that the "pig-system" is an important part of the "eco-function-system" (e.g. disturbance regime in forest, food uptake). The number of pigs will heavily influence the ecosystem used by them. This also means that the pigs are depended on the performance of the "natural-environment system", although this may be buffered due to their additional supply through humans. On the other hand the pigs play an important part in the belief system of the people. The reputation of a Kamuanse is linked strongly to their ability to produce a sufficient number of pigs required for the performance of rituals and feasts. In this way the "natural environment-system" is linked through the "pig-system" to such things as status, relation to others and self.

In **Figure 18** the connection between the pig-system and the dynamics of the human population is highlighted. The dynamics of the "pig-system" (notably population numbers) is linked to the population development of the Kamuanse (family-unit) as a dead case in the Kamuanse triggers an increased demand of pigs for the Ossuary-feast.

Natural Environment

The Natural Environment focuses on the ecosystems inside the defined system boundaries and their interactions with each other and properties on higher and lower levels. Interactions between ecosystems are usually seen as the flow of energy, matter or information between them. Interactions on a lower level are interactions between populations and between populations and bio-physical components.

Linking the "Natural-Environment"

The discussion on how far perception of the environment is encoded in the environment itself is in its largest parts only of academic interest. An exception may be the conservation of traditional/local knowledge as described by Brodt (2001).

The human-system extracts resources from the natural environment and depends on ecosystem services provided by different parts of the ecosystems. The interactions between the systems can be sustainable that means the respective system used is not changed over a long time due to this use.

Components of the “Natural Environment” (Ecosystems):

The natural-environment systems can be grouped into ecosystems. As already discussed earlier these systems are organized in a hierarchic/panarchic way. On Trinket following ecosystems can be classified:

Forest Systems:

52% of Trinket's area are covered by forest. Only parts of this forest can be considered as intact. Especially the forests close to the settlements show signs of degeneration due to overuse. The forest is used by the humans for collection of firewood for copra production and household use, construction material and Non Timber Forest Products (NTFP) e.g. roots, tubers etc. Additionally the pig-herds scavenge in the forest (70% of pig diet is made up from food found in forest). The humans also hunt animals like wild boar, living in the forest

Grassland:

About 32% of Trinket is covered by grassland.

The traditional house roofs are covered with grass. Today the grass is bit by bit substituted by iron sheet. The grasslands are burnt regularly. The mode of burning differs from island to island. In some cases burning is started when smoke from the neighboring island is sighted.

Mangroves:

The mangroves seem not to be used at all. The reasons for this are unknown. The mangroves provide important Ecosystem functions they are an important breeding place for reef-fish.

Reef:

The humans strongly depend on the reef, as fish are the main protein source. Besides fishing, the collection of other seafood is also important. There have been conflicts between indigenous users and outsider users. The Nicobarese complain that the outsiders utilizing the fish resources do not observe the same rules then they do (i.e. closed seasons, mesh-size, fish size). They fear that this will cause a general reduction of fish stocks. Construction activity of jetties for motorboats by the people of Trinket also endangers the reefs.

In general it has to be said that there is very little information and data available concerning the status of the ecosystems on Trinket. The available information given in Roy et al (2004) has not enough resolution to be useful in this work. The lack of data in this field is visible in the computer model, where the respective systems are very simple.

VI.
Results

This chapter is structured into two major parts. The first part describes the computable model of a “virtual” society on Trinket Island (Trinket Island Model – TIM). In the second part results obtained by running the Trinket Island Model are presented.

The model combines the data of energy and material flows with population models of human and non-human organisms. Additionally the attempt was made to integrate variables representing the decision making of the human.

The model meets the claims made by a “non-linear modeling process” as described by Richerdson (2002):

- Show gaps in data and understanding
- Integrate available information of different sources with a focus on processes.
- Identify some important processes and stocks.
- Provide a basis for further discussions concerning human – nature interactions between:
    - Scientists of different disciplines
    - Scientist and other stake holders

The important variables (human population, pig population, copra production, rice consumption etc.) can be influenced in various ways. This makes it possible to play with a number of different assumptions regarding the development and inter-linkages of these variables. This should make the integration of new data and insights into processes as well as the involvement of experts and stakeholders easier.

The behavior of the variables and stocks in the model can be influenced in two principle ways. The first is by manipulating variables determining the growth of the populations (e.g. fertility rate, consumption patterns), which will produce a feedback to the resource base. The second is by influencing the factors determining the availability of resources (e.g. maximum area for coconut plantation), which in turn leads to a feedback on the population.

As mentioned earlier the current TIM is only a first attempt to model the social-ecological system on Trinket. The presented results aim to show some principle dynamics of the variables in the model. They do not intend and they cannot produce or forecast numerical results exactly related to real world Trinket.

The results presented here show the development of a virtual human and pig population and its reaction to changing variables over time.

General Structure of the Model

The TIM is designed to run four scenarios at once using a multiple-instance submodel. This implicates that the structure of the model is represented four times in the same way on each level, with the possibility to change key-variables separately for each scenario/level. This has three major advantages:

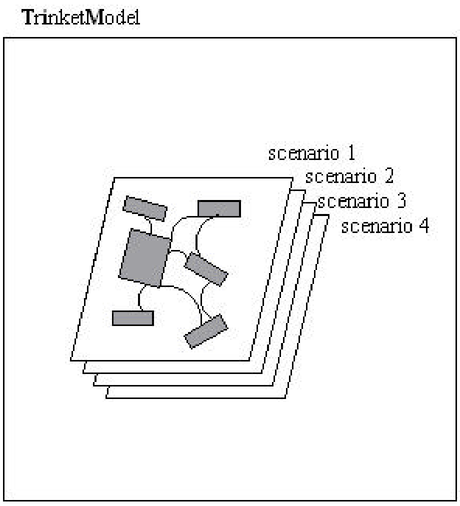


Figure 20: The Trinket Model is organised in four layers.

The first is due to the probabilistic character of the individual population modules, which create slightly different values for each run, creating a probability space for the future population development. With the four scenarios running with the same set of variables the user gets an immediate feeling for the fact that this kind of models do not yield exact results, but shows a range of possible developments.

The second is that when changing the variables (e.g. fertility rate in humans) the effects can be observed and compared directly while running the model.

The third advantage refers to the fact that the model should stay open for further uses. It would be very easy to change the four different scenarios into four (or more) different villages on one island using the same common resource base, or to four (or more) islands in the archipelago. In both cases the only thing to be done would be to change the starting variables (e.g. population size at starting time) and to consider possible interactions between the different levels.

For a listing of the entire equations used in the model see Appendix IV for the model structure see Appendix V.

Submodels

The model is organized in 12 different submodels, which themselves can contain other submodels. Some of these sub-submodels are only used to extract information out of the model (e.g. separating a population in certain age classes or calculating per capita values). In the model diagram these submodels are orange and there contents are hidden. Figure 21 shows all submodel compartments of the Model. The light gray compartments represent submodels only used to process or transform information out of the model.

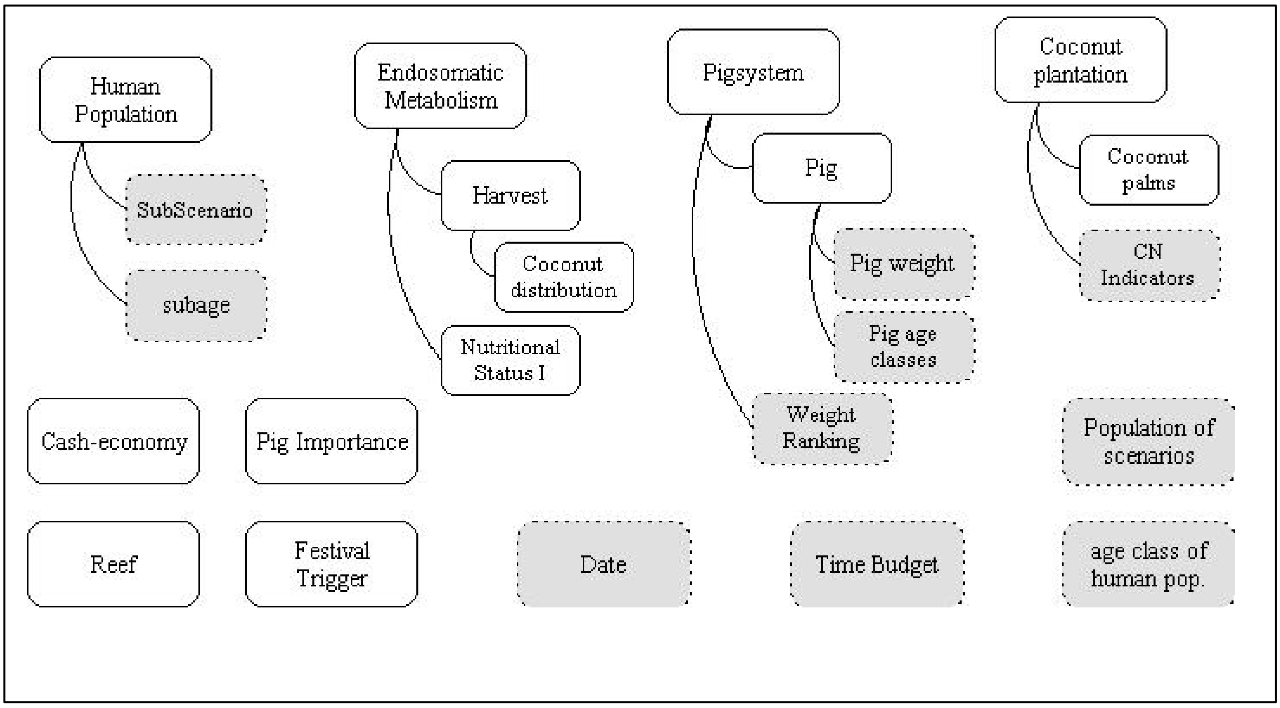


Figure 21: The organization of submodels in TIM

External variables:

There are two variables placed outside the socio-ecological system:

- Copra price
- Rice price

Both are considered to be external variables, which cannot be influenced by the actors inside the system. It is possible to manipulate these two variables during the run of the model via sliders.

Biophysical Relations and Flows in TIM

The model assumes that there are four important productive system used by the humans (reef, coconut plantation, pigs and forest). Reef and Forest differ from the other two systems in scale and in a qualitative way, as they are common resources. In the current stage of the model both of them are still quite simplified. The NTFP-resources (and also the fire and construction wood) will be incorporated in a spatial land-use model. Regarding the reef system the necessity using a more complex model has to be discussed.

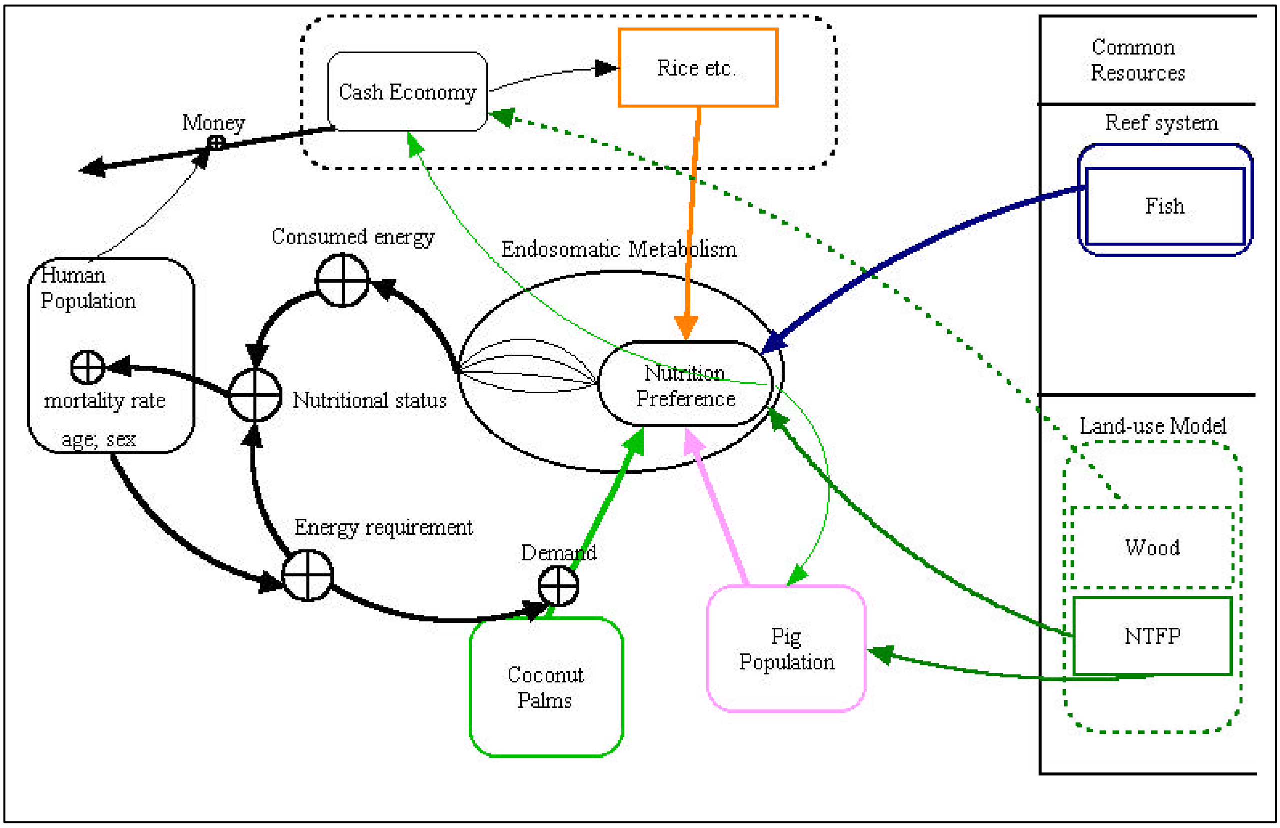


Figure 22: The organization of flows between systems in TIM influencing the human population. The colored lines represent flows of energy or matter the black lines flow of information.

Figure 22 shows the organization of matter respectively energy flows (colored lines) and the information flow (black lines) between the Human system and the resource base and the economy. Dashed lines indicate that these parts of the model are still missing. Squares represent stocks. The units of the flows out of the productive systems are all converted into kcal when entering the Endosomatic Metabolism – sub-model. The amount of calories needed from each stock is calculated by splitting up the kcal needed for the whole society (energy requirement) according to the average distribution of food items.

This is done in the submodel "Nutrition Preference I", interchanging this submodel with different values for the distribution of calories in the menu of the agents ("Nutrition Preference II") would be an easy way modeling the effects of altered eating habits.

Foods	In Grams	In Kcal
Rice	150	549
Fish	79	156
Coconuts	541	1688
Flour	8	28
Pandanus	38	
Tubers	41	55
Coconut Oil	10	88
Immature Coco water (Daab)	100	22
Toddy	80	40
Sugar	65	250
Total	1112	2876

Table 7: Daily food consumption per capita (Singh)

Variables as used in TIM	Included Food Items	Percentage of KCAL
Rice	All imported food stuff	64%
Fish	Fish	14%
Coconut	All products of the coconut	13%
NTFP	All roots, tubers fruits and vegetables harvested in the forest	9%

Table 8: The Categories of food used in TIM and there fraction in total kcal consumption as used in the submodel "Nutrition Preference I".

The total consumed energy is then summed up and compared with the total energy requirement (which is a function of age and sex). If the total energy requirements are not met over a certain time period the mortality rate of the population increases. This leads to a different population development and therefore influences the Energy requirements of society. An Increasing demand for a certain source of calorie will trigger some activity e.g. more planting of coconut trees in the respective sub-model.

Variables defined as sliders

In the TIM eleven variables are defined as sliders:

- Copra Price
- Rice Price
- Reproduction rate of humans
- Pig - human ratio
- Pig-meat distribution factor (percentage of pig meat that is given away)
- Consume demand (Money spend for consume articles).
- Pig vs. copra preference (determining the direction of the coconut flow)
- Technical demand (Money needed to maintain and run technical devices)
- Outsider catch (Fish caught in the Trinket reef system but not entering the societies metabolism)
- Max. available space (defines the maximum space available for coconut plantations)
- Percentage loss of harvested calories

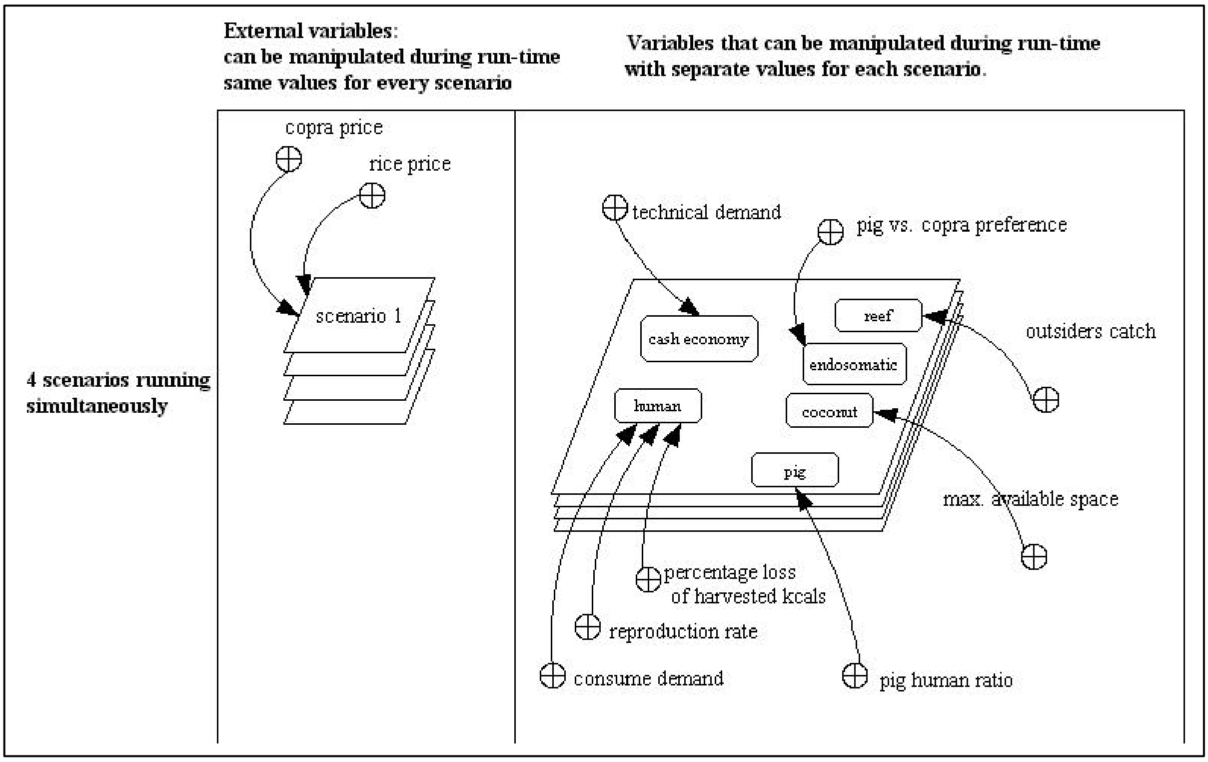


Figure 23: The four levels of TIM showing the variables that can be manipulated in run-time.

There were different reasons for choosing exactly these eleven variables:

Human Reproduction Rate, Consume Demand, Technical Demand are all variables considered to change in a traditional subsistence based society exposed to the growing influence of world market and cash economy and also have great influence on the other variables of the model.

In the real world these variables are affected by decisions of the actors who again are influenced by diverse events occurring on very different scales of the system (Giampietro 2004). These events can include influence from actors outside of the modeled system e.g. Indian development projects or emerging properties e.g. new markets or new technologies. Other variables like pig-human ratio or pig vs. copra preferences capture the perceptions the people have from their environment. Very complex transitions in society e.g. change in live style (no more pigs needed) influence these variables in the real world. So apart from being important variables, which are considered to change, there is also a difficulty in modeling these various influences first in general and second without participative methods. This is also partly true for the variable “pig meat distribution”, which determines the percentage of pig meat given away i.e. not consumed by the inhabitants of the island. Additionally the possibility to manipulate this variable is important when analyzing the effects of a change in the praxis of ritual performance.

The reason for the “outsider catch” and “max. space” – variables to be defined as sliders is rather simple. In the case of “outsider catch” there is no data available in the moment and one could also argue that this variable also undergoes changes that are triggered from outside the modeled system. The variable “max. space” is a simplification used as long as no adequate Land-use data is available.

The “percentage loss of harvested calories” provides the user with a short cut to simulated resource scantiness. In this way it is not necessary to manipulate different variables of different submodels (pig, coconut, NTFP, economy, endosomatic-metabolism).

A closer look into the Sub-models

The Human Population

The human population submodel is an individual based population model. The population starts with 400 people. The values for the reproduction rate and the death rates for the different age classes were taken from the "District Level Estimates of Fertility from India's 2001 Census" (Guilmoto 2002). This Census is carried out every ten years. The rates are calculated for district level (whole Nicobar Archipelago).

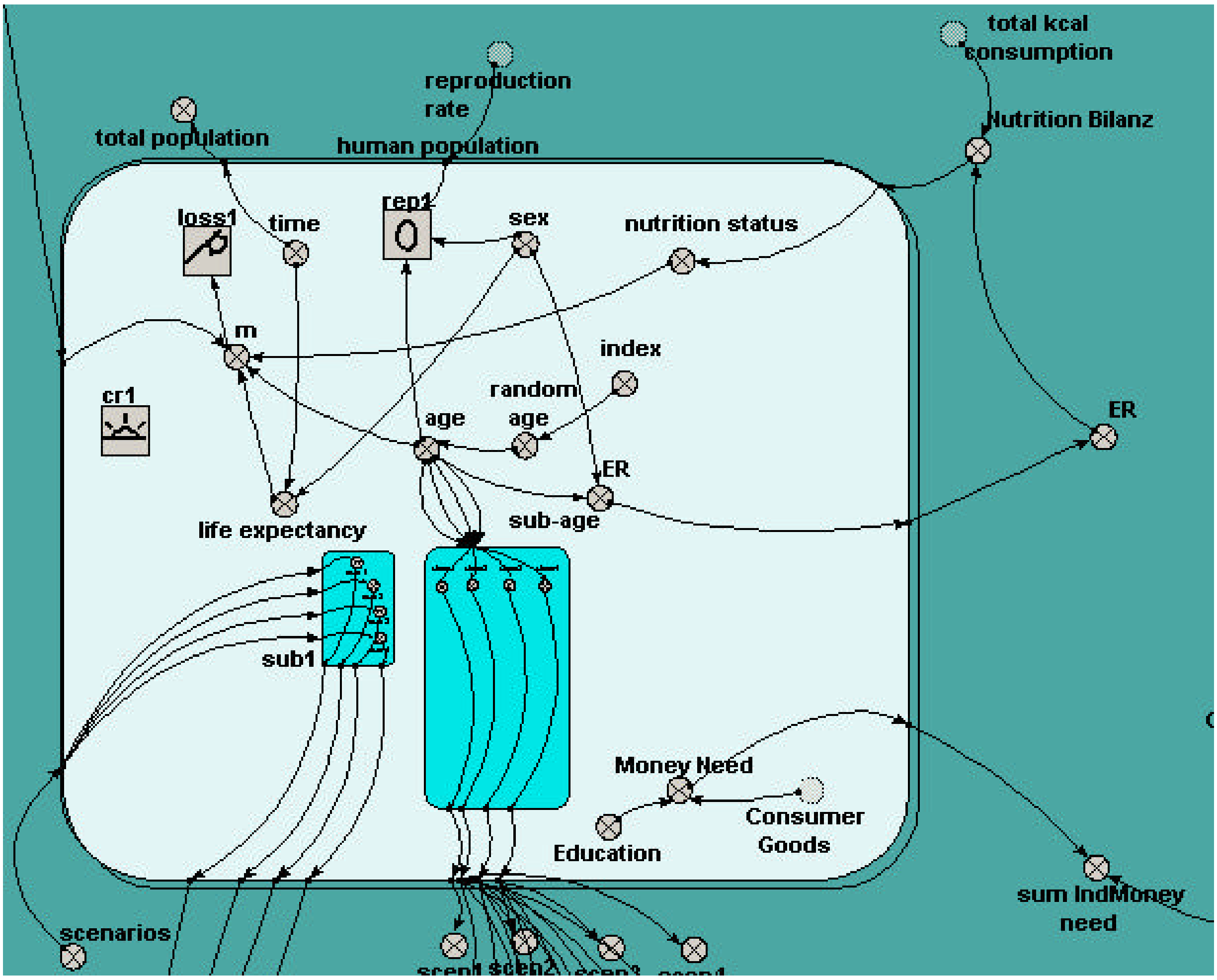


Figure 24: The Human-population submodel

The reproduction rate can be influenced in run-time. The mortality rate is influenced by the "nutritional status". If the balance between the energy requirement and the kcal consumption is negative for 6 time steps (= 216 days) then the mortality rate increases.

The energy requirement is calculated using a table of the FAO (2001) and depends only on age. The values provided by the FAO are averages over different kind of societies including traditional and western ones and are therefore possibly to high. Definition of energy requirement as used by the FAO:

"The amount of food energy needed to balance energy expenditure in order to maintain body size, body consumption and a level of necessary and desirable physical activity, and to allow optimal growth and development of children, deposition of tissues during pregnancy, [...], consistent with long term good health." (FAO 2001)

The Pig System

The main component of the pig system submodel is the pig-population model, which is an individual population model. The death rates were taken from Australian studies (Giles, 1999) on wild pigs (*Sus scrofa*).

Age class	I_x	d_x	q_x	I_x	d_x	q_x	I_x	d_x	q_x
0	1	0.85	0.85	1	0.89	0.89	1	0.94	0.94
1	0.15	0.06	0.40	0.11	0.03	0.27	0.06	0.02	0.034
2	0.09	0.02	0.22	0.08	0.02	0.28	0.04	0.01	0.25
3	0.07	0.02	0.29	0.06	0.03	0.45	0.03	0.01	0.28
>4	0.05	0.02	1	0.03	0.33	1	0.02	0.02	1

Table 9: Mortality patterns of feral pig populations from three habitats in NSW (Giles 1999). Statistically tabulated are age class at commencement of the year, probability of surviving to age X (I_x), probability of dying between ages X and X+1 (d_x) and mortality rate q_x, the proportion of animals alive at age X that die before age X+1 (d_x/I_x)

The rates were slightly modified, as they should be lower under the conditions of Trinket – casual feeding and no predators. The death rates are influenced from the human time invested in pig rearing. The more time spend the lower the mortality, especially in the first year.

The underlying assumption is that most time used for pig rearing is spend in controlling the equal distribution of the feed (Singh 2000). Especially the smaller and weaker pigs (infants and females) should benefit from this, which is reflected in a decreasing mortality rate in one-year-old piglets.

The time spends for pig rearing are influenced by the variable "pig importance factor". It determines the human to pig ratio which together with the total human population gives the received "minimum pig requirement" which is the benchmark for the "time invested in pigs" e.g. if the "minimum pig requirement is below a certain percentage of the real pig population the time spend on pigs increases and the mortality rate of piglets decreases.

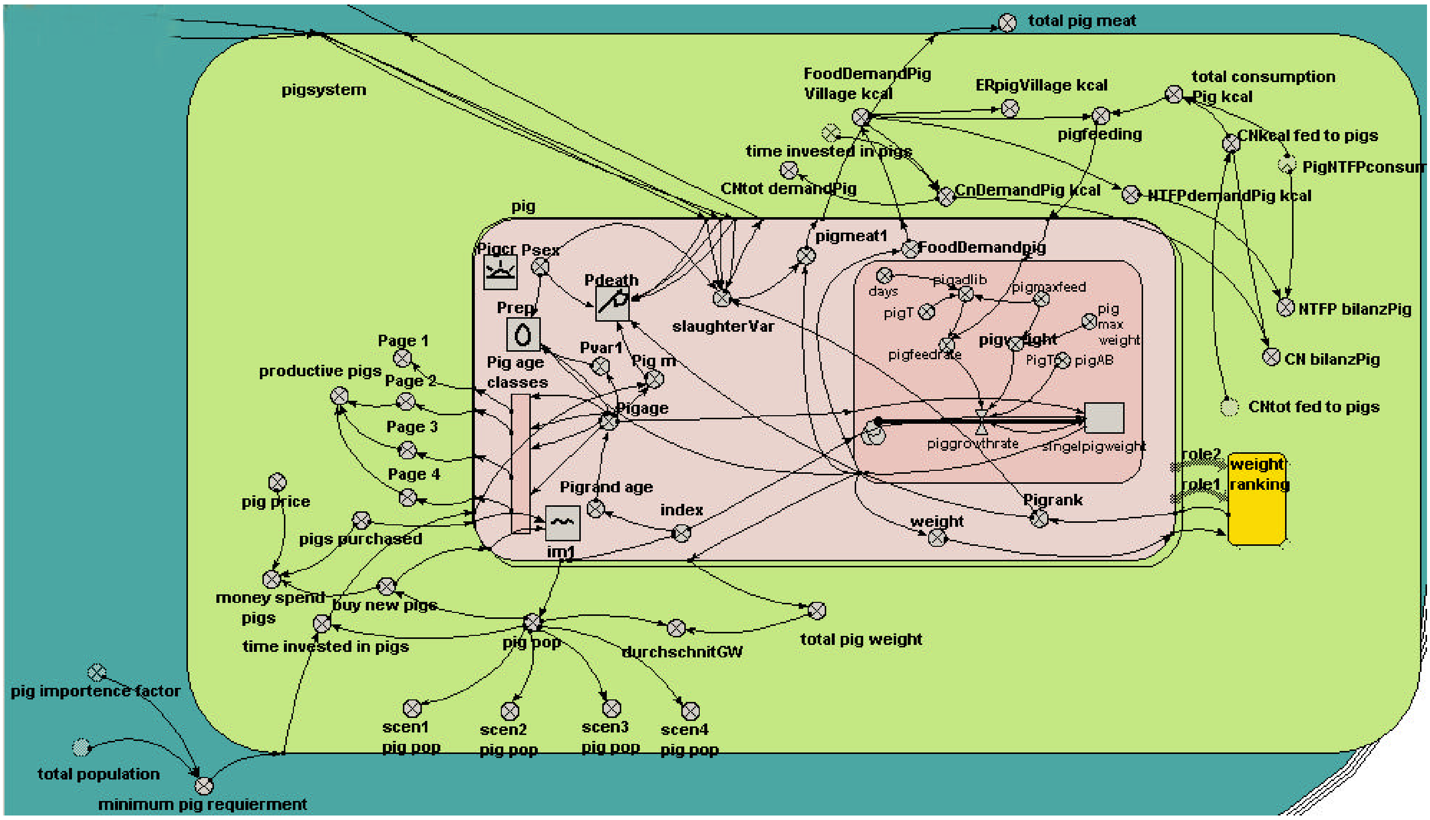


Figure 25: The Pigsystem sub-model

The reproduction rate is derived from information of local veterinary. (Singh p.c.). It is influenced by age, sex and body weight. In the model the sow will give birth to 8 – 12 piglets every eight months beginning at the age of 8 months but only if the weight is above 110 kg. With a weight between 90 kg and 110 kg the size of the litter will be randomly set between 5 and 9 piglets, if the weight drops below 90 kg there will be no piglets born.

The submodel “pigweight” calculates the weight increase of the single pigs according to the percentage of energy intake to energy requirement. The main structure and equations were taken from the Stella model “Farmsim” (Schaber 1997) and then slightly modified to fit the Trinket case.

The demand for food intake in pigs is calculated using following equation:

DE intake (kcal/day) = 13,162 * $(1\text{-}e^{-0.0176BW})$ (Nutrient Requirements of Swine 1998)
BW = Body weight

The maintenance energy requirement is about 4 to 3 times less as the ad libitum food intake. The pigs on Trinket Island have two food sources one are the coconuts fed to them by the humans the other is the food they find while scavenging in the forest. In the moment the model runs with the assumption that the total calorie intake of the pigs as it is now (30% coconut, 70% scavenging) is ideal and does not change (until one resource gets into shortage). However the energy requirements and even more the actual food intake is influenced by various factors (genetics, environmental, dietary) so that the results of the above equation should only be seen as a guiding line as long as there is no proper field data available.

The Festival-sector

The occurrence of the feasts is determined in the submodel "Date" it includes three variables, one creating a cycle from 1 to 360 (one year) one from 1 to 720 (two years) and one from 1 to 3600 days (ten years). The model creates three small feast occurring every year, one medium feast (e.g. wedding) every two years a big feast (first ossuary feast – Tanoiny) every five years and a very big feast (Kinruaka) every ten years. The amount of pigs slaughtered depends on the type of feast, on the human population and on the amount of available pigs. The pigs are ranked according to their weight and the heaviest will be slaughtered first. When the demand for pigs is higher then the available numbers of pigs only the male pigs are slaughtered.

The Coconut Plantation

The population model of the coconut palms is an individual based one. The creation of new palms is determined by three factors. First by the natural reproduction, seconded by the "human" substitution and third by planting new palms due to a higher demand on coconuts. The substitution of palms is a tribute to the fact that the people on Trinket prefer to keep their old plantations out of sentimental reasons even if they have grown unproductive and just substitute single dead palms (Singh p.c.).

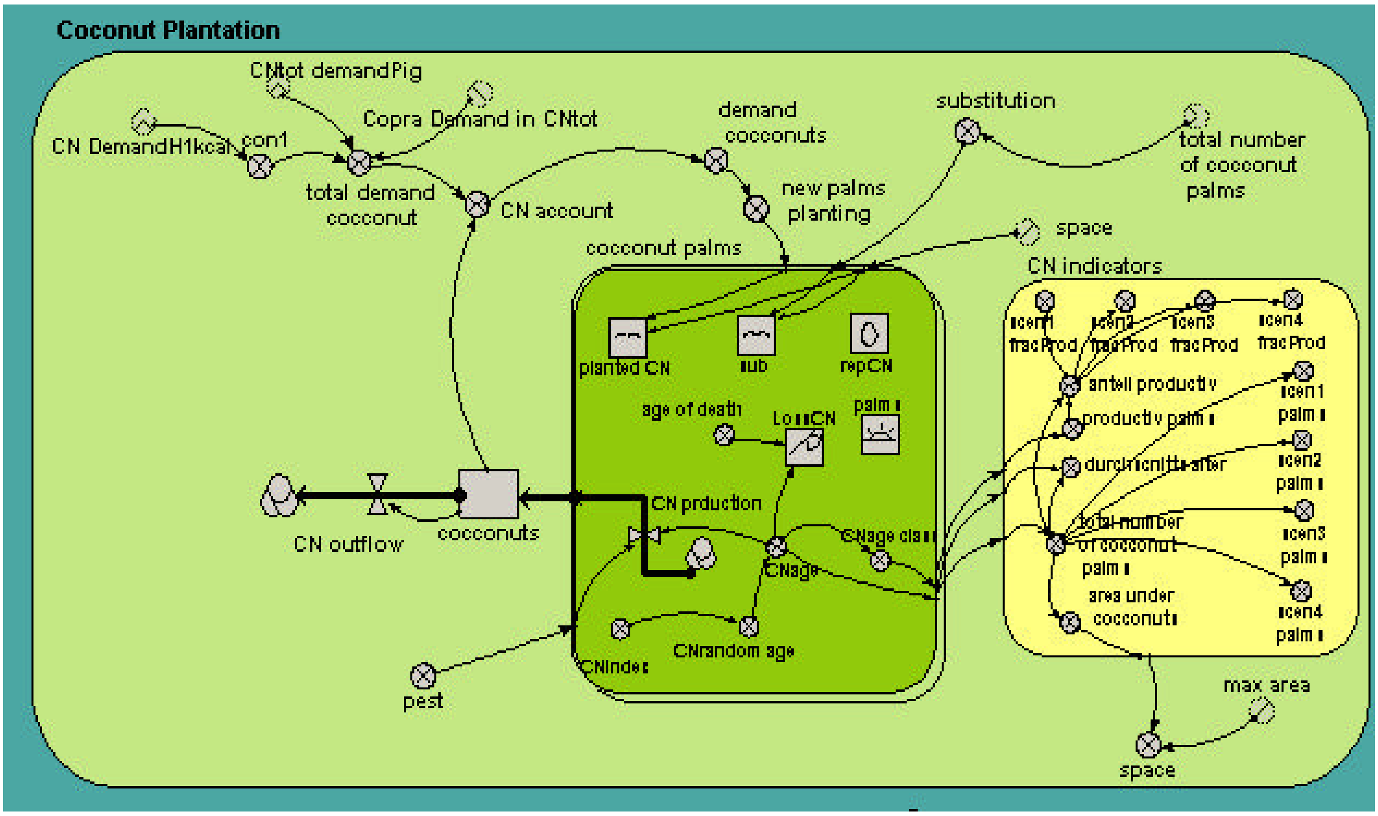


Figure 26: The Coconut-plantation sub-model.

The planting of new palms is triggered when the actual coconut production is lower as the total demand (human, copra, pigs) of coconuts.

The number of new palms is restricted by a benchmark of 300 per year (in the next stage of the model the benchmark will be influenced by the available working time) and by the available "maximum area" which can be changed in run time.

The number of coconuts produced is determined by a graph-function. The variable "pest" fixes the fraction of coconuts lost to pests, as there is no information available on this number it is currently set to one.

In the sub-model "CN Indicators" the total number of coconuts per scenario and the fraction of palms in a productive age are calculated.

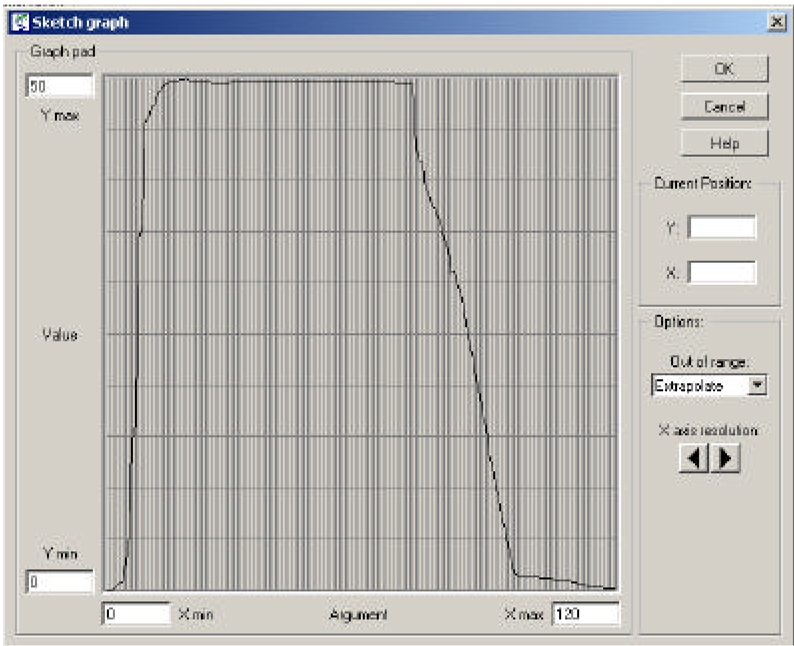


Figure 27: Development of productivity (coconuts per time) in the model. After six years the coconut palms start fruiting, after about 15 years 50 coconuts can be yielded per palm per year. At the age of 50 years the yield starts declining until it tropes down to nearly zero after 85 years. (Franke 1975)

The Reef

The reef submodel contains one stock (fish in kg). The flows “hatching” and “death” define the natural turnover of the system, where “m” the mortality rate is density dependant. The “hatch fraction” is also influenced by the “Mangrove Area”, which is currently set to one.

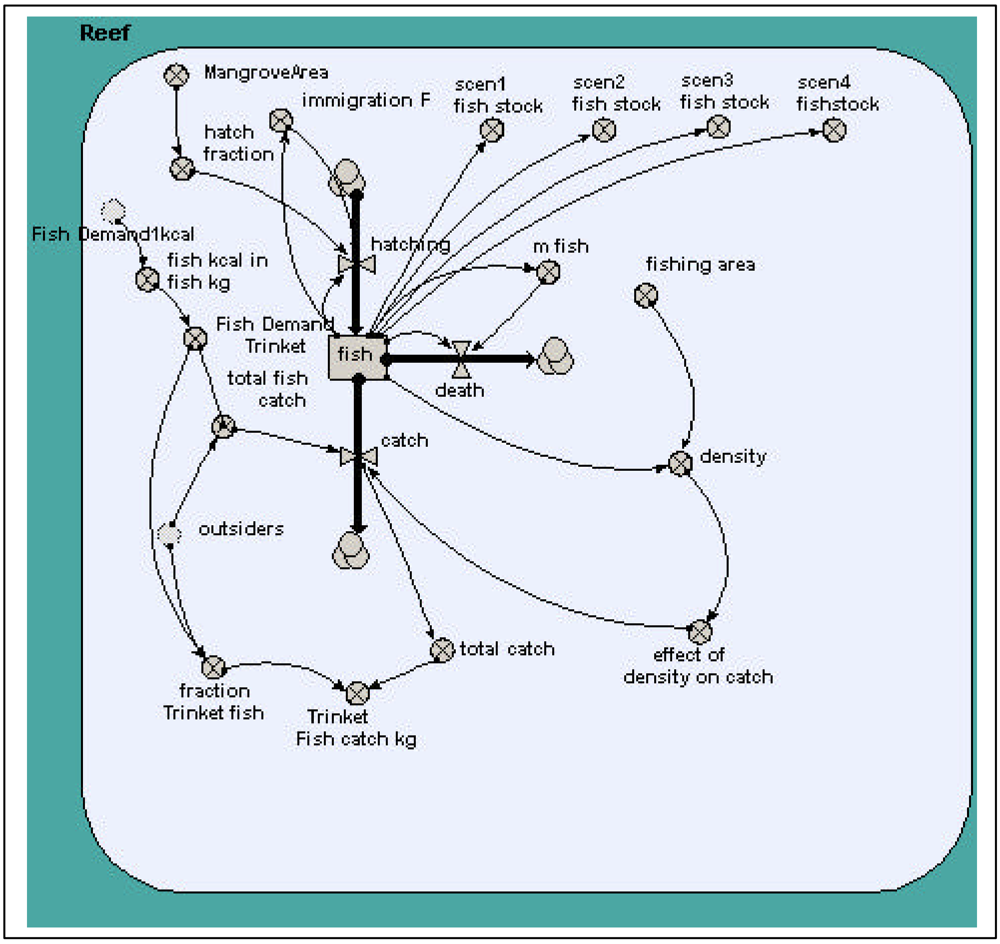


Figure 28: the reef sub-model

The out flow “catch” determines the amount of fish leaving the system for human consumption. It is made up of the “Fish Demand Trinket” and the amount of fish harvested by “outsiders” – this variable can be manipulated in run time. The density of fish also influences the “total catch” (the lower the density – the lower the return).

This part of the model is due to the lack of data quite simple – possibly too simple – but on the other hand it can be assumed that in the moment the fish resources around Trinket are still not exhausted or over used.

For a at least rough estimation of the maximum sustainable yield (MSY) a equation suggested by Gulland (Sparre et al, 1998) was used:

MSY = 0.5*M*Bv

Were Bv is the virgin stock biomass and M the natural mortality.

The values for Bv and M were again rough estimates extracted from some case studies on reef systems in the Indian Ocean.

Endosomatic Metabolism

This sub-model puts together the calories produced by the productive systems (coconut plantation, pig system, reef), consumed by the humans and their livestock. It also determines the preferences of using coconuts as feed for pigs or for producing copra. The sub-model "Nutritional Situation I" splits up the calories calculated for the human energy requirement into the four main sources of energy on Trinket (Coconut, Fish, NTFP, Rice).

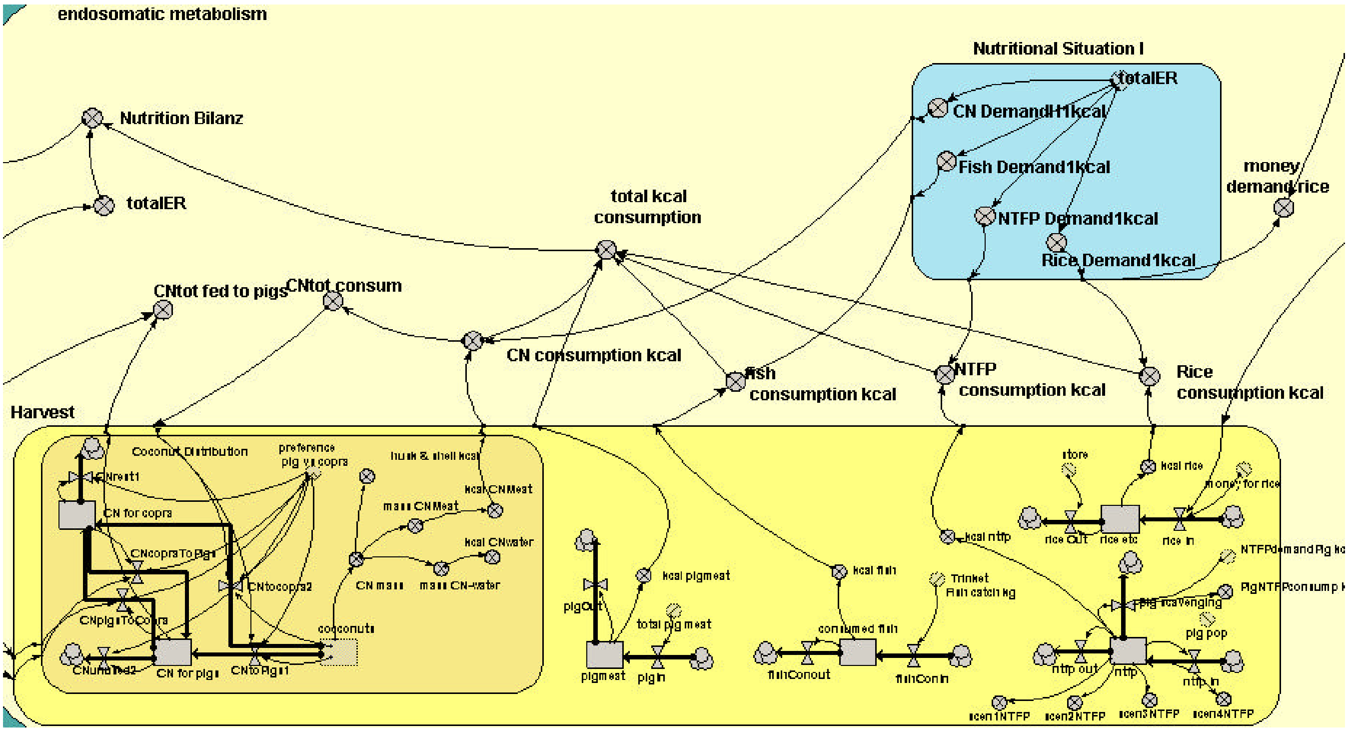


Figure 29: The Endosomatic Metabolism sub-model with the Harvest and Coconut Distribution sub-models nested in side.

The "Harvest" sub-model contains four stocks (pig meat, fish, rice, NTFP[17]) the inflows consist of the amount extracted / harvested from the respective system the outflows equal the

[17] Non Timber Forest Products

inflows, as storage of food is not considered. The unit of the stocks is in kg, which is converted into kcal and then summed up to the "total kcal consumption".

The NTFP-stock is just a simple compartment with in and outflows, with the regeneration rate influenced by pig density.

"Coconut Distribution"

In the submodel "coconut distribution", which is nested into the Harvest-submodel, the allocation of the coconuts is determined. It is assumed that first the coconuts needed for human consumption are consumed / put aside. Then there are two possibilities: the amount of coconuts needed for feeding the pigs are taken away first, the rest can go into the copra production or vice versa. This can be decided via the variable "preference pigs vs. copra" during run time.

	% of Weight	Weight in kg	Kcal/kg
Coconut	100%	1.2	16110
Meat	30%	0.36	4210
Water	21.7%	0.26	2400
Husk	33.3%	0.4	4000
Shell	15%	0.18	5500

Table 10: Weight and caloric values of the components of an average coconut (Nao, Wenkam. 1990) used in the model

The calories consumed by the humans are summed up in the variable "total kcal consumption". The variable "Nutrition Balance" then compares the kcal intake with the total energy requirement ("totalER"), and submits the information to the variable "Nutrition status" inside the human population model.

The variable "CNtot fed to pigs" gives the amount of whole Coconuts fed to the pigs. The amount of Coconuts used for copra production is found in the "Cash- economy" submodel.

Cash economy

The only source of income on Trinket is the sale of copra. The inflow in the “money-stock” is therefore calculated by the amount of sold copra times the “Copra Price” which can be manipulated in run time.

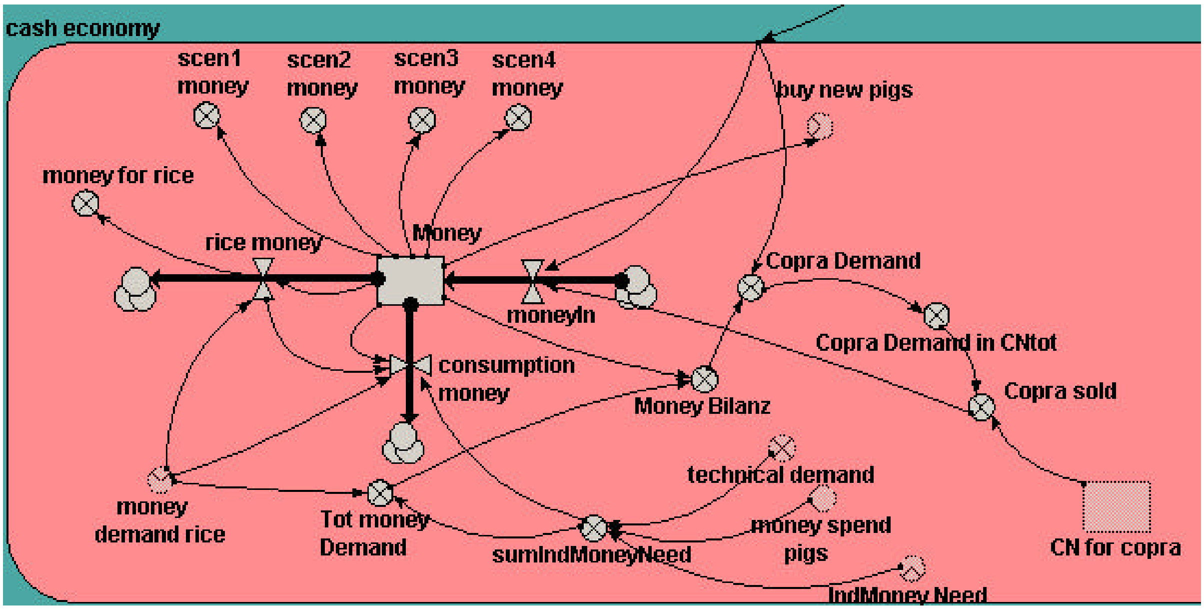


Figure 30: The Cash Economy submodel

The total “money demand” is made up of four variables:

Rice (includes all essential foodstuff like sugar, flour etc. traded by the people of Trinket)

Technical Demand (includes all expenditures for technologies (e.g. motorboats, gasoline, spare parts), which are essential for live or economic activities on Trinket. This variable can be manipulated in run-time – the more technical devises the society uses the higher should the money demand be needed to maintain and run these technical devices

Individual money need (This variable is used to determine money spend on consumer goods). It was placed in the “Human – population submodel” to allow influences from factors which are situated at the individual level (e.g. age, religion, sex). This variable can also be manipulated during the simulation run.

Money spent on pigs (spending money for buying pigs needed for feasts is a recent and controversial phenomenon in the Nicobars (Singh p.c.).

The four types of money-”demand” were chosen to allow a high flexibility in creating different scenarios.

Results of Model runs

The Base Runs

The presented results aim to show some principle dynamics of the model. All runs were conducted with a time step of 1 representing one year. The model is updated every 0.1 time steps. The display interval was set to one. The results presented here show runs over 150 time steps equalling 150 years. All figures are screenshots taken from the model-display provided by SIMILE. The base runs were conducted to obtain an overview over the behaviour of the model, when all parameters were set to resemble real world Trinket as close as possible. All the variables are set according to the information and data available from Trinket Island.

The Human Population

The human populations' rate of growth is influenced by the fulfillment of the energy requirements of the population. A negative energy balance over six time-steps (equals about half a year) will increase the mortality rate. The dynamics of the population can be influenced by the user in two ways, either through manipulating the fertility rate (**Figure 41**) directly or through increasing the mortality rate indirectly.

Unlike the fertility rate the mortality rate cannot be influenced directly by the user. The mortality can be influenced through the consumed energy. The percentage loss of required energy can be manipulated directly through a slider. Already a small reduction of the consumed energy has a recognizable influence on population development. Another possibility to influence the amount of available calories and therefore the mortality rate is reducing the available amount of rice. This can be done through reducing the copra-price, increasing the rice price, increasing the money spends on technical equipment and consumer articles.

The Carrying Capacity of Virtual Trinket

For the following runs the slider variables were set according to Table 11. The money amount spend was estimated by using the data of fuel consumption per year and capita (Singh et al 2001). The „Carrying Capacity" of Virtual Trinket is strongly dependant on the availability of rice, and therefore on the availability of money. There are three ways of influencing the money budget on the spending side. With the variable termed "technical demand" a specific amount between 99 and 10000 Rupees can be fixed. This amount will not change during the model run i.e. it is not dependent on any other variable (one can think of this variable as public spending). The second variable is termed “Consumer Goods” it can be set in a range between 0 and 9000 Rupees. This variable determines the money needed per capita (private spending). With growing population this variable sums up to a growing charge. The third variable determines the price of rice. In the following runs the rice price was set to 2.5 Rupees per kg.

Base Runs	**Run 1**	**Run 2**
Rice price	2.5	2.5
Reproduction rate	2.2	2.2
Kcal loss	1	1
Pig importance factor	0.76	0.76
Pig meat distribution	0.5	0.5
Copra price	30	30
Max. Area	29.9	29.9
Consumption Goods	**90**	**810**
Reef Outsider	5	5
Harvest Store	1	1
Pig vs. Copra	0	0
Technical demand	**891**	**99**

Table 11: The values of the variables defined as sliders as set for the two base runs.

The variables determining the amount of incoming money (copra price per kg and maximum size of coconut plantations) and the rice price were set to resemble the situation on Trinket in 2002, the year in which most of the data used in this model was collected.

Human Population in the Base Runs

The outcome shows that setting the variable “technical demand” to 891 Rupees and the variable “consumption goods” to 90 Rupees, gives the human population the possibility to grow 80 to 90 years without restrictions (**Figure 31**).

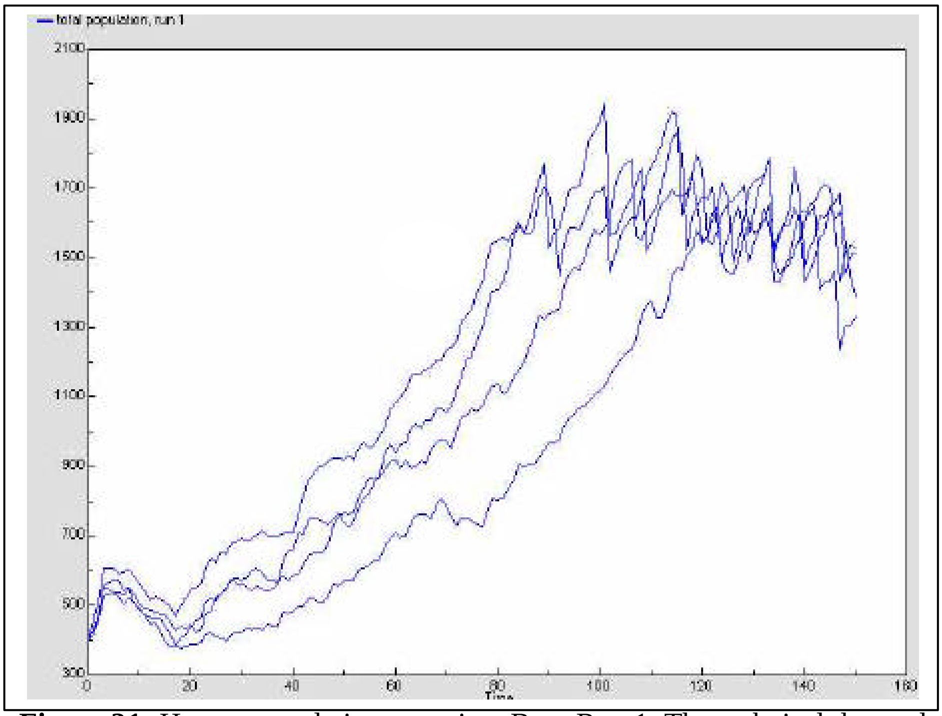


Figure 31: Human population over time Base Run 1. The technical demand is set to 891 Rupees, consumption goods set to 90 Rupees. All runs oscillate between 1300 and 1900 people.

Figure 32 shows the development of the human population over time with the more realistic assumption that the demand for money is linked to the single human agents. The variable “consumption goods” was set to 810 rupees. The population now oscillates between 350 and 450 people which is close to the current population number on trinket.

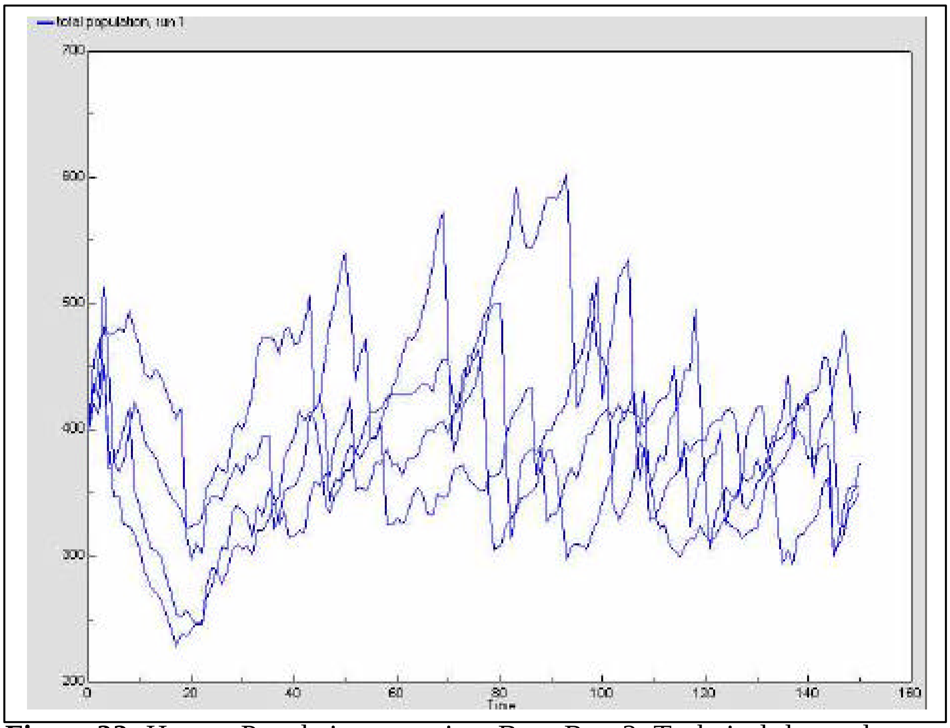


Figure 32: Human Population over time Base Run 2. Technical demand set to 99 Rupees, consumption goods set to 810 Rupees. The population oscillates around 400 people which is close to the current population number on Trinket

Endosomatic Metabolism and Cash Economy

The following figures want to give an overview over the dynamics of some of the other variables of the model, which the human population development depends on. The figures were taken from the base run 1 & 2.

Figure 33 shows the copra demand and the actual amount of copra sold (in total coconuts over time) in base run 1.

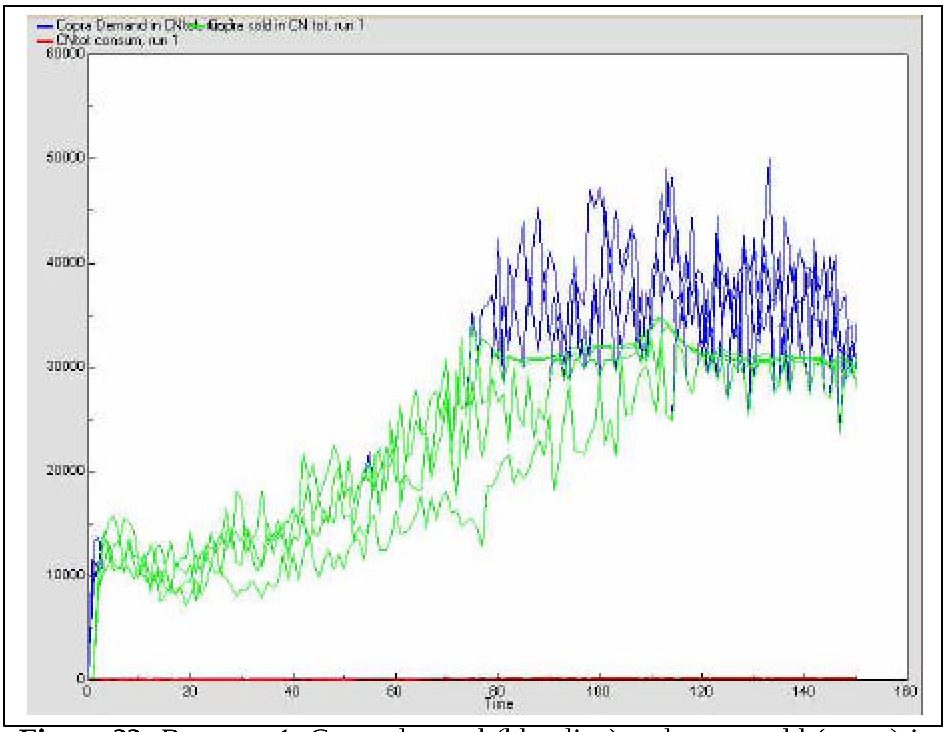


Figure 33: Base run 1. Copra demand (blue line) and copra sold (green) in coconuts over time. The demand is lower than in base run 2 and can therefore be full filled over a longer period of time.

The demand can be met over about 80 years. Then the maximum productivity is reached and the demand outruns the sold copra. The results can also be observed in Figure 34, which shows the rice consumption versus the rice demand. As a result of a lack of copra there is not enough money to import a sufficient amount of rice. This leads to a shortage of calories, which in turn imposes a pressure on the population. This can also be observed when monitoring the variable “nutrition status”. A nutrition status of one indicates that the energy requirements of the population can be met a negative nutrition status indicates that the energy requirements cannot be fulfilled. A negative nutrition status over 0.6 time steps (216 days) raises the mortality rate of the human population.

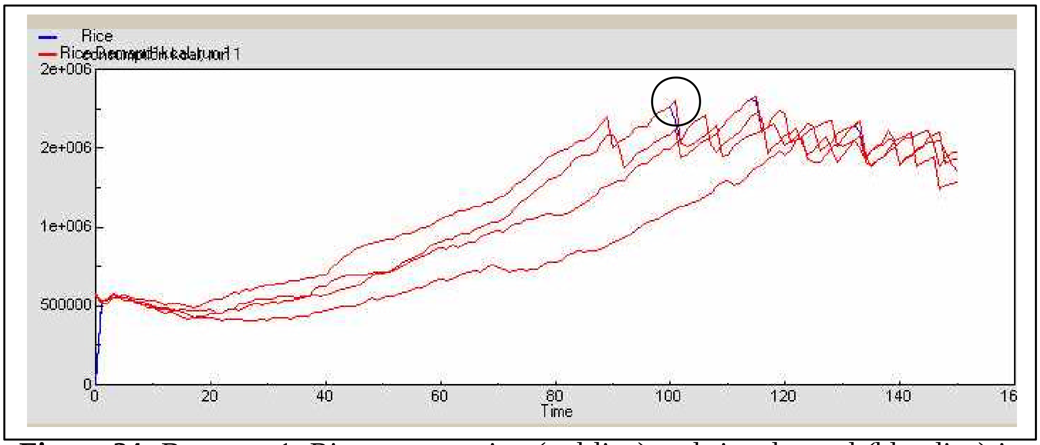


Figure 34: Base run 1. Rice consumption (red line) and rice demand (blue line) in kcal over time. The demand can be met over about 90 years or up to a population of 1600 people. In this time the human population can grow without restrictions.

Figure 35 shows the development of the kcal intake per capita of the human population. The peaks were caused by the availability of pig meat after major feasts. The times of food shortage are hardly visible in this representation, as the human population number is regulated to drop when there is a shortage of kcal over 0.6 timesteps.

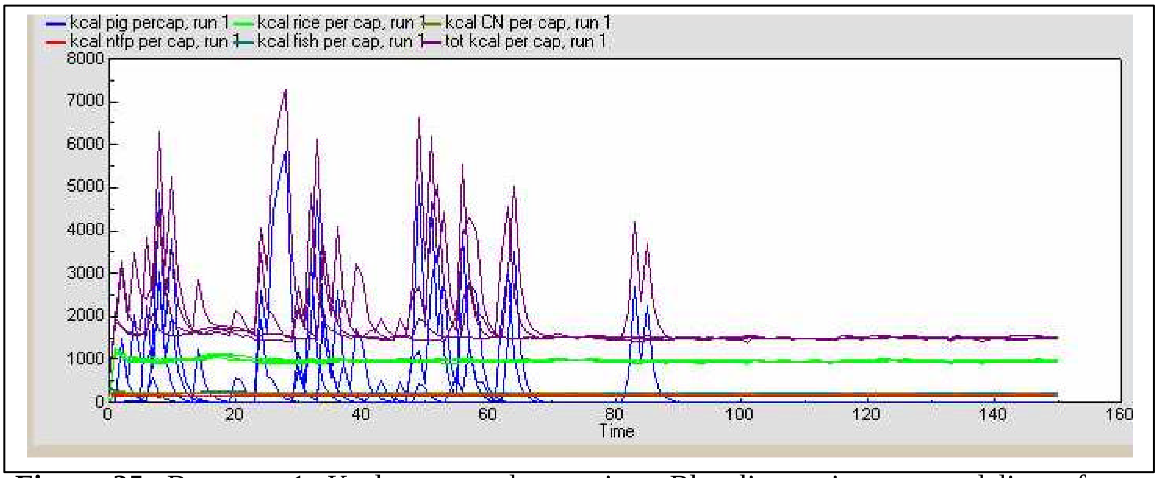


Figure 35: Base run 1. Kcal consumed over time. Blue lines: pig meat; red lines: forest products; light green line rice; dark green line fish; olive line: coconuts; violet line: total kcal consumes.

Figure 36 shows the demand of copra versus the sold copra in base run 2. Due to the increasing amount of spend money the demand is higher then in base run 1 and can never be met.

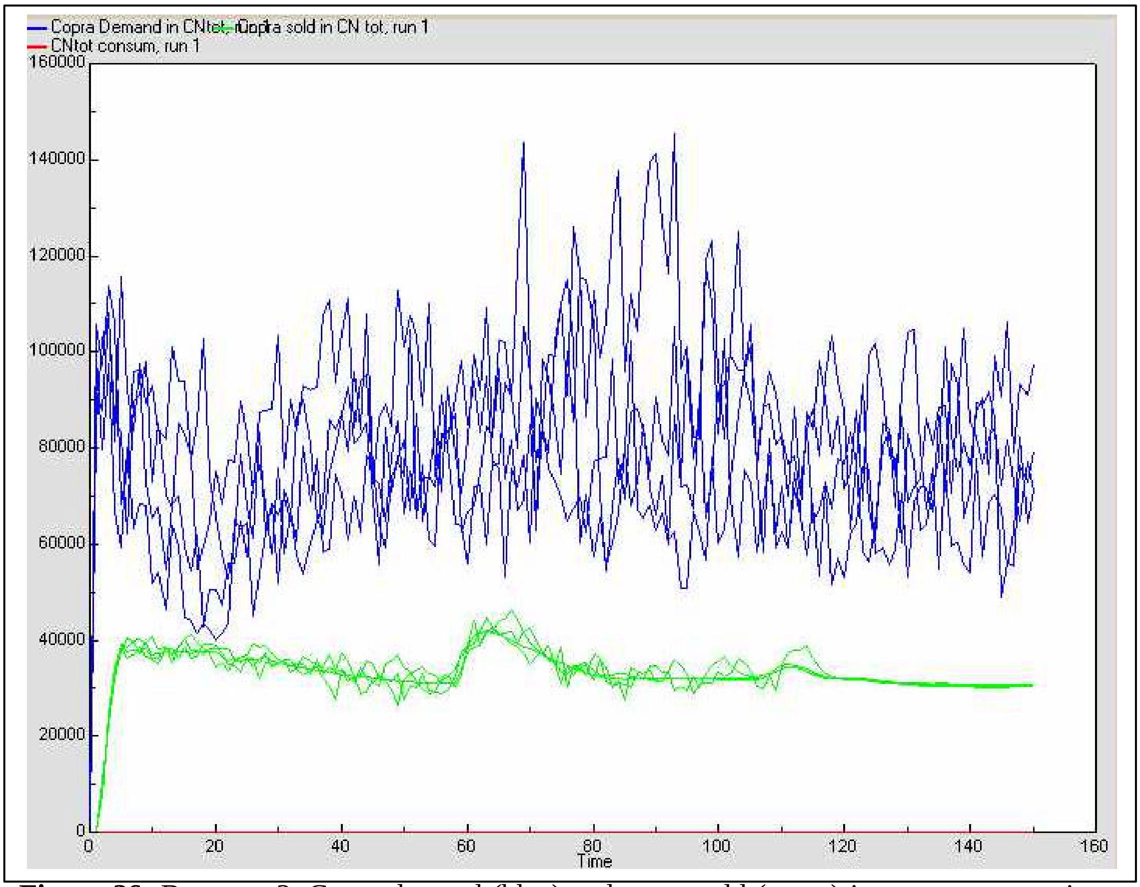


Figure 36: Base run 2, Copra demand (blue) and copra sold (green) in coconuts over time. The demand for copra is always higher then the produced amount.

Figure 37 shows the development of rice demand versus rice consume over time for base run 2. Due to the higher spending on consumption goods, the demand for rice can not be fulfilled on a regular basis.

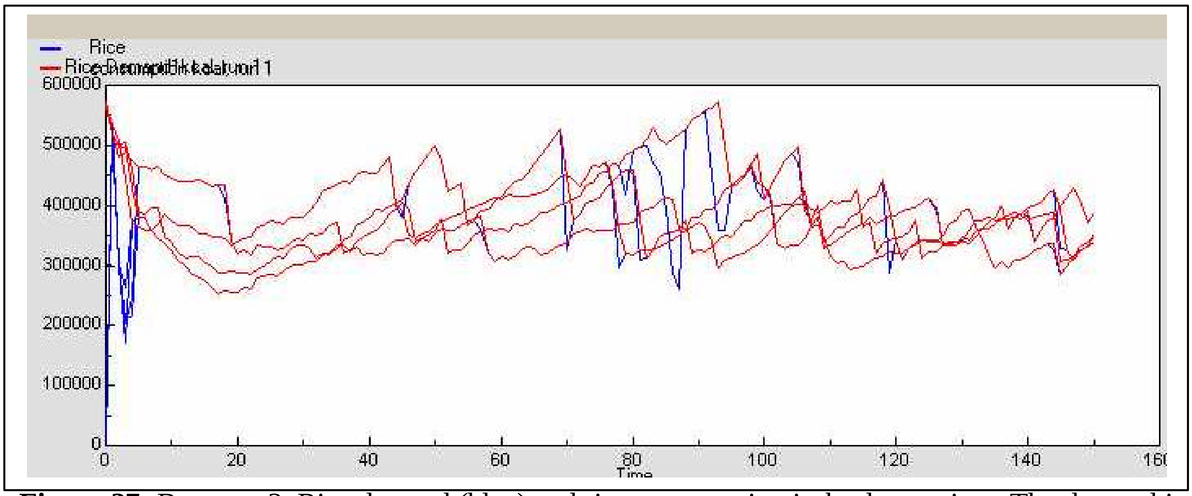


Figure 37: Base run 2. Rice demand (blue) and rice consumption in kcal over time. The demand is occasionally higher than the consumption. This keeps the population in check.

Again the consumption of kcal per capita (Figure 38) has only small discrepancies downward.

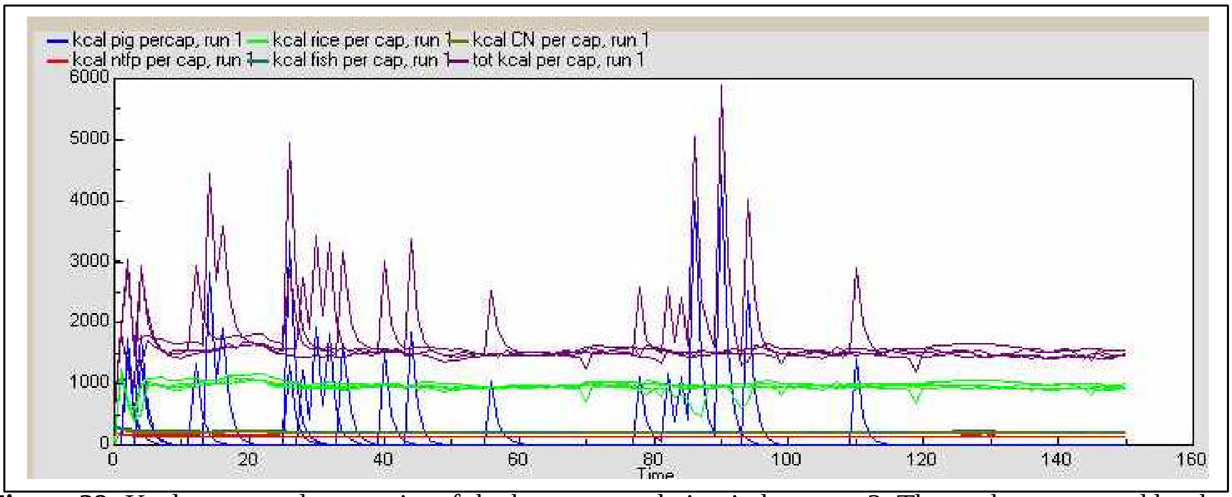


Figure 38: Kcal consumed per capita of the human population in base run 2. The peaks are caused by the availability of pig meat after feasts. Blue lines: pig meat; red lines: forest products; light green line rice; dark green line fish; olive line: coconuts; violet line: total kcal consume.

The Pig population

The reproduction of the pigs is determined by their age and weight. The weight gain per time depends on the feed-rate. A feed-rate of 100% means optimal growth. The maximum weight assumed is 150 kg. Fertility declines when the weight drops below 80 kg.

The death rate of the pigs is influenced by their natural death rate and by the demand for festivals. Four different kinds of festivals exist. Small ones, occurring about three times a year, bigger ones every two years, even bigger ones every five years, and really large ones every ten years. The number of pigs demanded is correlated to the size of the human population. If the size of the pig herd is below a critical number ("minimum pig requirement") no killing will take place. This critical number can be changed through the user in runtime, with the variable called "pig importance factor". While the human population develops more smoothly until it reaches it upper limit, the pig-population shows sharp declines as a result of slaughtered pigs due to festivals.

Besides being influenced by a different "pig requirement variable" the population dynamics of the pigs vary in every run due to the probabilistic nature of the population model. Figure 39 shows four runs of the pig-population always with the same variables.

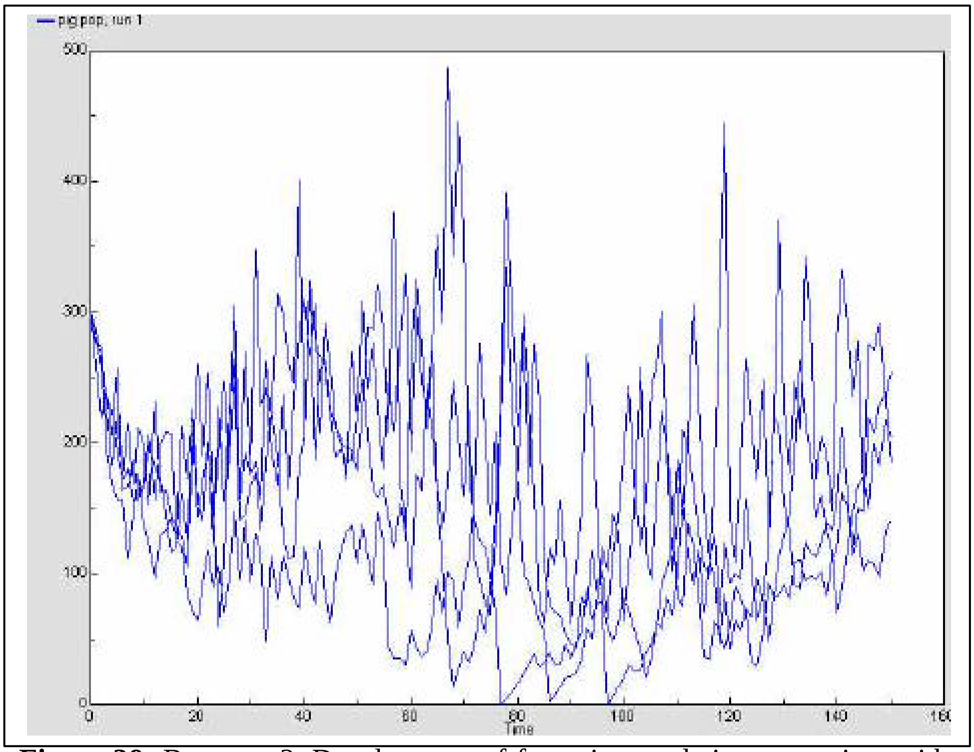


Figure 39: Base run 2. Development of four pig populations over time with the settings of base run 2.

If the pig population falls to zero new pigs are bought if money is available. Figure 40 shows that the food demand of the pigs is hardly met to 100%. The values used to calculate the different determining variables of the pig population (energy requirements, weight gain per calorie, mortality rates) were taken from various studies. For an exact representation of the pig populations on Trinket data of the indigenous pig breed would be necessary, as these variables have a strong influence on the population development in the model.

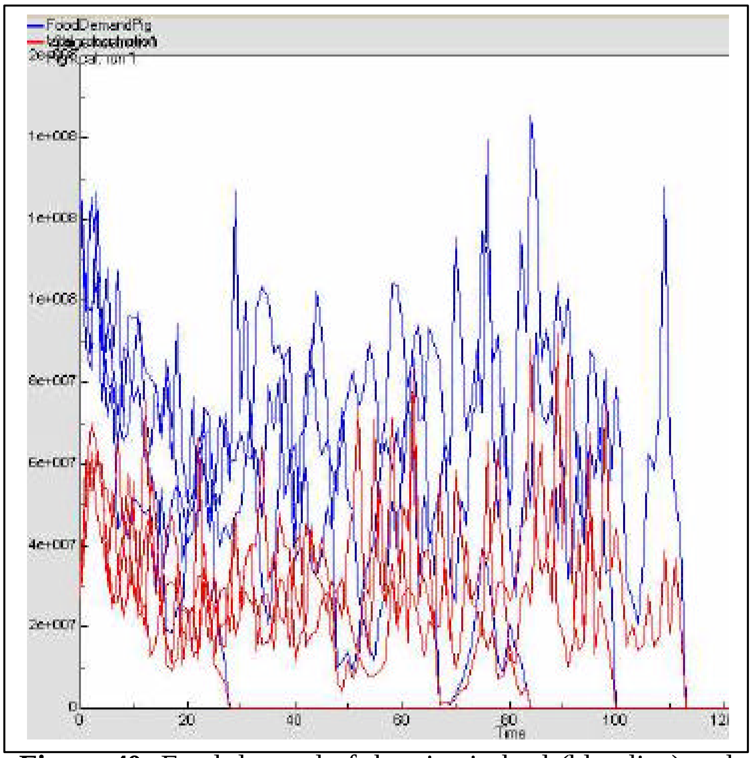


Figure 40: Food demand of the pigs in kcal (blue line) and consumed kcal by pigs.

Manipulating the Model

To meat the claims made by a nonlinear modeling approach (Richerdson 2002) it was decided to build slider-variables into the model to allow the user to influence the model very easily. The following results show the behavior of the human population and some other important variables when different fertility rates are set for the human population. All other variables were set as in base run 2 (**Table 11**).

Effects of different Fertility rates

Figure 41 shows the development of three times four populations with three different fertility rates. The population with a fertility rate of 2.8 (green line) grows rapidly but also declines abrupt. One population run even drops down below hundred people. This due to the decline of the NTFP consumption due to overuse.

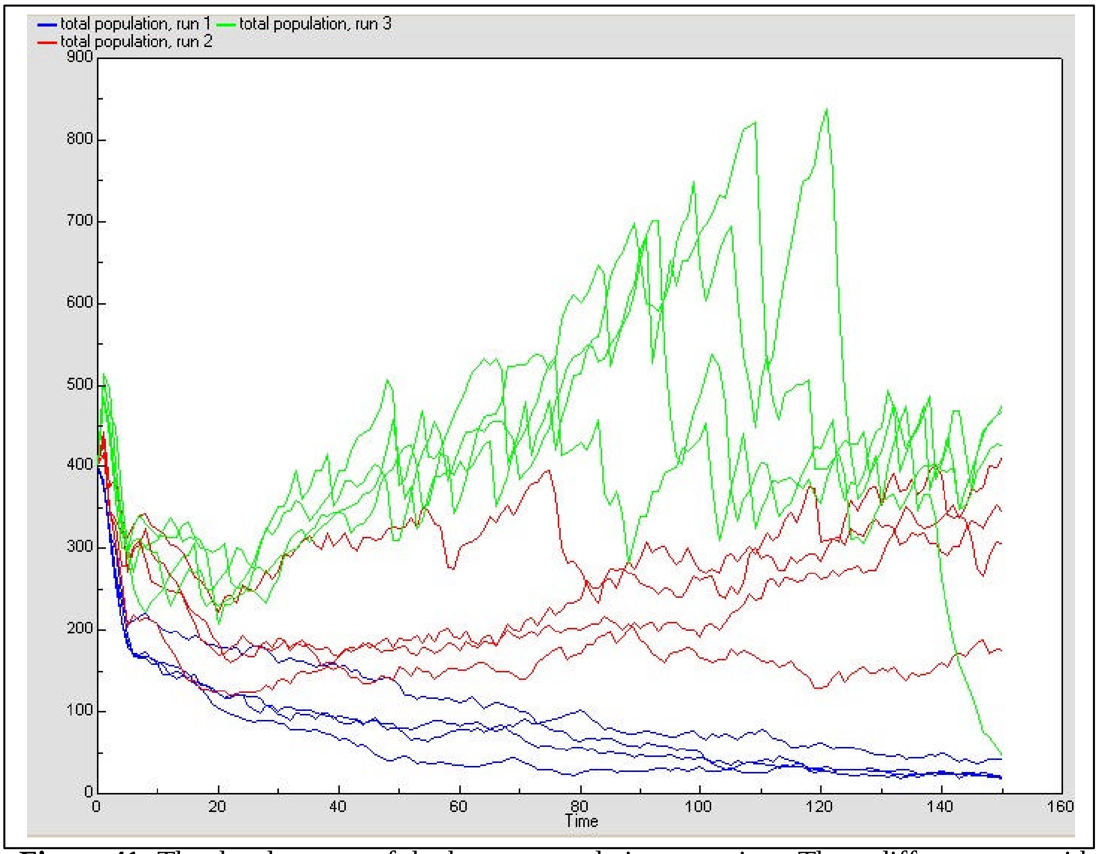


Figure 41: The development of the human population over time. Three different runs with different fertility rates. Blue line fertility rate = 1; red line fertility rate = 1.8; green line fertility rate = 2.8.

Figure 42 shows the development of the corresponding pig populations. As the maximum amount of desired pigs is linked to the human population number the pig population of the run with a human fertility rate of 2.8 is the largest.

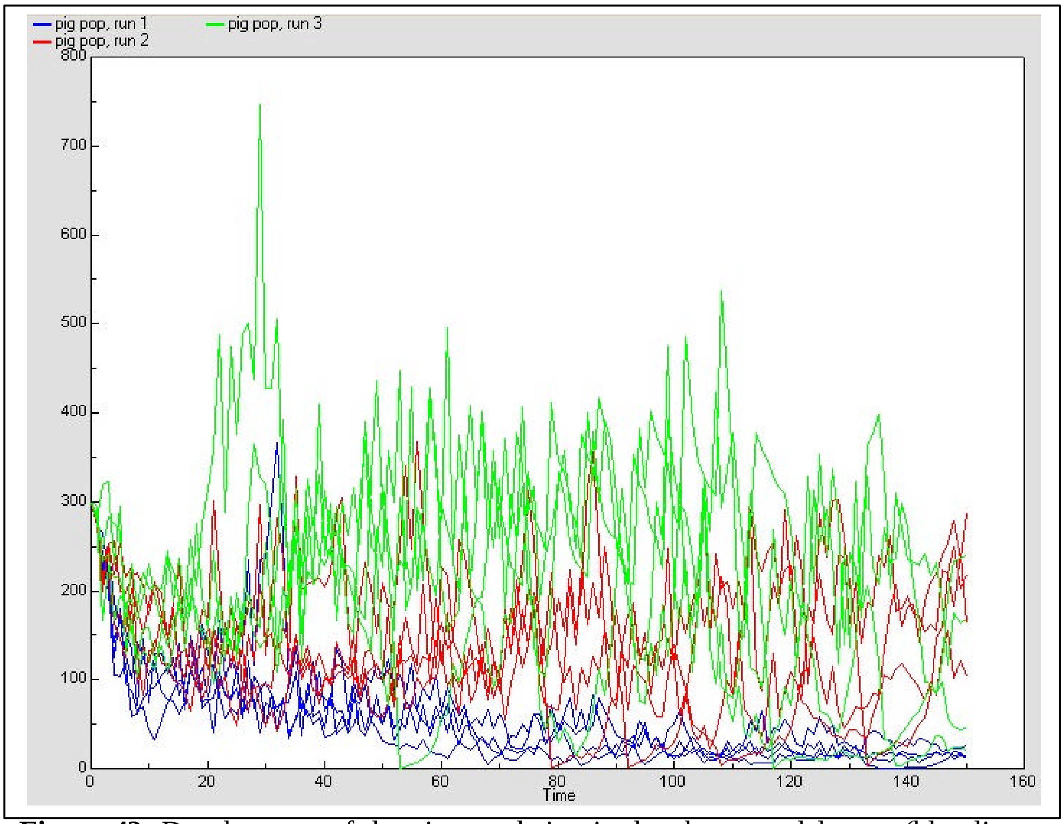


Figure 42: Development of the pig population in the above model runs. (blue line = human population fertility rate = 1; red line human fertility rate = 1.7 green line human fertility rate = 2.8.)

Figure 43 and Figure 44 show the development of rice consumption versus demand and the nutrition status for a human population with a fertility rate of 1 over time.

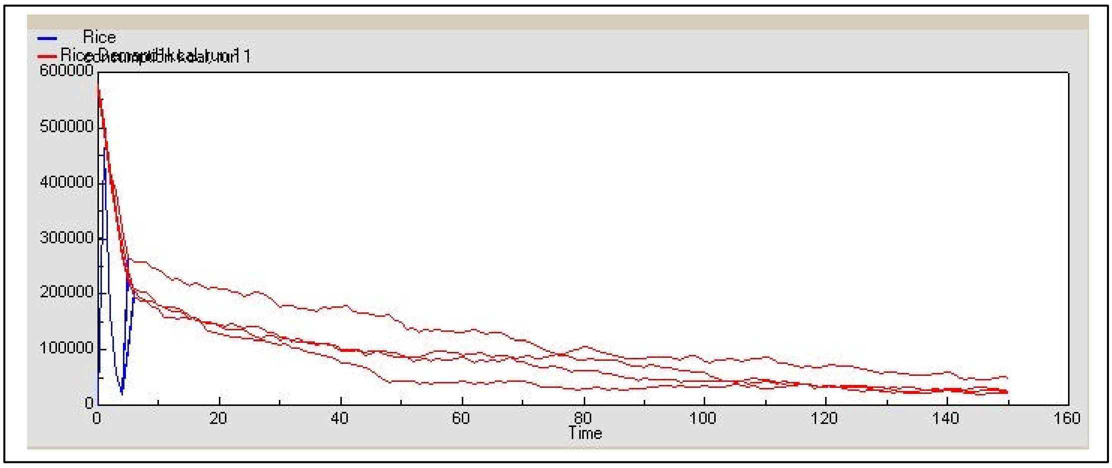


Figure 43: Rice demand of the population (blue line) and rice consumption (red line) in kcal fertility rate = 1. After the first ten years the demand can always be met.

The discrepancy in the first ten years is an artifact of the model, which needs some time to regulate itself. Besides this the human population number remains that low that there are no restrictions due to a shortage of kcal.

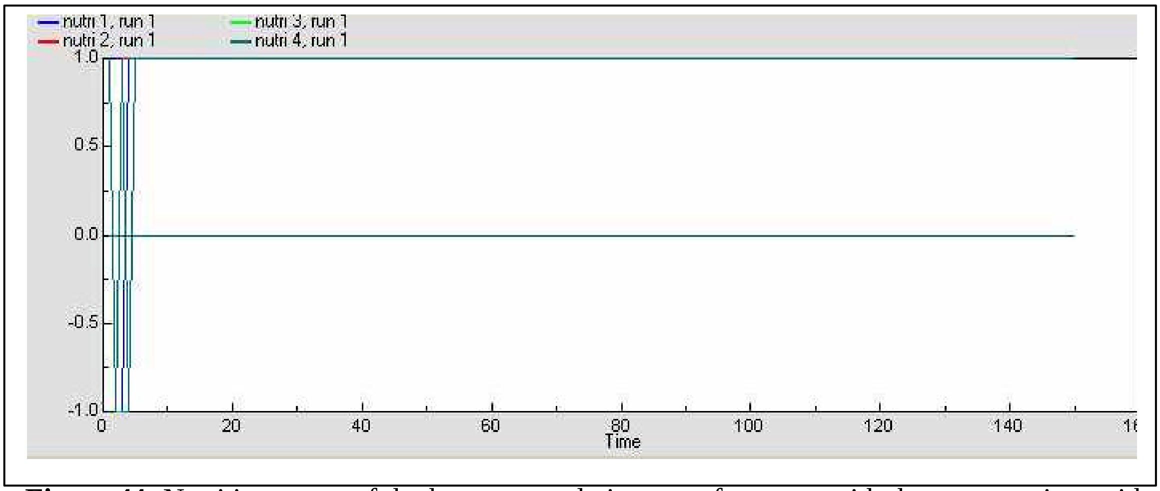


Figure 44: Nutrition status of the human population over four runs with the same setting, with a fertility rate of 1. Each color represents one run

Figure 45 and Figure 46show the development of rice consumption versus demand and the nutrition status for a human population with a fertility rate of 1.7 over time. The population grows slowly and so does the rice demand. Therefore it can be met over a longer period of time. The population development is quite smooth.

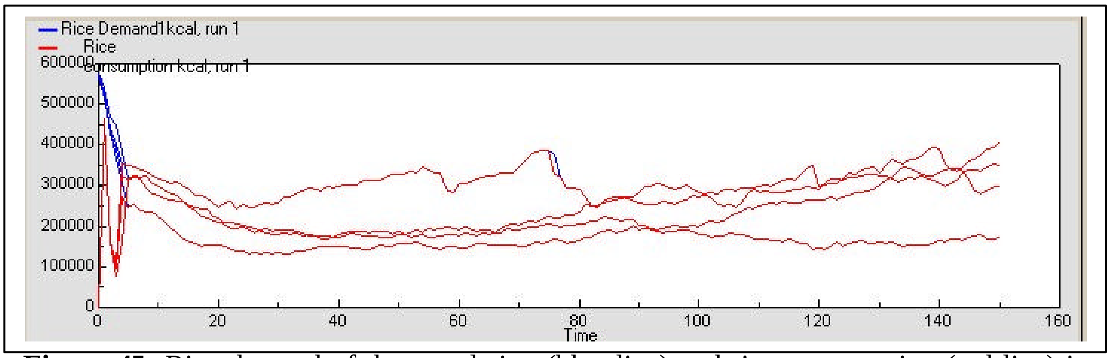


Figure 45: Rice demand of the population (blue line) and rice consumption (red line) in kcal fertility rate = 1.7. The demand cannot be met all the time.

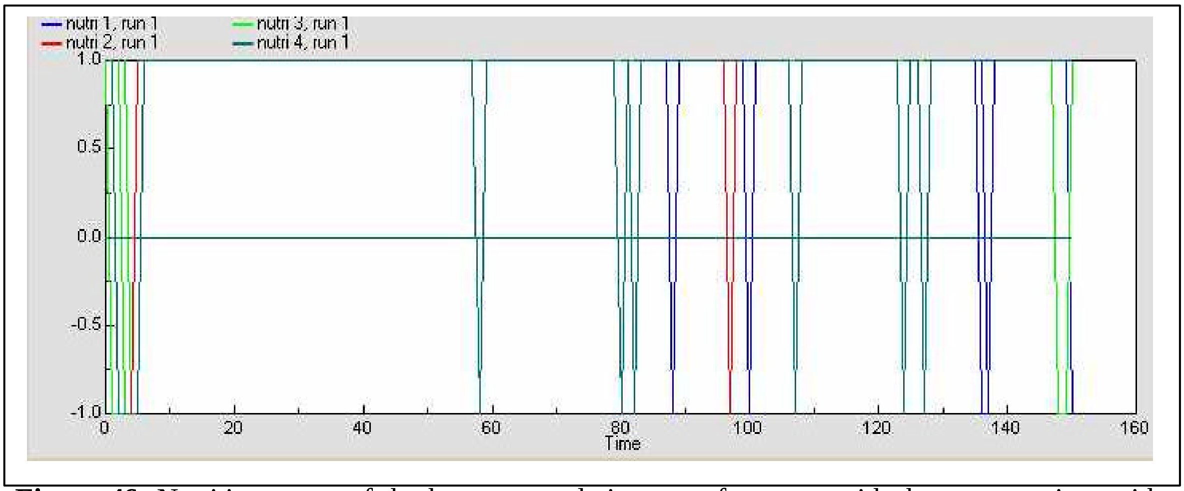


Figure 46: Nutrition status of the human population over four runs with the same setting, with a fertility rate of 1.7. Each color represents one run

Figure 47 and Figure 48 show the development of rice consumption versus demand and the nutrition status for a fertility rate of 2.8 over time. Due to the fast growing human population the rice demand can not be met after a relatively short time.

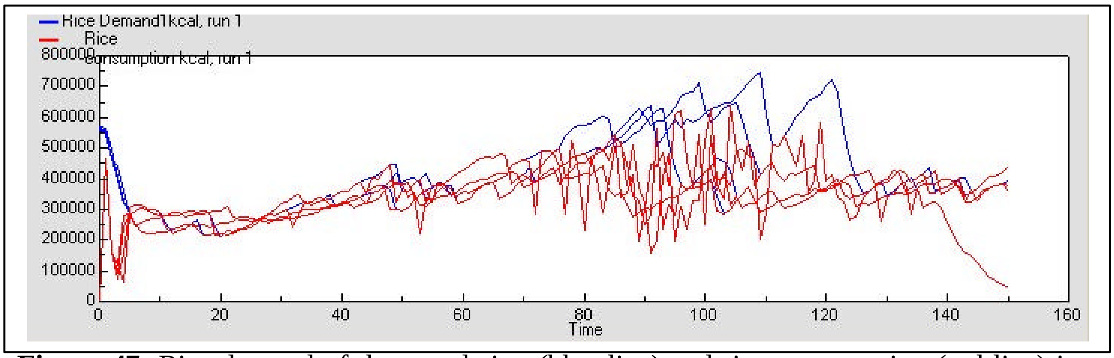


Figure 47: Rice demand of the population (blue line) and rice consumption (red line) in kcal fertility rate = 2.8. The demand can hardly be fulfilled over time.

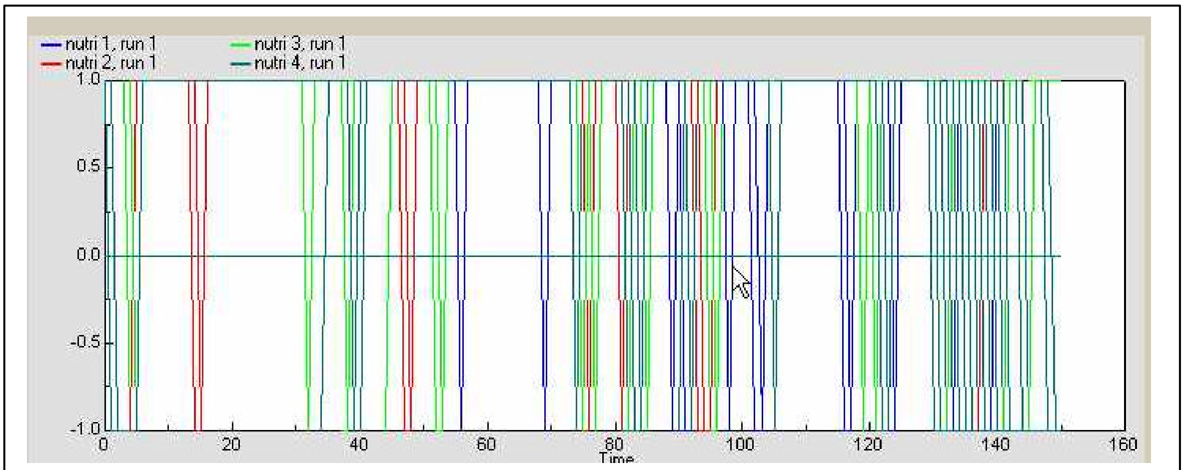


Figure 48: Nutrition status of the human population over four runs with the same setting, with a fertility rate of 2.8. Each color represents one run

Figure 49: The variable CNaccount calculates the difference between the total demand of coconuts and the actual produced / harvested coconuts. Blue line: human fertility set to 1; red line: 1.7; green 2.8.In the model it is used to trigger the planting of new coconut-palms. The runs show that in the population with the highest fertility rate has the highest negative balance until it drops down, as a reaction of a reduce in the population numbers (Figure 41).

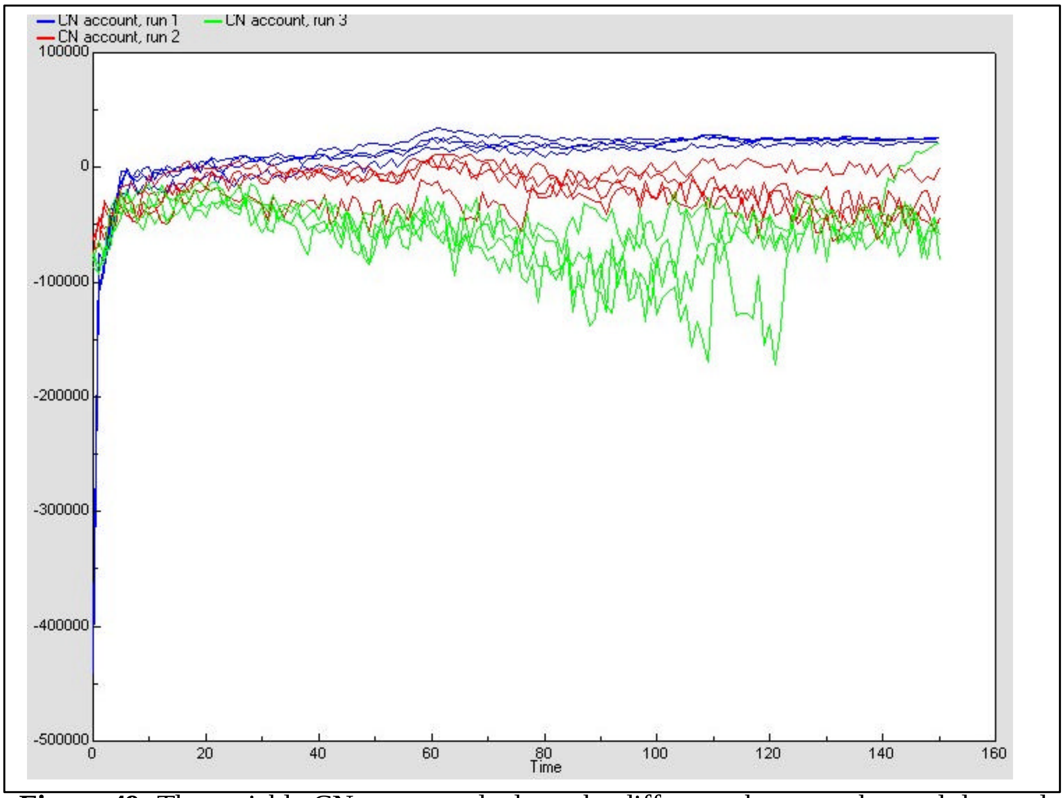


Figure 49: The variable CNaccount calculates the difference between the total demand of coconuts and the actual produced / harvested coconuts. Blue line: human fertility set to 1; red line: 1.7; green 2.8.

Figure 50 shows the amount of sold copra in the three runs with different fertility rates. The two runs with a fertility rate from 1.7 and 2.8 both reach the maximum possible production under the given constraints (available space). The run with a fertility rate of 1 does not need to produce such high amounts of copra, as the population number keeps low.

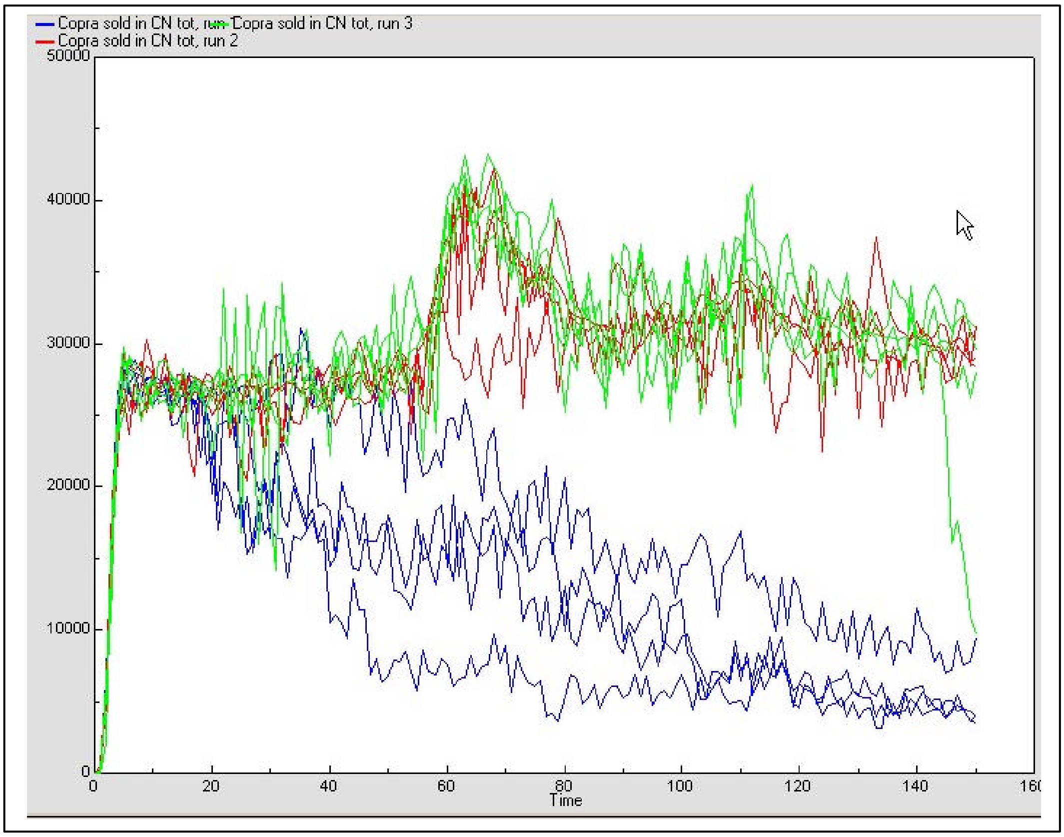


Figure 50: The amount of copra sold in three runs with different human fertility rates. (blue = 1; red = 1.7; green = 2.8)

Figure 51 shows the inflow of money per capita. As the inflow of money is directly dependant on the amount of produced copra it has an upper limit in the productivity of the current coconut plantations. Therefore it is higher if the population number is low and vice versa.

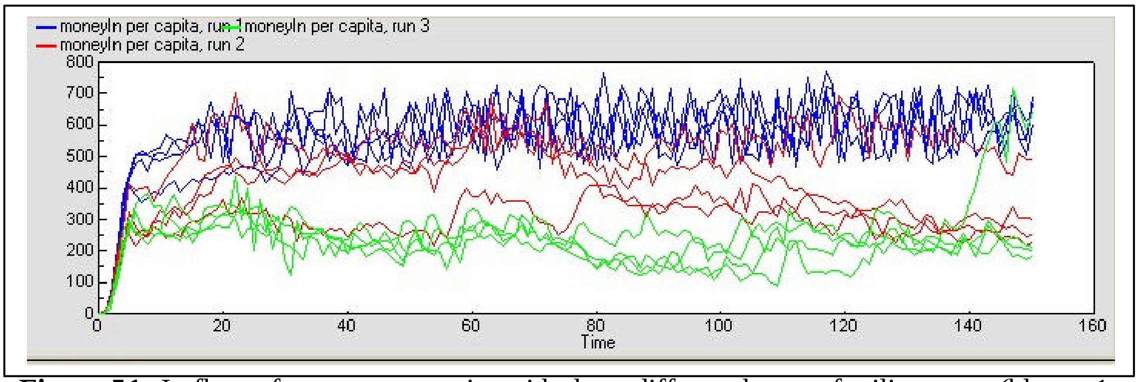


Figure 51: In-flow of money per capita with three different human fertility rates. (blue = 1; red = 1.7; green = 2.8)

The Influence of the Pig-system on the Population Dynamics of the Human-System

There are three build-in possibilities to manipulate the relations of the pig system to the human system. The first is by determining the percentage of pig meat (in kcal) which is utilized by the human population, the second by manipulating the desired pig to human ratio. The third by determining if the harvested coconuts are first fed to the pigs and the reminders are used for copra production or vice versa.

Manipulating the Distribution of Pig Meat after Festivals.

Figure 52 shows the development of eight human populations. Four of them utilize the kcal of the slaughtered pigs four do not. The human populations which do not use pig meat develop nearly the same as the others, but miss an additional buffer in times of need. In the runs shown in figure 58 one population even drops to zero. In this case it was due to a condition were the pig population was high, therefore the pressure on the common resource base of human and pigs elevated and led to a shortage of resources for the human population. The absent of additional kcal obtained through occasional pig-slaughters finally led to a drop of the population.

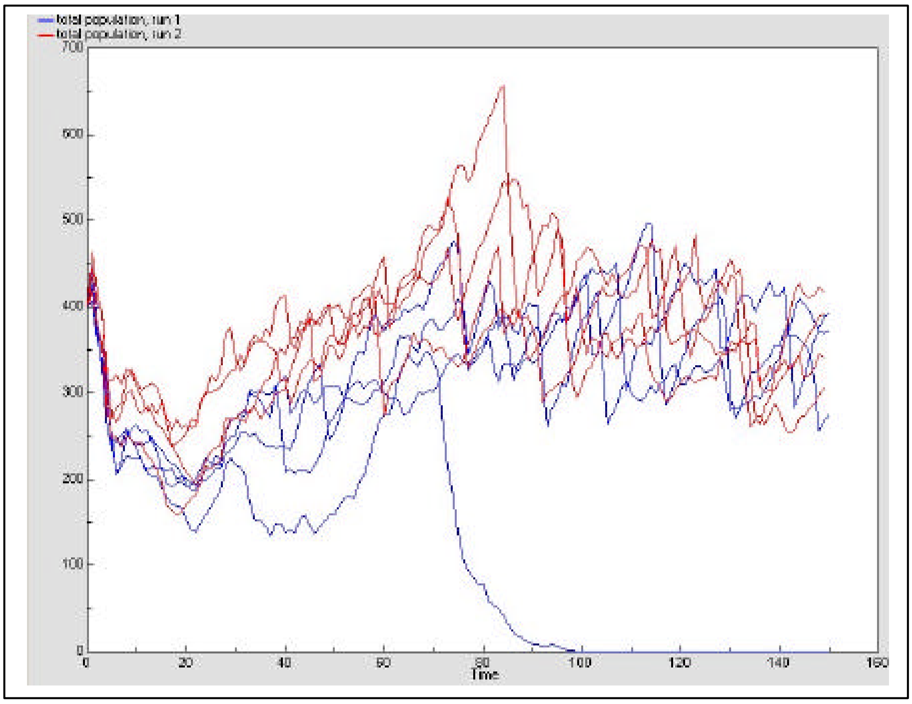


Figure 52: Development of population over time (settings of base run 3). The blue lines show four runs when the people themselves do not utilize the pig meat. In one of the runs the population even drops to zero.

Manipulating the Preference of Pigs vs. Copra

Another way of manipulating the pig-human relations is by setting the preference of coconut allocation towards copra instead pigs. Figure 53 shows eight populations, where four feed the coconuts to the pigs first and use the reminders for copra production and four the other way.

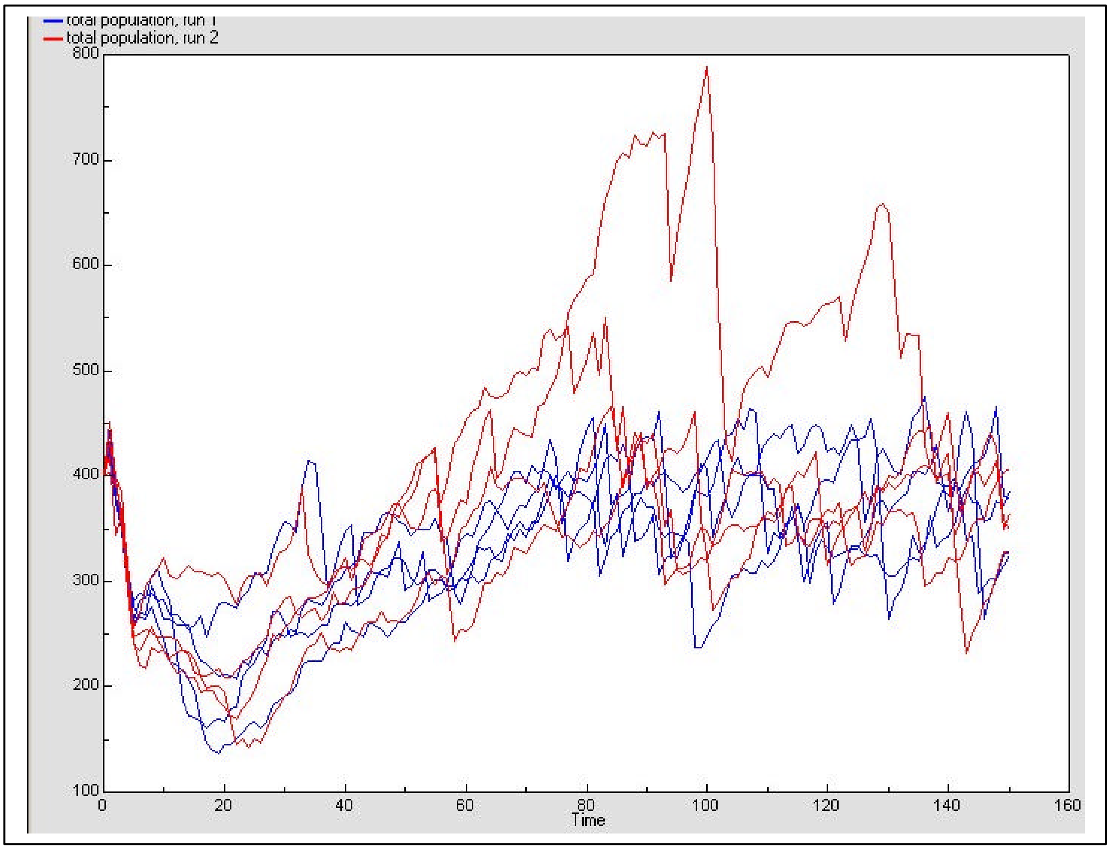


Figure 53: Development of human population over time (settings of base run 2), the blue lines represent a society in which almost all coconuts are used for producing copra instead of feeding pigs.

If coconuts are used for copra production first than the pig population drops to about 50 animals. The results show that the populations with small pig herds do not oscillate as heavy as the one with large pig herds.

Figure 54**Fehler! Verweisquelle konnte nicht gefunden werden.** and Figure 55 show the nutrition balance of the human populations in the above runs. In the runs with large pig herds (Figure 55) the times where large amounts of pig meat are available often composed the times with a lack of kcal and therefore allow the human population to grow.

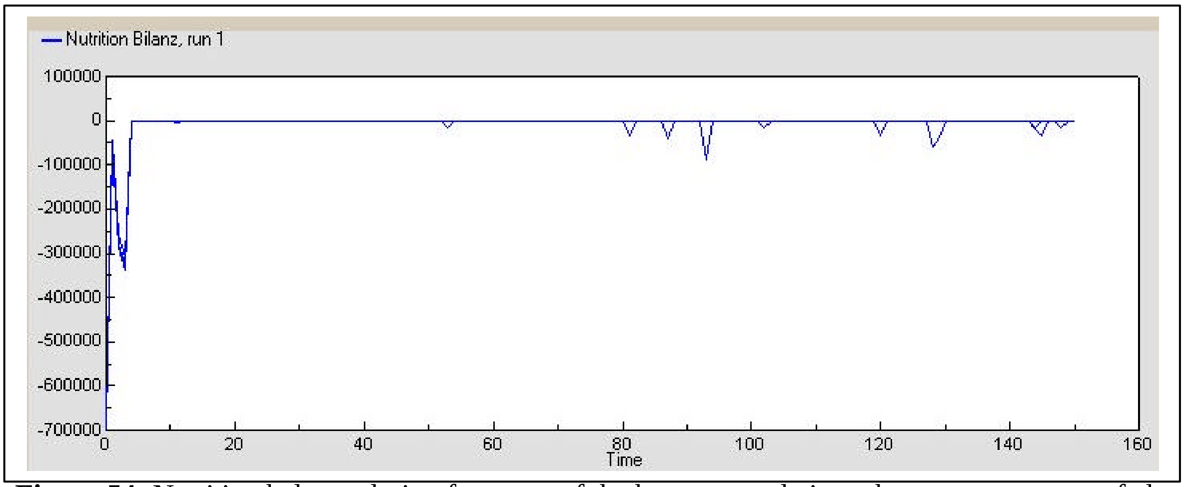


Figure 54: Nutrition balance during four runs of the human population when no coconuts are fed to the pigs.

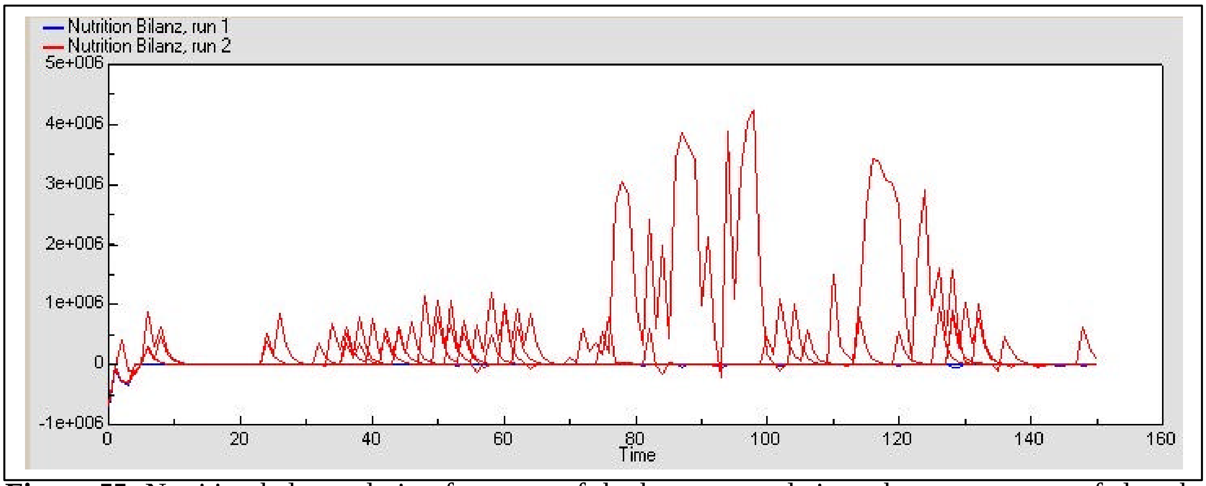


Figure 55: Nutrition balance during four runs of the human population when coconuts are fed to the pigs.

Manipulating the Human Pig Ratio

Figure 56 shows the development of the human population; Figure 57 the development of the corresponding pig populations with different human to pig ratio. Both runs with a high human to pig ratio show a decline in human respectively pigs. This decline can be linked to a decline in the NTFP stocks (Figure 58). A high number of pigs deplete this resource base. This in turn leads to a shortage of kcal in the human population which can not be compensated with rice due to a lack of money.

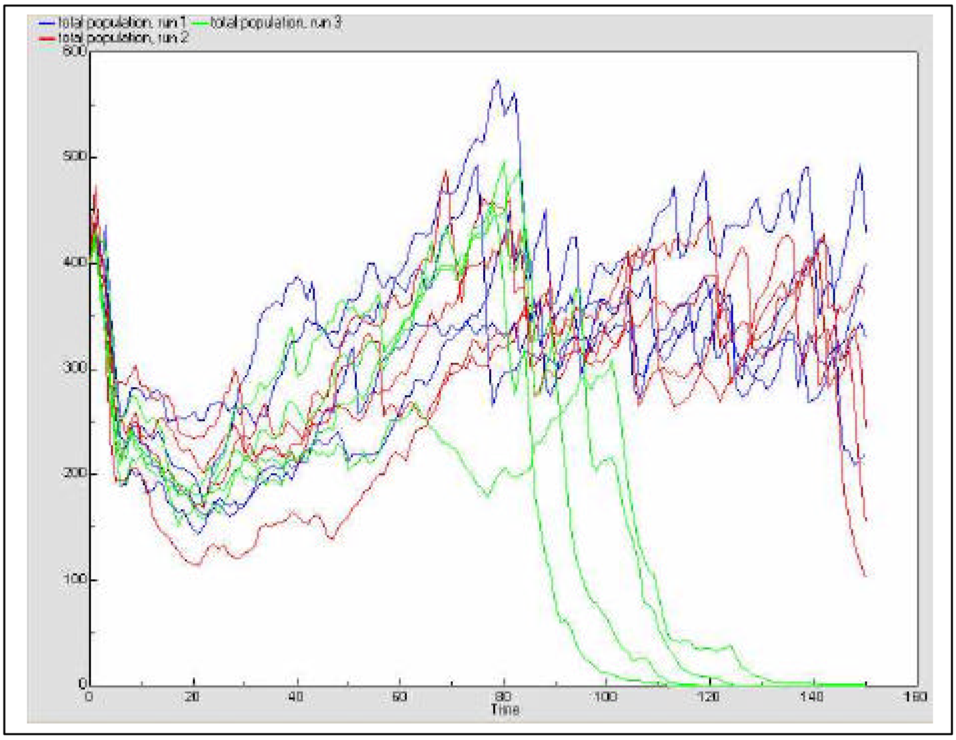


Figure 56: Three runs with each four populations with different pig to people ratio. Blue line: 0.5; red line 1.2; green line 2.

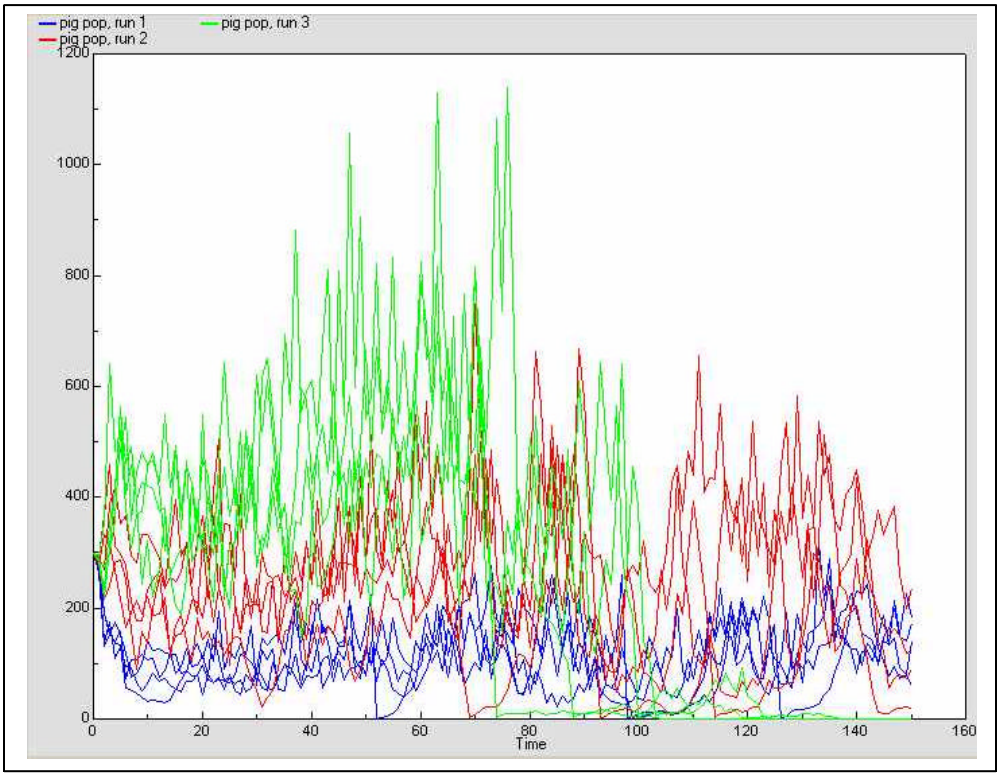


Figure 57: Development of pig populations with different human to pig ratio. Blue line: 0.5; red line 1.2; green line 2.

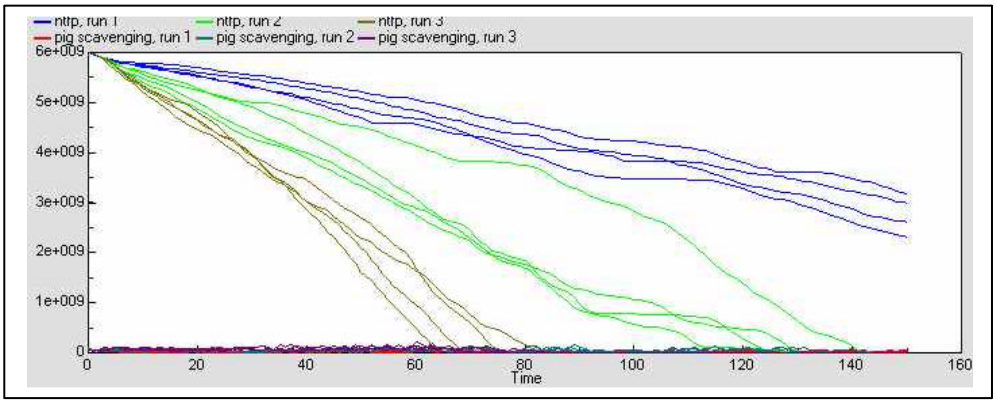


Figure 58: Development of NTFP resource base over time with different human to pig ratio. Blue line: 0.5; green line 1.2; brown line 2.

VI.

Discussion

The Model Results

The results of the base runs show that the human population oscillates quite heavy when reaching the maximum sustainable size (Figure 31 and Figure 32). In reality a society would react with a change in either consumption or acquisition patterns respectively emigration (total or partial i.e. for work) would take place. This would allow the population either to reach the carrying capacity more smoothly or as the case may be, push the carrying capacity to a higher number through the utilization of new resources.

The development of the human population in the model should therefore be interpreted as showing an array of development possibilities with certain upper or lower limits rather then the exact course of population growth.

Figure 32 shows the population development with all variables set to resemble the situation on Trinket Island in the time the data was collected. The results show that the population oscillates around 400 people, which is also the number of the actual population. This indicates that the assumptions about energy requirements of the population respectively harvested energy are not too far from reality. Anyway for a more realistic simulation of the social-ecological system on Trinket Island the model would need to be extended.

A crucial part missing is, above all, an adequate land-use model. This element is important as it links together the copra-production (firewood demand), the pigs (scavenging the forest) and the NTFP and fire- and construction-wood demand of the humans. In the moment the entire forest system is represented by a single stock-compartment. This clearly is not adequate. Another important part still missing is the calculation of required and possible working time and some decision rules to what activity the working time is applied.

When manipulating the variables determining the relations between pig and human-population one can recognize following effects:

If the pigs are still maintained in the same way, but most of the pig meat is given away, society faces a risk of extinction (about every eighth run). This is due to the fact that the pigs still consume coconuts and NTFP but do not contribute to the nutrition of the people, which means a considerable amount of calories is lost both in terms of rice and pig meat

If the coconuts are used first to meet the requirements of copra production and only the reminders are fed to the pig, the population does not face the risk of extinction, but experiences a negative nutrition balance more often.

When changing the pig to human ratio one can observe the parasitic relations the pigs have towards the human. In the current situation it will rather be not the case that the desired human to pig ratio will increase over its present value. Nevertheless these runs show the importance of the forest resources as link between human and pig system.

In the model the populations with pigs generally show more oscillation then the ones without pigs. This is due to the fact that the availability of pig meat allows the population to grow higher than it could only with the available rice.

This results are contradictory to the assumptions that the pig herds help keeping a society in equilibrium. In the model the availability of pig meat allows the population to overshoot the maximum number of people, which can be sustained by the available land. This leads to a cut in the population as soon as the pig meat is gone. Nevertheless the pigs also provide a buffer against occasional food shortages.

It can be assumed that there are several mechanisms in real societies which make the actual decisions and actions more complex as represented in the model and which possible help stabilizing the population numbers in this context. In general it can be said that providing a high resilience for a system does not necessarily require keeping all elements in an equilibrium condition over time.

Answering the Research Questions

Do the pig-festivals have an influence on the resilience of the social-ecological system?

The comparison with related case studies, theoretical considerations and some of the model results do support the thesis that the pig festivals have a positive effect on the resilience of the traditional social-ecological system on Trinket.

	Ritual use / consumption of significant amounts of resources	**Main social implication**	**Spiritual meaning**	**Consequences if not performed**	**Interpretations for effects on larger system**
Nicobarese	Yes – during pig feats /sec. Ossuary	Kin ties are sustained	Keeps cycle of live and death going	No possibility to inherit and use land of the dead	Buffering Diversified resource base Increased food availability Integrates / stabilize society
Maring	Yes - Kaiko	Allies for fighting are invited	Keeps cycle of live and death going	No allies for fighting – no fights or defeat	Population control device, Ecosystem monitoring, Controlling the behavioral plasticity
North-West-Pacific-Tribes	Yes - Potlach	Neighboring titleholders affirm power of titleholder	Keeps cycle of live and death going	No acceptance as title holder through neighbors and members of the tribe	Cooperative decision making Social learning Environmental ethics Contingent proprietorship Balanced reciprocity Public accountability

Table 12: Comparing the different aspects of Ritual Resource Consumption (Rappaport 1984, Anderies, 1998 Tropser, 2003).

If this "resilience enhancing capacity" is still working for a society departing more and more from traditional lifestyle is an open question worthwhile investigation.

What are the Aspects of the Ritual that are Responsible for Enhancing Resilience?

Different aspects of the Nicobarese pig-festivals/rituals can be related to features that are identified as enhancing the resilience (or some other notion of equilibrium/stability in the older studies) discussed in chapter IV.

One important feature of the ritual is that the pigs are not solely needed as meat source for the rituals, but also for representation of status and wealth. The special status the pigs have in society ensures that the people are willing to invest time and resources into pig keeping without direct material rewards. "*Controlling the behavioral plasticity*" (Anderies 1998) and "*driving down the Hyper-cycle*" (Giampietro 2003, Mayer 2004) can be used in a similar way to argue for the stabilizing effects of pig-festivals on Trinket. Both state that through the time spend for pigs respectively for creating "piginess" working force is bound to (possibly) not destructive labor and keeps the system stable. The rituals are seen as a device for buffering unsustainable fast growth of the communities.
An important condition for the buffering capacity of pig husbandry is that there have to be some restrictions on the total amount of pigs kept. These will most likely be in the form of resource or working time scarcity. If this is not the case because e.g. food for pigs is available from outside the socio-ecological system the number of pigs could become too high and unsustainable for the system. An argument that is reminiscent by Rappaport (1984), Foin et al (1987) and Anderies (1997) is that, as pigs and human have a similar food spectrum, the borderline of the maximum pig number is well below the carrying capacity because of human – pig competition for the same resources. This argument can also be used on Trinket, where the pigs consume considerable amounts of coconuts.

Rappaport also mentions the role of pigs as an "ecosystem monitoring device". It is not possible to prove this for Trinket although there are some indications pointing in this direction[18]. A point to be made here is that through their involvement in pig keeping the Nicobarese have to deal with parts of their environment with the view of pig-keepers. Although there are no evidence for this argument one could state that viewing the environment under different aspects (as pig-keepers, fire-wood collectors, hunters, gatherers)

[18] Although Agrawal (2004) states: "They tell that indication of arrival of cyclone and rough weather is predicted by the agitation and behaviour of pigs, [...]. If they have any doubt regarding the cyclone or bad weather, they closely observe the pigs at home."

will reduce the probability of overusing the system for the sake of one single sector. If traditional societies are seen as land managers involved in a continuous process of adaptive management then one could argue that a "ritual-oriented" land-use praxis enlarges the number of available mind-models for what and how land can be used. In this sense it would be in line with the request of Giampietro (2003) towards adaptive management to produce "*actively as many views of the system as possible.*"

Besides the arguments made above, which are more related to the special cases of pig-keeping or animal husbandry for ritual purpose, the next arguments apply to the aspect of giving away large amounts of goods in a ritualized context.

Some of the resilience enhancing effects Tropser (2003) ascribes to the Potlach-rituals can also be applied to the pig-festivals on the Nicobar Archipelago.

At least two of the requirements proposed for a resilient socio-ecological system can be directly related to the pig-festivals.

The Ability to Buffer

Public accountability: A big pig herd is the visible sign to the community that the head of the Kamuanse is capable of producing additional resources. He is only allowed to inherit land when he manages to bring together a sufficient amount of resources to hold an appropriate secondary ossuary feast for the deceased. The house of a Kamuanse that has yet not fulfilled its obligation to the dead is marked and the members are taunted to be not capable of working properly (Singh p.c.).

Balanced reciprocity: A big ossuary feast is visited by up to 400 guests. This provides the host with a network of people spread over several islands of the archipelago. Additionally the host has shown that he or she is a capable and reliable man/woman. This could be important in times of need, when different islands may be better off then others. The willingness to help will be higher if the person (or Kamunse) seeking help has proven to be able to serve obligations.

Food storage: An additionally buffering aspect, which is also mentioned by Rappaport (1968), is the function of the pig-herds as living protein storages. In times of need they can serve as high-quality food. This is also indicated through the model, where populations without pigs respectively with pigs but no pig meat have a higher probability of experiencing food shortages.

Social Learning:

Information exchange / social Learning: The gathering of some hundred people may have boosted information transfer and learning in societies without modern communication technologies. Especially in island environments where there are natural barriers between the single groups of a population.

Additional information about environment and resource allocation: The engagement with pig herding supplies the human population with additional information about their environment. This information may prove important when it becomes necessary to find alternative sources of supply in times of need.

What will change when pig-festivals dwindle?

The third question will be constricted to the consequences changes in the ritual praxis have for possible sustainable development pathways. Still the question remains so complex that it cannot be fully answered here. Nevertheless some suppositions can be made based on the model and the theoretical considerations presented above.

A part of the answer to this question lies in the reasons of change observed on Trinket respectively on the whole archipelago. The main driving force behind the changes in ritual praxis is young people saying that the pig-husbandry is too costly (in terms of resource and working time expanses) for the received gains (Singh p.c.).

Like Byod (2001) describes for a Papua New Guinea tribe the reasons for this modified worldviews reflect changes in two major areas:

- Religion (replacing old animistic believes and eluding the basis of the rituals/pigs)
- Integration in cash-economy (creates growing dependency on cash) and as a results a changing valuation-system.

A small scenario

The status symbol “pig” is replaced more and more by insignia of modern life like radio, television etc.. These products have to be obtained from outside with cash. Additionally they require electricity and maintenance. Their lifetime as working machines is if possible not longer than two to five years. Their lifetime as representative status symbol may even be shorter, as they only represent status as long as only a few people posses these objects. This leads to a higher demand in cash. The only way of producing cash on Trinket in the moment is through the export of copra. An increasing copra production faces following risks: depletion of natural resources especially firewood for clines. A growing dependency on world market and vendors is the result.

Referring to the "driving down the hypercycle" and "controlling behavioral plasticity" function of the pig-rituals one could make following considerations: If the new status symbols are ones with no direct connection to the environment of the socio-ecological system than there is a growing danger of overusing the natural systems. Through missing or delayed feedbacks the socio-ecological system runs in danger of damaging the resource base irreversibly before even noticing.

Effects on the resilience of the socio-ecological system without pig rituals:

Ability to buffer

Regarding the buffering effects against catastrophic events of the ritual, the changes in the world-systems have to be considered. The recent incident of a big Tsunami hitting the whole region on the 26 of December 2004 can give some hints of what has changed.

Important for recovery measures were following aspects:

- The Archipelago being part of the Indian state, and therefore responsibility of Indian institutions
- Connections and networks to people and institutions in other parts of the world.
- Functioning and structure of NGOs involved in rebuilding measures.

These aspects interplayed with each other. Through their international contacts the Nicobarese were in the position to exert pressure on the central Indian government to provide adequate help. Additionally fund raising activities through NGOs could raise money for rebuilding measures.

How far these events will result in a system similar to the old is questionable. It can be presumed that the events will rather speed up the transitional processes in the society and the whole system.

Anyway these buffering mechanisms are in work because the catastrophic event that struck the Nicobars was that big that it could not be ignored by the Indian central government and raised attention in the whole world.

If smaller events are considered affecting only a single household or community it is questionable if any help from these resources can be achieved. Here the networks and mechanisms created by the pig-festivals come in place. When the pig-festivals disappear other festivals in line with new believes (e.g. Easter, Christmas) or attached to special events (wedding) could replace these. Boyd (2001) describes that the Irakia Awa after eliminating the production of pigs started organizing sport clubs and sportive competitions with other villages. These activities partly substituted services/effects formally provided through the activities around the pig-rituals.

Social Learning

The information technology has made it easier to communicate between the islands and with other parts of the world. Additionally traveling between islands is easier with motorboats. If these changes in the quality and quantity of information and learning are more positive or negative or a bit of both cannot be answered here.

Future Steps and Outlook

This chapter wants to give a short outlook of how the computer model could be further developed and how this could fit into the bigger attempt to find sustainable development pathways for the Nicobar Archipelago.

Although the available data, which was originally collected to conduct energy and material flow analysis, was very useful, critical data are still missing. There are a lack of information about land-use practices, land cover, land cover change in recent years, traditional resource management, condition and flows in eco-systems. Additionally there is a need on more “soft data” on subjects like preferences, perceptions, needs, desires of the people. This data needs to be collected with participative methods to ensure high quality. The participative data collection should also be the first attempt to test the existing model with the people. Ideally this should reveal three results. (1) Debugging and testing of the model through comparing it with mind-models of local experts. (2) Define missing or dispensable parts. (3) Start a discussion process about what the goals of a desired sustainable development path could be.

Conclusion

Is it useful to make models?

As we are always making some mind-models of our world the question is more concerned with computable models. During the process of writing this work I had different feelings about the usefulness of modeling. In the end it has to be said that it is just a tool and it largely depends on what you make out of it. In line with Richerdson (2002) and others I believe that the process of modeling is what pinpoints the usefulness of a model. A lot of the questions sciences and public are concerned with today have the characteristic that they involve larger systems of different scales and qualities. To understand the involved systems often requires integrating soft with hard data. If humans are involved and management is an aim then an open dialogue with the involved humans, who at the same time may be in the center of interest for the scientists, is required. I believe that modeling has abilities to deal with these research situations. It has great abilities to integrate different types of data and it can be used to interact with other interested researchers, stakeholders or the public.

VIII.

References

Abel T. & J.R. Stepp. 2003. *A New Ecosystem Ecology for Anthropology*. Conservation Ecology 7(3):12 Available from the Internet: http://www.consecol.org/vol7/iss3/art12

Agrawal P.D. 2003. *Traditional Knowledge Among Tribes of the Andaman and Nicobar Archipelago*. Available from the Internet: http://www.infinityfoundation.com/mandala/t_es/t_es_agraw_islands.htm

Allen, T.F.H. & T.W. Hoekstra. 1992. *Toward a Unified Ecology*. New York, Columbia Press.

Amaral L.A.N. & J.M.Ottino. 2004. *Complex networks - augmenting the framework for the study of complex systems*. The European Physical Journal B 38, 147-162 (2004) Available from the Internet: (Url.: http://www.northwestern.edu/research/nico/what/

Ames, K. M., and H. D. G. Maschner. 1999. *Peoples of the Northwest Coast: their archeology and prehistory*. Thames and Hudson, London, UK. In: Trosper, R. L. 2003. Resilience in pre-contact Pacific Northwest social ecological systems. Conservation Ecology 7(3): 6. Available in the Internet: URL: http://www.consecol.org/vol7/iss3/art6

Anderies J.M. 1998. *Culture and human agro-ecosystem dynamics: the Tsembaga of New Guinea*. Journal for Theoretical Biology. 192(4):515-30

Andrew P.V. (ed*). Environment and Cultural Behavior*. *Ecological Studies in Cultural Anthropology*.1969. Austin & London. University of Texas Press.

Andrews H.V., & S. Vasumathi (eds.) 2002. *Sustainable Management of Protected Areas in the Andaman and Nicobar Islands*. New Delhi. ANET, IIPA, FFI.

Ayers 1996, *Limits to the Growth Paradigm*. Ecological Economics. 19:117-134.

Barbe P. 1847. *Notice of the Nicobar Islands*. Asiatic Societies Journal. In: Singh 2003

Bates, D.G. and S.B Lee, 1979.*The Myth of Population Regulation.* Evolutionary Biology and Social Behavior. N. Changon & W. Irons (eds.) North Scituate. Duxbury Press.

Bengtsson J., K. Engelhardt, P. Giller, S. Hobbie, D. Lawrence, J. Levine, M. Vilá & V. Wolters. 2002. *Slippin´ and Slidin´ Between the Scales: the Scaling Components of Biodiversity-Ecosystem Functioning Relations*. In: Loreau M., S. Naeem, P. Inchausti. (eds.) 2002. Biodiversity and Ecosystem Functioning. Synthesis and Perspectives. Oxford. Oxford University Press.

Benjamin G. 1976. *Austro-Asiatic Subgroupings and Prehistory in the Malay Peninsula*. In: Austro-Asiatic Studies 1.

Berkes F., Folke C. (eds) *Linking Social and Ecological Systems. Management Practices and Social Mechanisms for Building Resilience*. 1998. Cambridge. Cambridge University Press

Berkes, F., J. Colding, & C. Folke (eds). *Navigating Social and Ecological Systems. Building Resilience for Complexity and Change*. 2003. Cambridge. Cambridge University Press

Boekhorst I.J.A., C.K. Hemelrijk. 2000. *Nonlinear and Synthetic Models for Primate Societies*. In: Kohler T.A. & Gumerman G.J. (eds.). 2000. Dynamics in Human and Primate Societies. New York. Oxford University Press, Inc.

Boyd, D.J. 1985. *The production and Management of Pigs: Structural Options and Demographic Patterns in an Eastern Highlands Village.* Oceania 55(1): 27-49.

Boyd, D.J. 2001. *Life Without Pigs: Recent Subsistence Changes Among the Irakia Awa, Papua New Guinea*. Human Ecology, Vol.29, No 3,

Buchbinder 1977. *Nutritional Stress and Postcontact Decline Among the Maring of New Guinea*. In: Malnutrition, Behavior, and Social Organization. L.S. Greene, (ed.) New York. Academic Press. in Foin & Davis 1987

Carpenter S., W. Brock, P. Hanson. 1999. *Ecological and Social Dynamics in Simple Models of Ecosystem Management*. Conservation Ecology 3(2):4. Available from the internet: http://www.consecol.org/vol3/iss2/art4

Carpenter, S.R., W.A. Brock & D. Lubwig. 2002. *Collapse learning and Renewal*. In: Gunderson, L. H. & C. S. Holling (eds). Panarchy. Understanding Transformations in Human and Natural Systems. 2002. Washington, Island Press

Checkland, P., J. Scholes. 1990. *Soft-System Methodology in Action*. Chicester U.K., John Wiley. In: **Giampietro, M.** 2004. *Multi-Scale Integrated Analysis of Agroecosystems.* Boca Raton. CRC Press

Colding, J., and C. Folke. 1997. *The relations among threatened species, their protection, and taboos*. Conservation Ecology 1(1): 6. Available from the Internet. URL: http://www.consecol.org/vol1/iss1/art6

Cushman J.H., 1995. Ecosystem Level Consequences of Species Additions and Deletions on Islands. In: **Vitousek, P.M., L.L Loope, H. Andersen**, (eds.) 1995. *Islands: Biological Diversity and Ecosystem Function. - Ecological Studies ; 115*. New York. Springer

Davidson-Hunt I.J. & F. Berkes 2003. *Nature and Society Through the Lens of Resilience*. In: **Berkes F., Folke C**. (eds) *Linking Social and Ecological Systems. Management Practices and Social Mechanisms for Building Resilience*. 1998. Cambridge. Cambridge University Press

DeAngelis D.L., L. Donald. 1992. *Dynamics of nutrient cycling and food webs*. 1. ed. London Chapman and Hall

Diffloth G. 1975. *Austro-Asiatic Languages. In: The New Encyclopedia Britannica: Macropedia; Knowledge in Depth.* Chicago/London/Toronto/Geneva. Encyclopedia Britannica Inc. In: Singh 2003

Doran J.E. 2000. Trajectories to Complexity in Artificial Societies: Rationality, Believe, and Emotions. In: Kohler T.A. & Gumerman G.J. (eds.). 2000. Dynamics in Human and Primate Societies. New York. Oxford University Press, Inc.

Doran J.E. 2001a. *Intervening to Achieve Co-operative Ecosystem Management: Towards an Agent Based Model*. Journal for Artificial Societies and Social Simulation vol.4 no.2. Available from the Internet: http://www.soc.surrey.ac.uk/JASSS/4/2/4.html

Doran J.E. 2001b. *Multi-Agent Systems and Applications.* In: 9th ECCAI Advanced Course ACAI 2001 and Agent Link's 3rd European Agent Systems Summer School, EASSS 2001, Prague, Czech Republic, July 2-13, 2001, Selected Tutorial Papers Editors: M. Luck, V. Maík, O. tpánková, R. Trappl (Eds.): Chapter: p. 383 Online Date: May 2003

Ellen, R. 1982 *Environment, Subsistence, and System: the Ecology of Small Scale Social Formations*. Cambridge University Press, Cambridge.

FAO 2001. *Interim Report. FAO/WHO/UNU Expert Consultation Report on Human Energy Requirements.* Available in the internet: ftp://ftp.fao.org/docrep/fao/007/y5686e/y5686e00.pdf

Foin, T.C., Davis, W.G. 1987 *Equilibrium and Nonequilibrium Models in Ecological Anthropology: An Evaluation of "Stability" in Maring Ecosystems in New Guinea*. In: American Anthropologist Vol. 89, No. 1:9-31.

Forrester J. 1971. *World Dynamics*. Wright-Allen, Cambridge, Massachusetts

Franke G. (hrsg.) 1975. *Nutzpflanzen der Tropen und Subtropen. Band I.* Leipzig. S. Hirzel Verlag.

Fürer-Haimendorf C. 1985. *Tribal Populations and the Cultures of the Indian Sub-*

Continent. Leiden/Cologne.

Giampietro, M. 2004. *Multi-Scale Integrated Analysis of Agroecosystems.* Boca Raton. CRC Press

Gilbert N., S, Bankes. 2002. *Platforms and Methods for Agent-Based Modeling*. Proceedings of the National Academy of Science of the United States of America. Vol.99 suppl.3.

Giles J.R. 1999. *The Dynamics of Feral Pig Populations in Australia : Implications for Management*. In: Johnson C.N. (ed). *Feral Pigs: Pest Status and Prospects for Control. Proceedings of a Feral Pig Workshop*. James Cook University, Cairns, March 1999. Cooperative Research Center for Tropical Rainforest Ecology and Management.

Golson J. 1982. *The Ipomean Revolution Revisited: Society and Sweet Potato in the Upper Wahgi Valley*. In: New Guinea Highland Societies. A Strathern (ed.), Cambridge. Cambridge University Press.

Guilmoto C.Z. & S.I. Rajan 2002. *District Level Estimates of Fertility from India's 2001 Census*. South Indian Fertility Project. Available from the Internet: http://www.demographie.net/sifp/Output/EPW%20district%20Feb02.pdf

Gunderson, L. H. & C. S. Holling (eds). *Panarchy. Understanding Transformations in Human and Natural Systems*. 2002. Washington, Island Press

Haldane J.S. 1884 *Life and Mechanism.* In: Ökologie. Nentwig, Bacher, Beierkuhnlein, Brandl, Grabherr 2004. München. Elsevier.

Hall, C.A.S. (ed). *Quantifying Sustainable Development. The Future of Tropical Economies*. 2000. San Diego. Academic Press

Haustein H.D. 1989. *Automation und Innovation*. Berlin Akademie Verlag.

Holling C.S. 1992. *Cross-scale morphology, geometry, and Dynamics of Ecosystems.* Ecological Monographes. 62:447-502

Holling, C.S. 1986. *The Resilience of Terrestrial Ecosystems: Local Surprise and Global Change*. In: Sustainable Development of the Biosphere. W.C. Clark & R.E. Munn (eds.). Cambridge. Cambridge University Press.

Holling, C.S. 1992. *Cross-scale morphology, geometry and dynamics of ecosystems.* Ecological Monographs. 62 (4): 447 – 502

Ingold T. (ed). 1996. *Key Debates in Anthropology*.. London Routledge

Ingold, T. 2000. *The perception of the environment: essays on livelihood, dwelling and skill.* London. Routledge

Justin A. 1990. *The Nicobarese*. Calcutta. Anthropological Survey of India, the ASI Andaman and Nicobar Tribe Series.

Kellman M. & R. Tackaberry. 1997. *Tropical Environments the Functioning and Management of Tropical Ecosystems.* London/New York. Routledge. In Singh 2003.

Kohler T.A., G.J. Gumerman (eds.) 2000. *Dynamics in Human and Primate Societies. Agent-Based Modeling of Social and Spatial Processes*. Oxford. Oxford University Press, Inc.

Kohler T.A., J. Kresl, C. Van West, E. Carr & R.H. Wilshusen. 2000. *Be There Then: A Modeling Approach to Settlement Determinants and Spatial Efficiency Among Late Ancestral Pueblo Populations of Mesa Verde Region, U.S. Southwest*. In: Kohler T.A. & Gumerman G.J. (eds.). 2000. *Dynamics in Human and Primate Societies*. New York. Oxford University Press, Inc.

Lake W.M. 2000. *MAGICAL Computer Simulation of Mesolitithic Foraging*. In: Kohler T.A. & Gumerman G.J. (eds.). 2000. *Dynamics in Human and Primate Societies*. New York. Oxford University Press, Inc.

Lansing J.S. 2000. *Anti-Chaos, Common Property, and the emergence of Cooperation.* In: Kohler T.A. & Gumerman G.J. (eds.). 2000. Dynamics in Human and Primate Societies. New York. Oxford University Press, Inc.

Lees S.H & D.G. Bates. 1996. *The Ecology of Culmative Change*. In: Bates D.G. & S.H. Lees (ed). *Case Studies in Human Ecology*. 1996. New York. Plenum Press.

Lowman C. 1980. *Environment Society and Health: Ecological Bases of Community Growth and Decline in the Maring Region of Papua, New Guinea*. PhD. Dissertation, Anthropology Department, Columbia University. In: Foin and Davis 1987.

Lynam T. 1999. *Adaptive Analysis of Locally Complex Systems in a Globally Complex World*. Conservation Ecology 3(2):13. Available from the Internet: http://www.consecol.org/vol3/iss2/art13

Lynam T., F. Bousquet, C. Le Page, P. d´Aquino, O. Barreteau, F. Chinembiri & B. Mombeshora. 2002. *Adapting Science to Adaptive Managers: Spidergramms, Belief Models, and Multi-agent Systems Modeling*. Conservation Ecology 5(2):24. Available from the internet: Url: http://www.consecol.org/vol5/iss2/art24

MacArthur 1974. Pigs for the Ancestors: a Review Article. Oceania 45:87-123. In Foin and Davis 1987

Mauss, M. 1967 [1950]. *The gift: forms and functions of exchange in archaic societies.* W. W. Norton, New York, New York, USA. In: Trosper 2003

Mayer L. 2004 *Design principles of an economy with built-in sustainability.* Available from the internet: http://www.fdavidpeat.com/forums/funding/papers.htm

McGlade J. (ed). *Advanced Ecological Theory. Principles and Applications*. 1999. Oxford. Blackwell Science Ltd.

McNeary, S. A. 1994. *Where fire came down: social and economic life of the Nisga'a.* Wilp Wilxo'oskwhl Nisga'a, New Aiyansh, British Columbia, Canada. In Trosper 2003

Meadows D.L. & D.H. Meadows (eds). *Das Globale Gleichgewicht. Modellstudien zur Wachstums Krise*. 1973. Stuttgart. Deutsche Verlags-Anstalt.

Moran E.F. (ed) *The ecosystem Approach in Anthropology. From Concept to Practice*. 1990. Manchester. Manchester University Press.

Moran E.F. (ed). 1984. *The Ecosystem Concept in Anthropology*. Boulder, Colorado. West View Press

Moylan T.1973. *Disequilibrium in a New Guinea Local Ecosystem*. Mankind 9:61-70. IN Foin and Davis 1987.

Muetzelfeldt R. & J. Massheder. 2003. *The Simile Visual Modeling Environment*. Europe Journal of Agronomy 18 345-358.

Muetzelfeldt R. 2004. *Position Paper on Declarative Modeling in Ecological and Environmental Research*. Belgium. European Community.

Nao, Wenkam. 1990. *Foods of Hawaii and the Pacific Basin*. Research Extension Series; 070. Honolulu: HITAHR

Nisga'a Tribal Council. 1995a. *Nisga'a clan histories.* Wilp Wilxo'oskwhl Nisga'a. (Ayuukhl Nisga'a Study; II.) New Aiyansh, British Columbia, Canada. In: Trosper 2003.

Nutrient Requirements of Swine: **10th Revised Edition** (1998) Board on Agriculture Subcommittee on Swine Nutrition, Committee on Animal Nutrition, Committee on Animal Nutrition

Odling-Smee, F.J., K.N. Laland & M.W. Feldman, 2003.. *Niche Construction the Neglected Process in Evolution*. Princeton. Princeton University Press.

Odum, E.P. 1971. *Fundamentals of Ecology*. Philadelphia. Saunders.

Ortiz M., R. Bilham. 2003. *Source area and rupture parameters of the 31 December 1881 Mw = 7.9 Car Nicobar earthquake estimated from tsunamis recorded in the Bay of Bengal*. Journal of Geophysical Research, Vol. 108, No. B4, 2215,

Pahl-Wostl C. 2001. *A new Understanding of Human Agency, Working Paper –FIRM* (Freshwater Integrated Resource Management with Agents) –Project. Available from the Internet: http://firma.cfpm.org/Documents/JASSforum2.htm

Peoples J.G. 1982. *Individual or Group Advantage? A Reinterpretation of the Maring Ritual Cycle*. Current Anthropology 23:291-310

Rappaport R.A. 1984 [1968] *Pigs for the Ancestors. Ritual and Ecology of New Guinea People*. Yale. Yale University Press.

Richerdson K.A. 2002. *Methodological Implications of Complex System Approaches to Sociality: Some Further Remarks*. Journal for Artificial Societies and Social Simulation vol.5 no.2. Available from the Internet: http://jasss.soc.surrey.ac.uk/5/2/6.html

Roy P.S. (Project Director) 2003. *Biodiversity Characterisation at Landscape Level in Andaman & Nicobar Islands Using Satellite Remote Sensing and Geographic Information System*. Dehradun. Indian Institute of Remote Sensing & Department of Environment and Forest.

Sachchidananda 1972. *Planning, Development and Applied Anthropology in India*. Journal of Indian Anthropological Society 7, pp11-28. In: Singh 2003

Salisbury R.F. 1975. *Non-equilibrium Models of New Guinea Ecology*. Antropologica 17:127-147.

Sankaran, R. 1995. *The Nicobar Megapode and other Endemic Avifauna of the Nicobars Islands*. Coimbatore. Salim Ali Center for Ornithology & Natural History. In: Singh 2003

Schaber J. 1997. *FARMSIM: A Dynamic Model for the Simulation of Yields, Nutrient Cycling and Resource flows on Philippine small-scale farming systems*. Master Thesis at the: Institut für Umweltsystemforschung, Osnabrück.

Schandl H., C.M. Grühnbühl, H. Haberl, H. Weisz. 2002. *Handbook of Physical Accounting. Measuring Bio-Physical Dimensions of Socio-economic activities. MFA – EFA – HANPP*. Wien. Fedreal Ministry of Agriculture and Forestry, Environment and Water Management.

Schumpeter, J.A. 1950. *Capitalism, Socialism and Democracy*. New York. Harper & Row. In Gunderson 2002.

Shantzis, S.B., W.W.III Behrens. 1973. *Population Control Mechanisms in a Primitive Agricultural Society*. In: Meadows D.L. & D.H. Meadows (eds). Das Globale Gleichgewicht. Modellstudien zur Wachstums Krise. 1973. Stuttgart. Deutsche Verlags-Anstalt.

Singh J.S. 2003. *In the Sea of Influence. A World System Perspective of the Nicobar Islands*. Lund. Lund University

Singh J.S., C. Grühnbühel, H. Schandl & N. Schulz. 2001. *Social Metabolism and Labor in a Local Context: Changing Environmental Relations on Trinket Island*. Population and Environment.. Vol. 23(1):71-104.

Smith S. & E. Reeves (eds). 1989. *Human Systems Ecology. Studies in the Integration of Political Economy, Adaptation and Socionatural Regions*. Boulder, Colorado. Westview Press.

Spare P., S.C. Venema 1998. *Introduction to Tropical Fish Stock Assessment*. FAO Fisheries Technical Paper 306/1 Rev. 2 INTERNATIONAL YEAR OF THE OCEAN '98; DANIDA Food and Agriculture Organization of the United Nations. Rome. FAO – FIAT PANIS Available from the Internet:
http://www.fao.org/documents/show_cdr.asp?url_file=/docrep/W5449E/w5449e00.htm

Sterman J.D. 1991. *A Sceptic´s Guide to Computer Models*. In: Barney, G.O. et al (eds.), Managing a Nation: The Microcomputer Software Catalog. Boulder. West View Press.

Suttles, W. 1960. *Affinalties, subsistence, and prestige among the Coast Salish*. American Anthropologist **62**:296–305. In Trosper 2003

Suttles, W., editor. 1990c. *Northwest coast.* U. S. Government Printing Office, Washington, D. C., USA. (W. C. Sturtevant, general editor, *Handbook of North American Indians* 7.) In Trosper 2003

Suttles, W.. 1987a. *Coping with abundance: subsistence on the Northwest Coast*. Pages 45–63 *in* W. Suttles. Coast Salish essays. University of Washington Press, Seattle, Washington, USA. In Trosper 2003

Syamchaudhuri, N.K. 1977. *The Social Structure of Car Nicobars Islanders: An Ethnic Study of Cognition*. Calcutta: Anthropological Survey of India. In: Singh 2003

Terna P. 1998. *Simulation Tools for Social Scientists: Building Agent Based Models with SWARM*. Journal of Artificial Societies and Social Simulation vol.1, no.2. Available from the internet: http://www.soc.surrey.ac.uk/JASSS/1/2/4.html

Trosper, R. L. 2003. *Resilience in pre-contact Pacific Northwest social ecological systems.* Conservation Ecology 7(3): 6. Available in the Internet: URL: http://www.consecol.org/vol7/iss3/art6

Vitousek, P.M. & T.L. Benning. *Ecosystem and Landscape Diversity: Islands as Model Systems.* In: **Vitousek, P.M., L.L Loope, H. Andersen**, (eds.) 1995. *Islands: Biological Diversity and Ecosystem Function. – Ecological Studies ; 115*. New York. Springer

Walker B., S. Carpenter, J. Anderies, N. Abel, G.S. Cumming, M. Janssen, L. Lebel, J. Norberg, G.D. Peterson & R. Pritchard. 2002. *Resilience Management in Socio-ecological Systems: a Working Hypothesis for a Participatory Working Approach*. Conservation Ecology 6(1):14 Available from the Internet: http://www.consecol.org/vol6/iss1/art14

Walters C. 1997. *Challenges in Adaptive Management of Riparian and Coastal Ecosystems.* Conservation Ecology 1(2):1 Available from the internet. Url: http://www.consecol.org/vol1/iss2/art1

Weiss, G. (ed.) 1999. *Multiagent systems: a modern approach to distributed artificial intelligence*. Cambridge, Mass. MIT Press

Westley, F. 1995. *Sustainability and the Cooperation.* Journal of Management Inquiry. 5 (2):104 – 119. In: Gunderson et al 2002.

World Commission on Environment and Development. 1987. *Our Common Future*. New York. Oxford University Press.

Internet Resources

Modeling Tutorial & Resources:

Resilience Alliance: http://resalliance.org/

Tutorial on different modeling techniques: http://www.schatten.info/info/index.html#it7

Journal for Artificial Societies and Social Simulation: http://jasss.soc.surrey.ac.uk/JASSS.html

Introduction to System Dynamics: http://www.systemdynamics.org/DL-IntroSysDyn/

Modeling Packages and Software:

ASCAPE: http://www.brook.edu/es/dynamics/models/ascape

CORMAS: http://cormas.cirad.fr/indexeng.htm

REPAST: http://repast.sourceforge.net/

SDML: http://www.cpm.mmu.ac.uk/sdml

SIMILE: http://www.simulistics.com/

SWARM: http://www.swarm.org

VENSIM: www.vensim.com

STELLA: http://www.iseesystems.com/

Appendix I

Basic Modeling Approaches

Cellular Automata

Cellular Automata (CA) are discrete dynamical systems and are often described as a counterpart to partial differential equations, which have the capability to describe continuous dynamical systems. The meaning of discrete is, that space, time and properties of the automaton can have only a finite, countable number of states. The basic idea is not to try to describe a complex system from "above" - to describe it using difficult equations, but simulating this system by interaction of cells following easy rules.

In other words: Not to describe a complex system with complex equations, but let the complexity emerge by interaction of simple individuals following simple rules. Hence the essential properties of a CA are

a regular n-dimensional lattice (n is in most cases of one or two dimensions), where each cell of this lattice has a discrete state,

a dynamical behavior, described by so called rules. These rules describe the state of a cell for the next time step, depending on the states of the cells in the neighbourhood of the cell.

(Alexander Schatten 2004, url: http://www.schatten.info/info/index.html#it7)

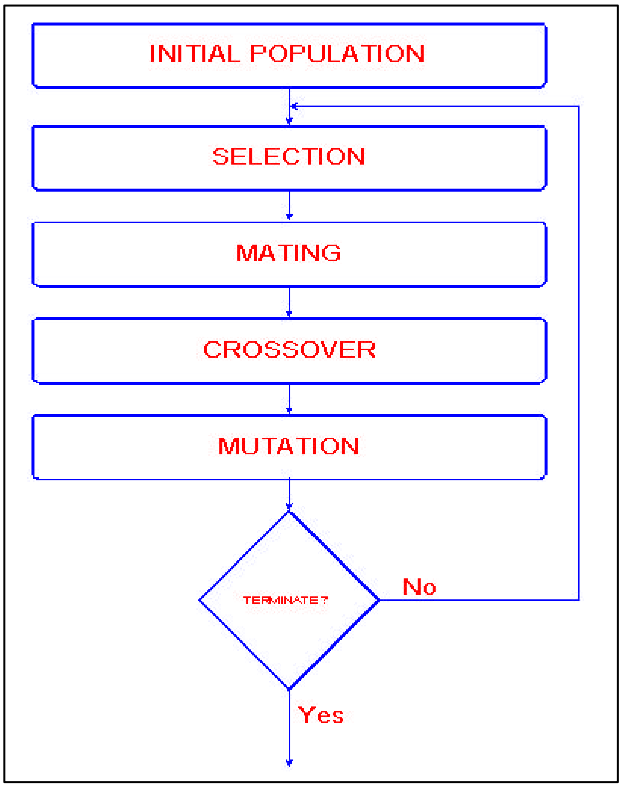
Genetic Algorithm (GA)

The idea behind GA's is to extract optimization strategies nature uses and transform them for application in mathematical optimization theory to find the global optimum in a defined phase space.

The three fundamental principles are

- Selection
- Mating / Crossover
- Mutation

In the first step a set of the best available solutions is selected. The remaining sections are recombined with each other. The "hope" behind this part of the algorithm is, that "good" sections of two parents will be recombined to yet better fitting children. Now there appears a problem. If only repeating these steps, no new area would be explored. The third step - the Mutation - ensures the necessary accidental effects. One can imagine the new population being mixed up a little bit to bring some new information into this set of genes. Whereas in biology a gene is described as a macro-molecule with four different bases to code the genetic information, a gene in genetic algorithms is usually defined as a bit-string (a sequence of b 1´s and 0´s).



It is not possible to project results obtained from GA-performance or different qualities of algorithm types to biological/genetic procedures. The aim of GA´s is not to model genetics or biological evolution. Consider GA´s as a kind of bionic in trying to extract successful natural strategies for mathematical problems.

(Alexander Schatten, 2004; http://www.schatten.info/info/index.html#it7)

Figure 59: The steps of a genetic algorithm.

(Artificial) Neural Networks

An Artificial Neural Network (ANN) is an information-processing paradigm that is inspired by the way biological nervous systems, such as the brain, process information. The key element of this paradigm is the novel structure of the information processing system. It is composed of a large number of highly interconnected processing elements (neurons) working in unison to solve specific problems. ANNs, like people, learn by example. An ANN is configured for a specific application, such as pattern recognition or data classification, through a learning process. Learning in biological systems involves adjustments to the synaptic connections that exist between the neurons. This is true of ANNs as well.

(url: http://neuralnetworks.ai-depot.com/Tutorials.html)

Appendix II

Central Questions and Resulting Spidergramms for Trinket

In the following the original questions used by Simron Singh on a visit to the Nicobars in 2004 and the resulting spidergramms are presented. Due to time shortage only two spidergramms could be conducted, one with a female field assistance and one with an old knowledgeable man (not from Trinket.).

Central Question:

What does an average household in xxx-village need to live?

Second set of questions:

Start with component with highest scores:

Food / Cash crops (e.g. fruits, fish, meat)

If it is a collective term (e.g. forest products, fruits, tubers…)

=> What fruits? What tubers?

If it is already specific enough

=> What is needed to gain this foodstuff? Respectively: What does ….(livestock) need?

=> *What factors influence the abundance?*

Ecosystems (e.g. forest, grassland)

=> If reasonable: What types of ….are on Trinket?

=> What can be found there?

Money

=> From where do you get money?

=> What can you buy with?

Textbox 3: Outline of questions for producing spidergramms on Trinket.

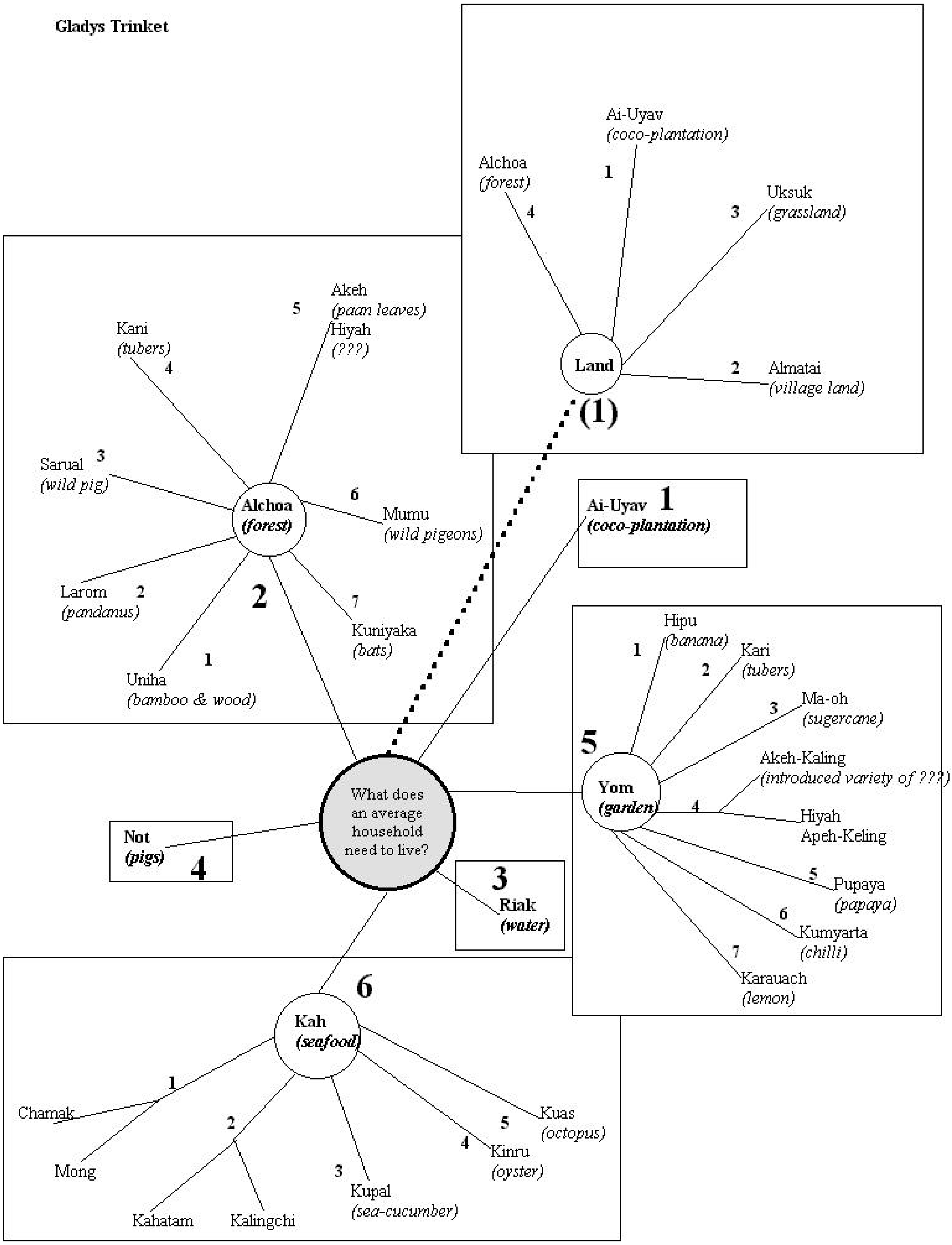


Figure 60: Spidergramm with the central question: “What does an average household need to live?” The numbers next to the legs show the ranking (1 == most important) the dotted line to land indicates that this leg was not counted in the ranking due to redundancy of information.

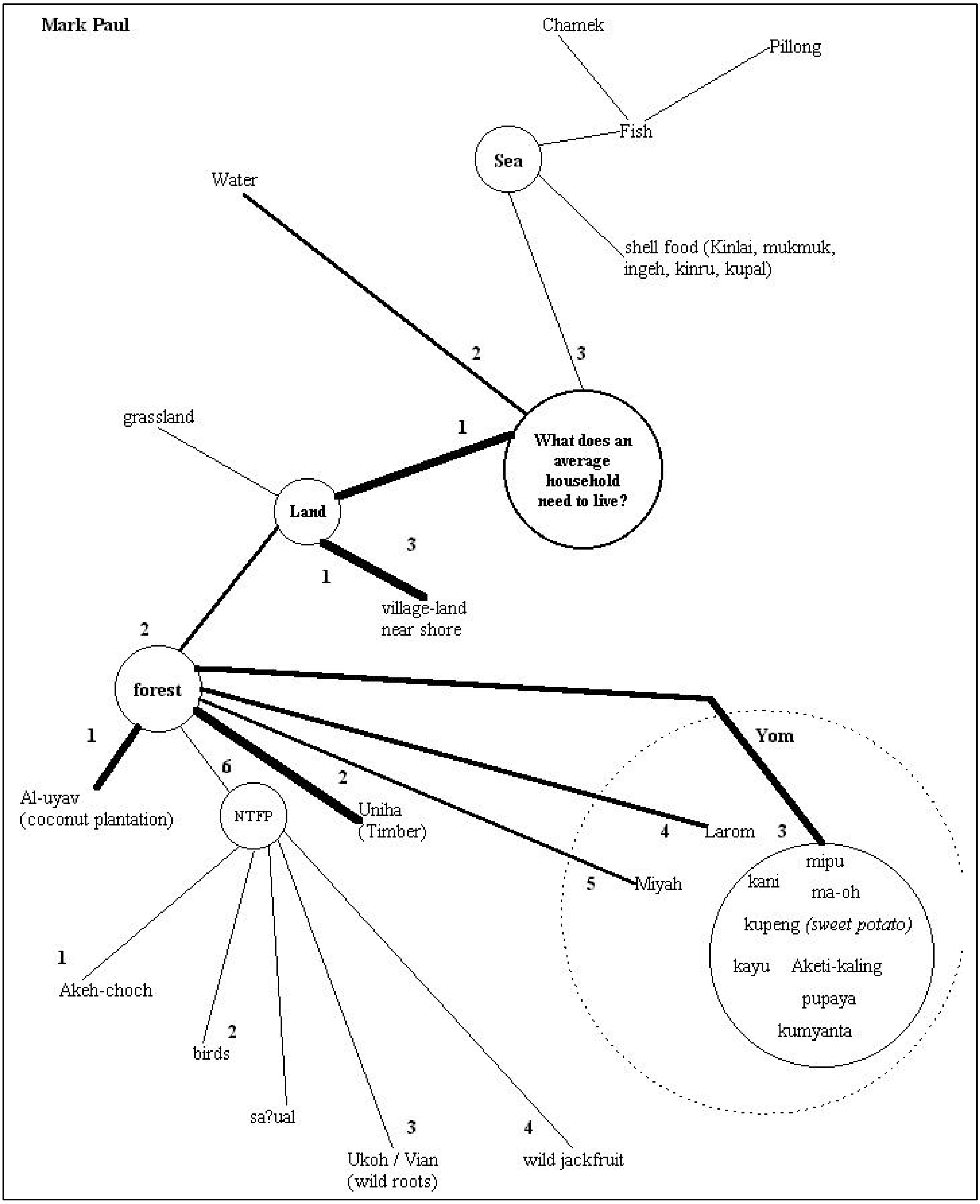


Figure 61: Spidergramm with the central question: "What does an average household need to live?" The numbers next to the legs show the ranking (1 == most important) the dotted line to land indicates that this leg was not counted in the ranking due to redundancy of information

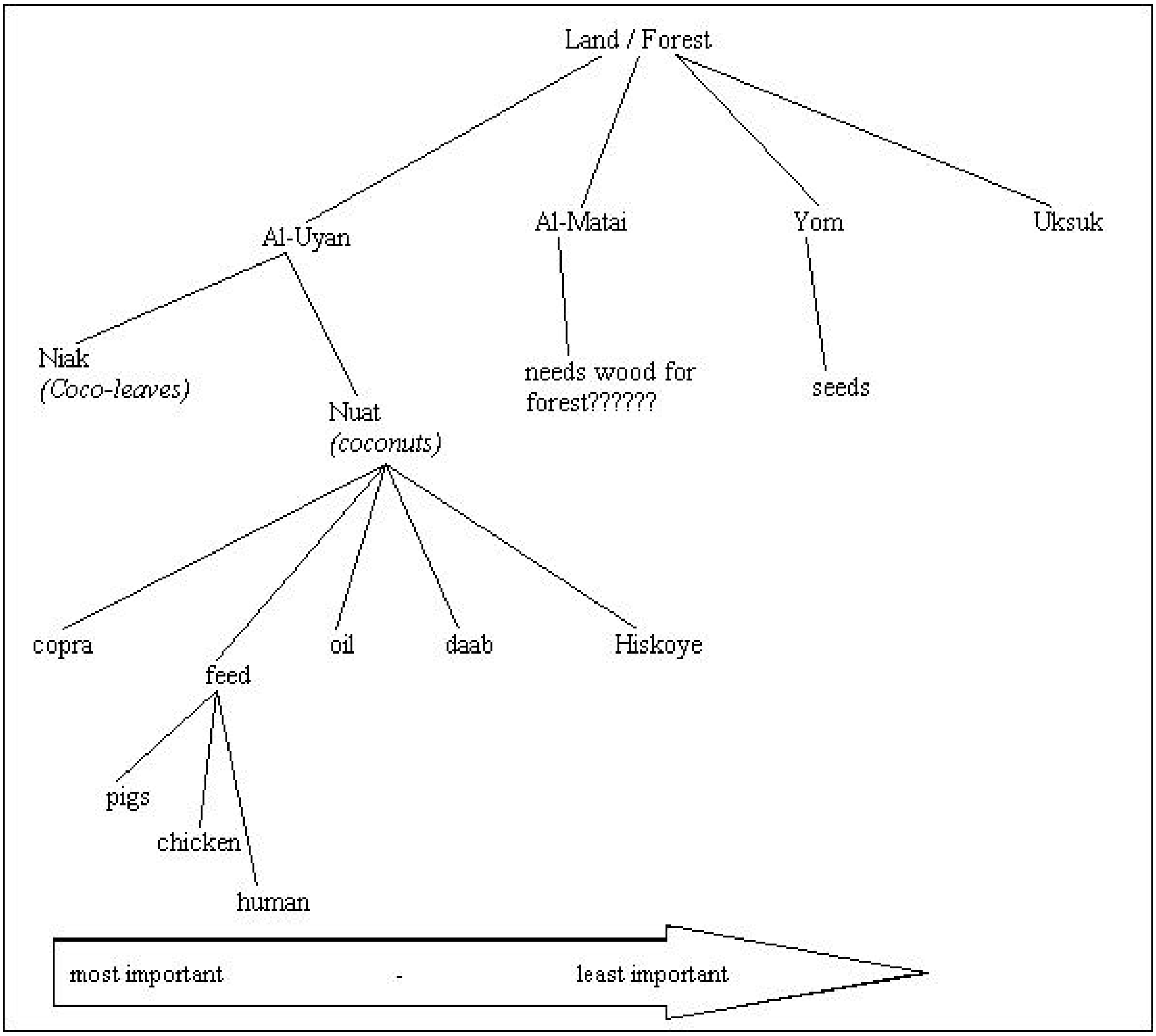


Figure 62: Spidergramm showing types of Land (Native terminology) and resources extracted from the different land-types ranked after there importance as perceived by the informant.

Appendix III

The Basic Components of SIMILE

A particular strength of SIMILE is to enable a combination of both “modeling worlds” in a very easy way. In the following the basic symbols used in SIMLE for system dynamics and individual based modeling are described.

System Dynamic Elements

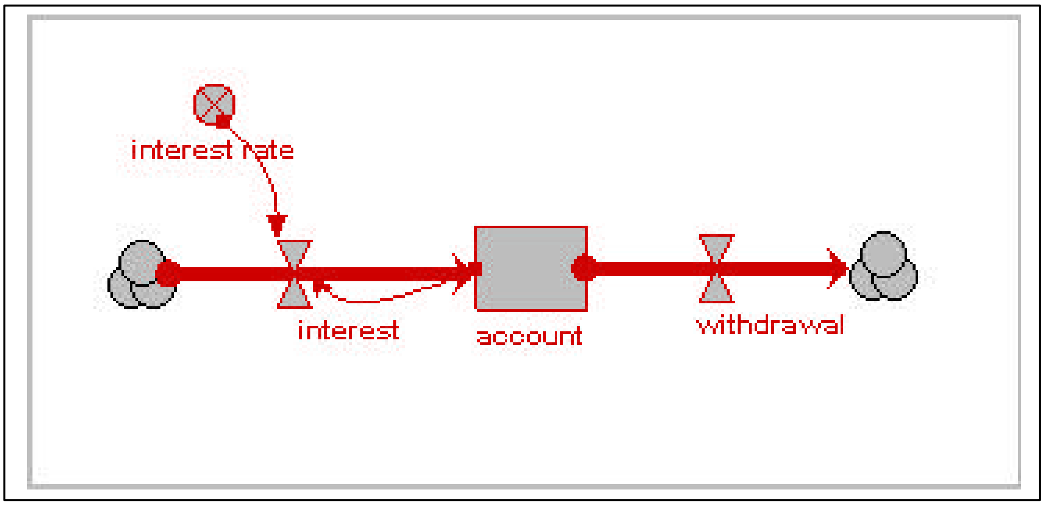


Figure 63: A simple model in SIMILE showing a model of a bank account. (Simile tutorial; url: http://simulistics.com/tutorials/index.htm)

The symbols used in SIMILE are similar to the ones used in other visual modeling environments (e.g. STELLA, Vensim). The stocks or compartments are shown as boxes (account in Figure 63).

“ We can think of a compartment as representing the amount of some substance, hence the use of other terms in the System Dynamics community, such as stock or level. Mathematically, a compartment represents a state variable whose behavior is defined by a differential equation. A compartment requires an initial value, which is usually a numeric constant, but can be calculated from other constants.” (SIMILE Homepage url.: http://simulistics.com/tour/elements.htm)

The outflows are thick arrows with a valve-symbol (interest, withdrawal). They can either connect different stocks or departure from some “sources” and lead to some sinks (symbolized through the three circles).

“ A flow represents a process causing an increase or decrease in the amount of substance in a compartment. It is thus represented visually by an arrow pointing into or out of a compartment, possibly connecting two compartments. Mathematically, a flow is an additive term in a differential equation for the associated compartment (state variable). The value assigned to a flow can be a constant or a function of other quantities in the model.” (SIMILE Homepage url.: http://simulistics.com/tour/elements.htm)

The variables are smaller circles (interest rate).

“ A variable represents any quantity whose value is either a constant or calculated as a function of other quantities in the model. In modeling terms, a Simile variable can thus represent a parameter, an intermediate variable, an output variable, or an exogenous variable.” (SIMILE Homepage url.: http://simulistics.com/tour/elements.htm)

The influences are indicated by thin arrows. An influence arrow represents the fact that one quantity is used to calculate another.

Simile provides the possibility to define variables as sliders, so that their value can be changed while running the model (Figure 64:The input sliders in the Run-time environment of Simile The “Input sliders” as appearing in the run-time environment. The “reproduction rate” (left) can be set for every level. Copra and Rice Price can be set but are the same on all levels.

Figure 64:The input sliders in the Run-time environment of Simile The “Input sliders” as appearing in the run-time environment. The “reproduction rate” (left) can be set for every level. Copra and Rice Price can be set but are the same on all levels.

Individual Based Modeling Elements

System Dynamics modeling generally does not represent individuals in a population. All the individuals are lumped together and represented by a single value e.g.: the number of individuals in a population, the total weight/energy content of all the individuals. This approach does not allow accounting for interactions between individuals or between individuals and their environment. If the reaction or action of individual agents is important every single agent has to be represented. (An individual agent does not have to be a single person, it can also be a family-unit or household or community.) It is also sometimes much easier to construct individual based models (IBMs) as complex patterns can arise out of simple interactions of the individuals. (q.v.: Cellular Automata pxx).

The basic tool used in SIMILE to construct Individual Based Models is the sub-model tool. Two kinds of IBMs can be constructed: (1) a fixed membership model (e.g. used for spatial modeling) with a fixed number of members (individuals). (2) a population submodel with a dynamically changing number of individuals (Figure 65).

The creation of a population submodel is straightforward. First the inner structure of the individuals is constructed. In the example given below it is a simple system dynamics model (= some differential equations) determining the growth of a single tree. This structure is then encapsulated by a population-submodel. There are four symbols which can be used to determine important factors/conditions of the population submodel: (1) the creation symbol (initial in fig Figure 65) – it determines the starting size of the population. (2) the immigration symbol (recruitment in Figure 65) determines the number of individuals immigrating into the population. (3) the loss symbol (death in Figure 65) determines under which conditions a individual dies. (4) birth symbol (not included in Figure 65– looks like an egg) determines the conditions under which a new member is "born".

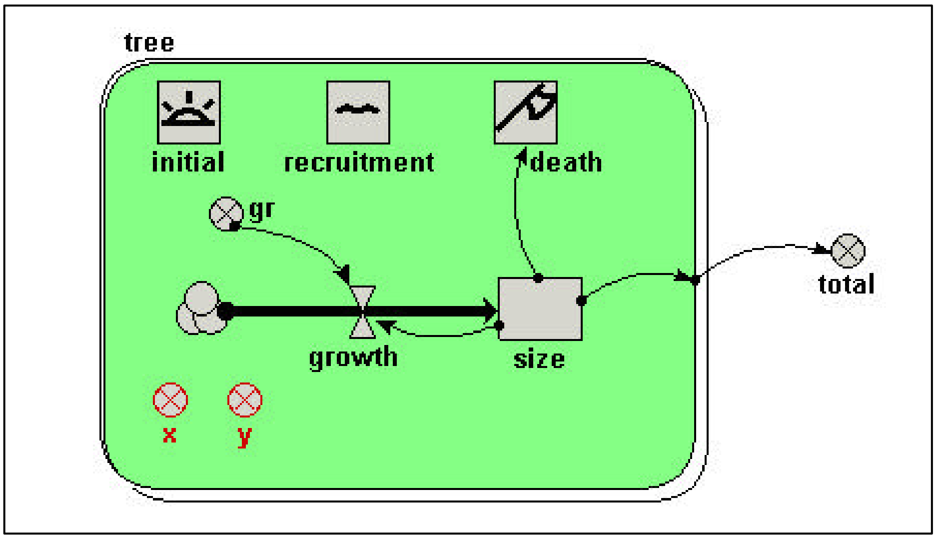


Figure 65: A simple individual based tree growth model (Simile tutorial; url: http://simulistics.com/tutorials/index.htm). The variables "x" and "y" are used for visualizing the trees in space.

These symbols can be influenced by other variables. In the above model for example the death of a tree is triggered by its size. The visual signs of a population submodel are that the submodel boundary now has an extra line on the top-and-left, and on the bottom-and-right. To create a population of "different" individual trees the variable "gr" appointing the growth rate can be multiplied by some random value. The variable "total" calculates the total size of all trees in the population. Variables calculating aggregated information always lie outside the submodel boundaries.

Appendix IV

The entire equations of the Trinket-Island-Model (TIM).

The following list shows the equations as used in the Trinket Island Model.

Equations in Desktop

Variable health
health = 1

Equations in human population

Creation cr1
cr1 = 400

Loss loss1
loss1 = if rand_var(0,1000)<=m then 1 elseif m== -1 then 1 else 0

Reproduction rep1
rep1 = if sex==1 then 0 elseif age<=16 then 0 elseif age>40 then 0 else reproduction_rate
Where:
reproduction_rate=../reproduction rate

Variable ER : energy requierment in kcal
ER = if age<1 then 650 else table([int(age),sex])
Comments:
energy requierement the amount of food energy needed to balance energy expenditure in order to maintane body size, body consumption and a level of necessary and desirable physical activity, and to allow optimal growth and development of children, deposition of tissues during pregnancy, [...], consistent with long term good health.

Variable Education
Education = 0

Variable Money Need
Money Need = Consumer____Goods+Education
Where:
Consumer____Goods=Consumer Goods

Variable age
age = random____age+(time(1)-init_time(1))
Where:
random____age=random age

Variable index
index = index(1)

Variable life expectancy
life expectancy = table([int(time),sex])+rand(-2,8)

Variable m

m = if age<=6 and nutrition_status==1 then 29*health elseif age<=6 and nutrition_status== -1 then 70*health elseif age<life_expectancy and nutrition_status==1 then 5.2*health elseif age<life_expectancy and nutrition_status== -1 then 20*health else-1

Where:

life_expectancy=life expectancy
nutrition_status=nutrition status
health=../../health

Variable nutrition status

nutrition status = if last(Nutrition_Bilanz)+last(last(Nutrition_Bilanz))+last(last(last(Nutrition_Bilanz)))+last(last(last(last(Nutrition_Bilanz))))+last(last(last(last(last(Nutrition_Bilanz)))))+last(last(last(last(last(last(Nutrition_Bilanz))))))+last(last(last(last(last(last(last(Nutrition_Bilanz)))))))<0 then-1 else 1

Where:

Nutrition_Bilanz=../Nutrition Bilanz

Variable random age

random age = if index<=floor(400*0.21)then rand(0,6)elseif index>floor(400*0.21)and index<=400 then rand(7,60)else 0

Variable sex : 1== male 2 == female

sex = if rand(0,1)<=0.5 then 2 else 1

Comments:

conventional female is == 0 but the table tool of simile does not read 0

Variable time

time = time(1)

Equations in Reef

Compartment fish

Initial value = 150000
Rate of change = + hatching - catch - death

Flow catch

catch = total_fish______catch*effect_of__density_on_catch

Where:

total_fish______catch=total fish catch
effect_of__density_on_catch= effect of density on catch

Flow death

death = m_fish*fish

Where:

m_fish=m fish

Flow hatching

hatching = hatch_fraction*fish+fish*immigration_F

Where:

immigration_F=immigration F
hatch_fraction=hatch fraction

Variable effect of density on catch

effect of density on catch = graph(density)

Variable fraction Trinket fish

fraction Trinket fish = Fish_Demand______Trinket/outsiders

Where:

Fish_Demand______Trinket=Fish Demand Trinket

Variable Trinket Fish catch kg

Trinket Fish catch kg = total_catch*fraction_Trinket_fish

Where:
total_catch=total catch
fraction_Trinket_fish= fraction Trinket fish

Variable Fish Demand Trinket
Fish Demand Trinket = fish_kcal_in__fish_kg
Where:
fish_kcal_in__fish_kg=fish kcal in fish kg

Variable Fish per capita kg
Fish per capita kg = Trinket_Fish_catch_kg/total_population
Where:
Trinket_Fish_catch_kg= Trinket Fish catch kg
total_population=../total population

Variable MangroveArea
MangroveArea = 1

Variable density
density = fish/fishing_area
Where:
fishing_area=fishing area

Variable fish kcal in fish kg
fish kcal in fish kg = Fish_Demand1kcal/rand_var(1800,2200)
Where:
Fish_Demand1kcal=../endosomatic metabolism/Nutritional Situation I/Fish Demand1kcal
Comments:
summs up values of kcal for all villages and converts them to kg

Variable fishing area
fishing area = 100

Variable hatch fraction
hatch fraction = MangroveArea*0.5

Variable immigration F
immigration F = graph(fish)

Variable m fish
m fish = graph(fish)

Variable scen1 fish stock
scen1 fish stock = if index(1)==1 then fish else 0

Variable scen2 fish stock
scen2 fish stock = if index(1)==2 then fish else 0

Variable scen3 fish stock
scen3 fish stock = if index(1)==3 then fish else 0

Variable scen4 fishstock
scen4 fishstock = if index(1)==4 then fish else 0

Variable total catch
total catch = catch

Variable total fish catch
total fish catch = outsiders+Fish_Demand______Trinket
Where:
Fish_Demand______Trinket=Fish Demand Trinket

Equations in sub-age

Variable class1
class1 = if age<=6 then 1 else 0
Where:
age=../age

Variable class2
class2 = if age>6 and age<=15 then 1 else 0
Where:
age=../age

Variable class3
class3 = if age>15 and age<=50 then 1 else 0
Where:
age=../age

Variable class4
class4 = if age>50 then 1 else 0
Where:
age=../age

Equations in Socio-ecological System

Variable ER total
ER total = sum({ER})
Where:
{ER}=human population/ER

Variable Nutrition Bilanz
Nutrition Bilanz = total_kcal__consumption-ER__total
Where:
total_kcal__consumption=endosomatic metabolism/ total kcal consumption
ER__total=ER total

Variable bilanz 1
bilanz 1 = if index(1)==1 then Nutrition_Bilanz else 0
Where:
Nutrition_Bilanz=Nutrition Bilanz

Variable bilanz 2
bilanz 2 = if index(1)==2 then Nutrition_Bilanz else 0
Where:
Nutrition_Bilanz=Nutrition Bilanz

Variable bilanz 3
bilanz 3 = if index(1)==3 then Nutrition_Bilanz else 0
Where:
Nutrition_Bilanz=Nutrition Bilanz

Variable bilanz 4
bilanz 4 = if index(1)==4 then Nutrition_Bilanz else 0
Where:
Nutrition_Bilanz=Nutrition Bilanz

Variable minimum pig pop
minimum pig pop = total_population*pig_importence_factor
Where:
pig_importence_factor=pig importence factor
total_population=total population

Variable pig meat per capita
pig meat per capita = total_pig_meat/total_population

Where:
total_pig_meat=total pig meat
total_population=total population

Variable scen1 class1
scen1 class1 = if index(1)==1 then sum({class1})else 0
Where:
{class1}=human population/sub-age/class1

Variable scen1 class2
scen1 class2 = if index(1)==1 then sum({class2})else 0
Where:
{class2}=human population/sub-age/class2

Variable scen1 class3
scen1 class3 = if index(1)==1 then sum({class3})else 0
Where:
{class3}=human population/sub-age/class3

Variable scen1 class4
scen1 class4 = if index(1)==1 then sum({class4})else 0
Where:
{class4}=human population/sub-age/class4

Variable scen1 slaughPigs
scen1 slaughPigs = if index(1)==1 then slaughtered_pigs else 0
Where:
slaughtered_pigs=slaughtered pigs

Variable scen2 class1
scen2 class1 = if index(1)==2 then sum({class1})else 0
Where:
{class1}=human population/sub-age/class1

Variable scen2 class2
scen2 class2 = if index(1)==2 then sum({class2})else 0
Where:
{class2}=human population/sub-age/class2

Variable scen2 class3
scen2 class3 = if index(1)==2 then sum({class3})else 0
Where:
{class3}=human population/sub-age/class3

Variable scen2 class4
scen2 class4 = if index(1)==2 then sum({class4})else 0
Where:
{class4}=human population/sub-age/class4

Variable scen2 slaughPigs
scen2 slaughPigs = if index(1)==2 then slaughtered_pigs else 0
Where:
slaughtered_pigs=slaughtered pigs

Variable scen3 class1
scen3 class1 = if index(1)==3 then sum({class1})else 0
Where:
{class1}=human population/sub-age/class1

Variable scen3 class2
scen3 class2 = if index(1)==3 then sum({class2})else 0
Where:

{class2}=human population/sub-age/class2

Variable scen3 class3
scen3 class3 = if index(1)==3 then sum({class3})else 0
Where:
{class3}=human population/sub-age/class3

Variable scen3 class4
scen3 class4 = if index(1)==3 then sum({class4})else 0
Where:
{class4}=human population/sub-age/class4

Variable scen3 slaughPigs
scen3 slaughPigs = if index(1)==3 then slaughtered_pigs else 0
Where:
slaughtered_pigs=slaughtered pigs

Variable scen4 class1
scen4 class1 = if index(1)==4 then sum({class1})else 0
Where:
{class1}=human population/sub-age/class1

Variable scen4 class2
scen4 class2 = if index(1)==4 then sum({class2})else 0
Where:
{class2}=human population/sub-age/class2

Variable scen4 class3
scen4 class3 = if index(1)==4 then sum({class3})else 0
Where:
{class3}=human population/sub-age/class3

Variable scen4 class4
scen4 class4 = if index(1)==4 then sum({class4})else 0
Where:
{class4}=human population/sub-age/class4

Variable scen4 slaughPigs
scen4 slaughPigs = if index(1)==4 then slaughtered_pigs else 0
Where:
slaughtered_pigs=slaughtered pigs

Variable scenarios
scenarios = index(1)

Variable slau_pig_per capita
slau_pig_per capita = slaughtered_pigs/total_population
Where:
total_population=total population
slaughtered_pigs=slaughtered pigs

Variable slaughtered pigs
slaughtered pigs = sum({slaughterVar})
Where:
{slaughterVar}=pigsystem/pig/slaughterVar

Variable sum IndMoney need
sum IndMoney need = sum({Money_Need})+money_spend_pigs+technical_demand
Where:
{Money_Need}=human population/Money Need
technical_demand=cash economy/technical demand
money_spend_pigs=pigsystem/money spend pigs

Variable   total pig meat
total pig meat = sum({pigmeat1})
Where:
{pigmeat1}=pigsystem/pig/pigmeat1

Variable   total population
total population = count({time})
Where:
{time}=human population/time

Equations in sub1

Variable   nutri 1
nutri 1 = nutrition_status*scen1
Where:
nutrition_status=../nutrition status

Variable   nutri 2
nutri 2 = nutrition_status*scen2
Where:
nutrition_status=../nutrition status

Variable   nutri 3
nutri 3 = nutrition_status*scen3
Where:
nutrition_status=../nutrition status

Variable   nutri 4
nutri 4 = nutrition_status*scen4
Where:
nutrition_status=../nutrition status

Variable   scen1
scen1 = if scenarios==1 then 1 else 0
Where:
scenarios=../../scenarios

Variable   scen2
scen2 = if scenarios==2 then 1 else 0
Where:
scenarios=../../scenarios

Variable   scen3
scen3 = if scenarios==3 then 1 else 0
Where:
scenarios=../../scenarios

Variable   scen4
scen4 = if scenarios==4 then 1 else 0
Where:
scenarios=../../scenarios

Equations in Nutritional Situation I

Variable   CN DemandH1kcal
CN DemandH1kcal = ER__total*0.13
Where:
ER__total=../../ER total

Variable Fish Demand1kcal
Fish Demand1kcal = ER__total*0.14
Where:
ER__total=../../ER total

Variable NTFP Demand1kcal
NTFP Demand1kcal = ER__total*0.09
Where:
ER__total=../../ER total

Variable Rice Demand1kcal
Rice Demand1kcal = ER__total*0.64
Where:
ER__total=../../ER total

Equations in Coconut Plantation

Compartment cocconuts
Initial value = 0
Rate of change = + CN + prduction - CN - outflow - CNtoPigs1 - CNtocopra2

Flow CN outflow
CN outflow = cocconuts

Variable CN account
CN account = cocconuts -total_demand____cocconut
Where:
total_demand____cocconut=total demand cocconut

Variable con1
con1 = CN_DemandH1kcal/4.2/0.3/rand_var(900,2000)
Where:
CN_DemandH1kcal=../endosomatic metabolism/Nutritional Situation I/CN DemandH1kcal

Variable demand cocconuts
demand cocconuts = if CN_account>1 then 0 else-(CN_account/28)
Where:
CN_account=CN account

Variable new palms planting
new palms planting = if floor(demand__cocconuts)>300 then 300 else floor(demand__cocconuts)
Where:
demand__cocconuts=demand cocconuts

Variable pest
pest = 1

Variable space
space = max_area-area_under__cocconuts
Where:
max_area=max area
area_under__cocconuts=CN indicators/area under cocconuts

Variable substitution
substitution = if 9465-total_number_of_cocconut__palms>0 then min(94565-
total_number_of_cocconut__palms,300)else 0
Where:
total_number_of_cocconut__palms=CN indicators/total number of cocconut palms

Variable total demand cocconut
total demand cocconut = con1+Copra_Demand_in_CNtot+CNtot_demandPig/0.3/rand_var(900,2000)

Where:

CNtot_demandPig=../pigsystem/CNtot demandPig

Copra_Demand_in_CNtot=../cash economy/Copra Demand in CNtot

Equations in cocconut palms

Creation palms

palms = 9500

Flow CN prduction

CN prduction = floor(graph(CNage))*dt(1)*2*pest

Where:

pest=../pest

Immigration planted CN

planted CN = if space>0 then new_palms__planting else 0

Where:

new_palms__planting=../new palms planting

space=../space

Immigration sub

sub = if space>0 then substitution else 0

Where:

substitution=../substitution

space=../space

Loss LossCN

LossCN = CNage>age_of_death or rand_var(0,500)>499

Where:

age_of_death=age of death

Reproduction repCN

repCN = 0.01

Variable CNage

CNage = CNrandom_age+(time(1)-init_time(1))

Where:

CNrandom_age=CNrandom age

Variable CNage class

CNage class = if CNage>8 and CNage<80 then 1 else 0

Variable CNindex

CNindex = index(1)

Variable CNrandom age

CNrandom age = if CNindex<=9465 then rand(0,120)else 0

Variable age of death

age of death = rand(100,120)*360

Equations in Harvest

Compartment ntfp

Initial value = 6000000000

Rate of change = + ntfp + In - pig - scavenging - ntfp - out

Compartment pigmeat

Initial value = 0

Rate of change = + pigIn - pigOut

Compartment rice etc
Initial value = 0
Rate of change = + rice + In - rice - Out

Flow ntfp In
ntfp In = fl_che_wald*1300
Where:
fl_che_wald=fläche wald

Flow ntfp out
ntfp out = fl_che_wald*1300
Where:
fl_che_wald=fläche wald

Flow pig scavenging
pig scavenging = if ntfp>=NTFPdemandPig_kcal then NTFPdemandPig_kcal else ntfp/1.5
Where:
NTFPdemandPig_kcal=../../pigsystem/NTFPdemandPig kcal

Flow pigIn
pigIn = total_pig_meat
Where:
total_pig_meat=../../total pig meat

Flow pigOut
pigOut = pigmeat

Flow rice In
rice In = money_for_rice*rice_price*dt(1)
Where:
money_for_rice=../../cash economy/money for rice
rice_price=../../../rice price

Flow rice Out
rice Out = rice_etc*store
Where:
rice_etc=rice etc

Variable PigNTFPconsump kcal
PigNTFPconsump kcal = pig_scavenging*0.1
Where:
pig_scavenging=pig scavenging

Variable kcal fish
kcal fish = Trinket_Fish_catch_kg*rand_var(1800,2200)
Where:
Trinket_Fish_catch_kg=../../Reef/ Trinket Fish catch kg

Variable kcal ntfp
kcal ntfp = ntfp*rand_var(500,800)

Variable kcal pigmeat
kcal pigmeat = pigmeat*2990*distribution_pigmeat
Where:
distribution_pigmeat=distribution pigmeat

Variable kcal rice
kcal rice = rice_etc*1600
Where:
rice_etc=rice etc

Variable scen1NTFP
scen1NTFP = if index(1)==1 then ntfp else 0

Variable scen2NTFP
scen2NTFP = if index(1)==2 then ntfp else 0

Variable scen3NTFP
scen3NTFP = if index(1)==3 then ntfp else 0

Variable scen4NTFP
scen4NTFP = if index(1)==4 then ntfp else 0

Equations in CN indicators

Variable anteil productiv
anteil productiv = productiv_palms/total_number_of_cocconut__palms*100
Where:
total_number_of_cocconut__palms=total number of cocconut palms
productiv_palms=productiv palms

Variable area under cocconuts
area under cocconuts = total_number_of_cocconut__palms*(29/9465)
Where:
total_number_of_cocconut__palms=total number of cocconut palms

Variable durchscnitts alter
durchscnitts alter = sum({CNage})/total_number_of_cocconut__palms
Where:
total_number_of_cocconut__palms=total number of cocconut palms
{CNage}=../cocconut palms/CNage

Variable palm density
palm density = total_number_of_cocconut__palms/area_under__cocconuts
Where:
area_under__cocconuts=area under cocconuts
total_number_of_cocconut__palms=total number of cocconut palms

Variable productiv palms
productiv palms = sum({CNage_class})
Where:
{CNage_class}=../cocconut palms/CNage class

Variable scen1 fracProd
scen1 fracProd = if index(1)==1 then anteil_productiv else 0
Where:
anteil_productiv=anteil productiv

Variable scen1 palms
scen1 palms = if index(1)==1 then total_number_of_cocconut__palms else 0
Where:
total_number_of_cocconut__palms=total number of cocconut palms

Variable scen2 fracProd
scen2 fracProd = if index(1)==2 then anteil_productiv else 0
Where:
anteil_productiv=anteil productiv

Variable scen2 palms
scen2 palms = if index(1)==2 then total_number_of_cocconut__palms else 0
Where:
total_number_of_cocconut__palms=total number of cocconut palms

Variable scen3 fracProd
scen3 fracProd = if index(1)==3 then anteil_productiv else 0
Where:
anteil_productiv=anteil productiv

Variable scen3 palms
scen3 palms = if index(1)==3 then total_number_of_cocconut__palms else 0
Where:
total_number_of_cocconut__palms=total number of cocconut palms

Variable scen4 fracProd
scen4 fracProd = if index(1)==4 then anteil_productiv else 0
Where:
anteil_productiv=anteil productiv

Variable scen4 palms
scen4 palms = if index(1)==4 then total_number_of_cocconut__palms else 0
Where:
total_number_of_cocconut__palms=total number of cocconut palms

Variable total number of cocconut palms
total number of cocconut palms = count({CNage})
Where:
{CNage}=../cocconut palms/CNage

Equations in date

Variable one year
one year = fmod(time(1)*360,1)

Variable ten years
ten years = fmod(time(1)*360,3600)

Variable two years
two years = fmod(time(1)*360,720)

Equations in festival trigger

Variable demand for feast
demand for feast = if two_years==684 then total_population*0.2 elseif ten_years==1500 then 40 elseif ten_years==3564 then 60 else total_population*0.002
Where:
total_population=../total population
two_years=../date/two years
ten_years=../date/ten years

Variable maxpigslaughter
maxpigslaughter = if demand_for_feast>=pig_pop then 1 else 0
Where:
demand_for_feast=demand for feast
pig_pop=../pigsystem/pig pop

Variable regular festivals
regular festivals = if one_year==0 and pig_pop>minimum_pig_pop or one_year==108 and pig_pop>minimum_pig_pop or one_year==252 and pig_pop>minimum_pig_pop then 1 elseif two_years==684 and pig_pop>minimum_pig_pop then 1 elseif ten_years==1800 and pig_pop>minimum_pig_pop or ten_years==3564 and pig_pop>minimum_pig_pop then 1 else 0
Where:
minimum_pig_pop=../minimum pig pop

pig_pop=../pigsystem/pig pop
two_years=../date/two years
ten_years=../date/ten years
one_year=../date/one year

Equations in pig

Creation Pigcr
Pigcr = 300

Immigration im1
im1 = if buy_new_pigs==1 then pigs_purchased else 0
Where:
buy_new_pigs=../buy new pigs
pigs_purchased=../pigs purchased

Loss Pdeath
Pdeath = if rand_var(0,1)<=Pig_m then 1 elseif Pig_m==1 then 1 elseif regular_festivals==1 and maxpigslaughter==0 and Pigrank<=demand_for_feast then 1 elseif regular_festivals==1 and maxpigslaughter==1 and Psex==1 then 1 else 0
Where:
Pig_m=Pig m
regular_festivals=../../festival trigger/regular festivals
demand_for_feast=../../festival trigger/demand for feast
maxpigslaughter=../../festival trigger/maxpigslaughter

Reproduction Prep
Prep = if singelpigweight<80 then 0 elseif singelpigweight>=70 and singelpigweight<=100 and Pvar1>=0.8 and Pvar1<=0.9 or Pvar1>=0.1 and Pvar1<=0.2 and Psex==0 and Pigage>=1.2 then rand_var(7,10)elseif singelpigweight>100 and Pvar1>=0.8 and Pvar1<=0.9 or Pvar1>=0.1 and Pvar1<=0.2 and Psex==0 and Pigage>=1.2 then rand_var(9,12)else 0
Where:
singelpigweight=pigweight/singelpigweight

Variable FoodDemandpig
FoodDemandpig = 13.162*(1-exp(-0.0176*singelpigweight))*1000
Where:
singelpigweight=pigweight/singelpigweight

Variable Pig m
Pig m = if Pigage<=1 and time_invested_in_pigs==0 then 0.85/15 elseif Pigage<=1 and time_invested_in_pigs==1.2 then 0.85/70 elseif Pigage<=1 and time_invested_in_pigs==2 then 0.85/100 elseif Pigage<=1 and time_invested_in_pigs==2.4 then 0.85/170 elseif Pigage<=1 and time_invested_in_pigs==5 then 0.85/290 elseif Pigage>1 and Pigage<=2 then 0.25/12 elseif Pigage>2 and Pigage<=3 then 0.29/10 elseif Pigage>3 and Pigage<=4 then 0.15/10 else 1
Where:
time_invested_in_pigs=../time invested in pigs

Variable Pigage
Pigage = Pigrand_age+time(1)-init_time(1)
Where:
Pigrand_age=Pigrand age

Variable Pigrand age
Pigrand age = if index<=400 then rand(0,3)else 0

Variable Pigrank
Pigrank = count({one_role2})+1
Where:
{one_role1}=../ weight ranking/one (to pig in role1)
{one_role2}=../ weight ranking/one (to pig in role2)

Variable Psex
Psex = if rand(0,1)>=0.5 then 1 else 0

Variable Pvar1
Pvar1 = fmod(Pigage,1)

Variable index
index = index(1)

Variable pigmeat1
pigmeat1 = if slaughterVar==1 then singelpigweight*0.75 else 0
Where:
singelpigweight=pigweight/singelpigweight

Variable slaughterVar
slaughterVar = if regular_festivals==1 and maxpigslaughter==0 and Pigrank<=demand_for_feast then 1 elseif regular_festivals==1 and maxpigslaughter==1 and Psex==1 then 1 else 0
Where:
regular_festivals=../../festival trigger/regular festivals
demand_for_feast=../../festival trigger/demand for feast
maxpigslaughter=../../festival trigger/maxpigslaughter

Variable weight
weight = singelpigweight
Where:
singelpigweight=pigweight/singelpigweight

Equations in weight ranking

Condition cond1
cond1 = weight_role1>weight_role2
Where:
weight_role1=../pig/weight (from pig in role1)
weight_role2=../pig/weight (from pig in role2)

Variable one
one = 1

Equations in Pig age classes

Variable ageclass1
ageclass1 = if Pigage<=1*360 then 1 else 0
Where:
Pigage=../Pigage

Variable ageclass2
ageclass2 = if Pigage>1*360 and Pigage<=2*360 then 1 else 0
Where:
Pigage=../Pigage

Variable ageclass3
ageclass3 = if Pigage>2*360 and Pigage<=3*360 then 1 else 0
Where:
Pigage=../Pigage

Variable ageclass4
ageclass4 = if Pigage>4*360 then 1 else 0
Where:
Pigage=../Pigage

Equations in pigweight

Compartment singelpigweight
Initial value = if index<=400 then graph(Pigage)else 15.2
index=../index
Pigage=../Pigage Rate of change = + piggrowthrate

Flow piggrowthrate
piggrowthrate = (-(pigAB/PigTo)*singelpigweight+pigAB*pigfeedrate)/dt(1)

Variable PigTo
PigTo = pig_max_weight/pigmaxfeed
Where:
pig_max_weight=pig max weight

Variable SPW1
SPW1 = if index(1)==1 then singelpigweight else 0

Variable days
days = (time(1)-init_time(1))*360

Variable pig max weight : max. potential pig weight
pig max weight = 150

Variable pigAB : can be interpretated as the imperical growth efficiency or food conversion efficiency factor.
pigAB = 0.336
Comments:
Value from ICLAR-ClLSU experiment (farmsim)

Variable pigT
pigT = 8.7/4
Comments:
adjustment parameter after thegrowth theory from brody (1945) and Parks (1982, p. 53). Parks gives this value in the unit of weeks, therefore it must be multiplied by seven.

Variable pigadlib : maximum foodintake
pigadlib = (pigmaxfeed-1.52)*(1-exp(-(days)/pigT))+1.5
Where:
pigT=pigT
Comments:
this is the potential maximumfood intake of pigs in relation to their age. potentialmaximum food intake increases to a a maximum value (pigmaxfeed) at maturity. Initial food intakeis assumed to be 10% of initial live weight.

Variable pigfeedrate
pigfeedrate = pigfeeding/100*pigadlib
Where:
pigfeeding=../../pigfeeding
Comments:
actual amountwhich is fed to one pig

Variable pigmaxfeed : max. potential food intake of a mature pig. Parks (1982)
pigmaxfeed = 61*4

Variable spw2
spw2 = if index(1)==2 then singelpigweight else 0

Variable spw3
spw3 = if index(1)==3 then singelpigweight else 0

Variable spw4

spw4 = if index(1)==4 then singelpigweight else 0

Equations in Coconut Distribution

Compartment CN for copra
Initial value = 0
Rate of change = + CNpigsToCopra + CNtocopra2 - CNcopraToPigs - CNrest1

Compartment CN for pigs
Initial value = 0
Rate of change = + CNtoPigs1 + CNcopraToPigs - CNpigsToCopra - CNunused2

Flow CNcopraToPigs
CNcopraToPigs = if CN_for_copra<0 then 0 elseif preference__pig_vs_copra>=0.5 and Copra_Demand_in_CNtot>=CN_for_copra then CN_for_copra-Copra_Demand_in_CNtot elseif Copra_Demand_in_CNtot<CN_for_copra then 0 else 0
Where:
Copra_Demand_in_CNtot=../../../cash economy/Copra Demand in CNtot
preference__pig_vs_copra=preference pig vs copra
CN_for_copra=CN for copra

Flow CNpigsToCopra
CNpigsToCopra = if CN_for_pigs<0 then 0 elseif preference__pig_vs_copra<0.5 and CN_for_pigs>=CNtot_fed_to_pigs then CN_for_pigs-CNtot_fed_to_pigs else 0
Where:
CN_for_pigs=CN for pigs
preference__pig_vs_copra=preference pig vs copra
CNtot_fed_to_pigs=../../CNtot fed to pigs

Flow CNrest1
CNrest1 = if preference__pig_vs_copra<0.5 then CN_for_copra else CN_for_copra-CNcopraToPigs
Where:
CN_for_copra=CN for copra
preference__pig_vs_copra=preference pig vs copra

Flow CNtoPigs1
CNtoPigs1 = if preference__pig_vs_copra<0.5 then cocconuts-CNtot_consum else 0
Where:
cocconuts=../../../Coconut Plantation/cocconuts
CNtot_consum=../../CNtot consum
preference__pig_vs_copra=preference pig vs copra

Flow CNtocopra2
CNtocopra2 = if cocconuts<0 then 0 elseif preference__pig_vs_copra>=0.5 and CNtot_consum>0 then cocconuts-CNtot_consum elseif preference__pig_vs_copra>=0.5 and CNtot_consum<0 then cocconuts else 0
Where:
CNtot_consum=../../CNtot consum
preference__pig_vs_copra=preference pig vs copra
cocconuts=../../../Coconut Plantation/cocconuts

Flow CNunused2
CNunused2 = if preference__pig_vs_copra>=0.5 then CN_for_pigs else 0
Where:
CN_for_pigs=CN for pigs
preference__pig_vs_copra=preference pig vs copra

Variable CN mass
CN mass = cocconuts*1.2
Where:
cocconuts=../../../Coconut Plantation/cocconuts

Variable husk kcal
husk kcal = CN_mass*0.4*4000
Where:
CN_mass=CN mass

Variable kcal CNMeat
kcal CNMeat = mass_CNMeat_kg*4210
Where:
mass_CNMeat_kg=mass CNMeat kg

Variable kcal CNwater
kcal CNwater = mass_CN_water_kg*0.24
Where:
mass_CN_water_kg=mass CN-water kg

Variable mass CN-water kg
mass CN-water kg = CN_mass*0.26
Where:
CN_mass=CN mass

Variable mass CNMeat kg
mass CNMeat kg = CN_mass*0.3
Where:
CN_mass=CN mass

Variable shell kcal
shell kcal = CN_mass*0.15*5500
Where:
CN_mass=CN mass

Equations in endosomatic metabolism

Variable Rice consumption kcal
Rice consumption kcal = if kcal_rice>=Rice_Demand1kcal then Rice_Demand1kcal else kcal_rice
Where:
Rice_Demand1kcal=Nutritional Situation I/Rice Demand1kcal
kcal_rice= Harvest/kcal rice

Variable money demand rice
money demand rice = Rice_Demand1kcal/1600*rice_price
Where:
Rice_Demand1kcal=Nutritional Situation I/Rice Demand1kcal
rice_price=../../rice price

Variable total kcal consumption
total kcal consumption = (CN_consumption_kcal+fish__consumption_kcal+NTFP__consumption_kcal+Rice______consumption_kcal+kcal_pigmeat)*kcal_loss
Where:
kcal_loss=../kcal loss
CN_consumption_kcal=CN consumption kcal
fish__consumption_kcal=fish consumption kcal
NTFP__consumption_kcal=NTFP consumption kcal
Rice______consumption_kcal= Rice consumption kcal
kcal_pigmeat= Harvest/kcal pigmeat

Variable CN consumption kcal
CN consumption kcal = if kcal_CNMeat>=CN_DemandH1kcal then CN_DemandH1kcal else kcal_CNMeat
Where:

CN_DemandH1kcal=Nutritional Situation I/CN DemandH1kcal
kcal_CNMeat= Harvest/Coconut Distribution/kcal CNMeat

Variable CNtot consum
CNtot consum = CN_consumption_kcal/4.21/0.3/rand_var(900,2000)
Where:
CN_consumption_kcal=CN consumption kcal

Variable CNtot fed to pigs
CNtot fed to pigs = if CN_for_pigs<0 then 0 elseif CNtot_demandPig<=CN_for_pigs then CNtot_demandPig*pig_max_pop else CN_for_pigs*pig_max_pop
Where:
CN_for_pigs= Harvest/Coconut Distribution/CN for pigs
CNtot_demandPig=../pigsystem/CNtot demandPig
pig_max_pop=../pigsystem/pig max pop

Variable NTFP consumption kcal
NTFP consumption kcal = if kcal_ntfp>=NTFP_Demand1kcal then NTFP_Demand1kcal else kcal_ntfp
Where:
NTFP_Demand1kcal=Nutritional Situation I/NTFP Demand1kcal
kcal_ntfp= Harvest/kcal ntfp

Variable fish consumption kcal
fish consumption kcal = if kcal_fish>=Fish_Demand1kcal then Fish_Demand1kcal else kcal_fish
Where:
Fish_Demand1kcal=Nutritional Situation I/Fish Demand1kcal
kcal_fish= Harvest/kcal fish

Variable scen1 CN kcal
scen1 CN kcal = if index(1)==1 then CN_consumption_kcal else 0
Where:
CN_consumption_kcal=CN consumption kcal

Variable scen2 CN kcal
scen2 CN kcal = if index(1)==2 then CN_consumption_kcal else 0
Where:
CN_consumption_kcal=CN consumption kcal

Variable scen3 CNkcal
scen3 CNkcal = if index(1)==3 then CN_consumption_kcal else 0
Where:
CN_consumption_kcal=CN consumption kcal

Variable scen4 CN kcal
scen4 CN kcal = if index(1)==4 then CN_consumption_kcal else 0
Where:
CN_consumption_kcal=CN consumption kcal

Equations in pigsystem

Variable CN bilanzPig
CN bilanzPig = CNkcal_fed_to_pigs-CnDemandPig_kcal
Where:
CnDemandPig_kcal=CnDemandPig kcal
CNkcal_fed_to_pigs=CNkcal fed to pigs

Variable CNkcal fed to pigs
CNkcal fed to pigs = CNtot_fed_to_pigs*4.21*0.3*rand_var(900,2000)
Where:
CNtot_fed_to_pigs=../endosomatic metabolism/CNtot fed to pigs

Variable CNtot demandPig
CNtot demandPig = CnDemandPig_kcal/4.21/0.3/rand_var(900,2000)
Where:
CnDemandPig_kcal=CnDemandPig kcal

Variable CnDemandPig kcal
CnDemandPig kcal = if time_invested_in_pigs==1.2 then FoodDemandPig_Village_kcal*0.3 elseif time_invested_in_pigs==2 then FoodDemandPig_Village_kcal*0.35 elseif time_invested_in_pigs==2.2 then FoodDemandPig_Village_kcal*40 else FoodDemandPig_Village_kcal*0.5
Where:
time_invested_in_pigs=time invested in pigs
FoodDemandPig_Village_kcal=FoodDemandPig Village kcal

Variable ERpigVillage kcal
ERpigVillage kcal = FoodDemandPig_Village_kcal/4
Where:
FoodDemandPig_Village_kcal=FoodDemandPig Village kcal

Variable FoodDemandPig Village kcal : Energyrequierment of all p igs in one village
FoodDemandPig Village kcal = sum({FoodDemandpig})*36
Where:
{FoodDemandpig}=pig/FoodDemandpig

Variable NTFP bilanzPig
NTFP bilanzPig = PigNTFPconsump_kcal-NTFPdemandPig_kcal
Where:
NTFPdemandPig_kcal=NTFPdemandPig kcal
PigNTFPconsump_kcal=../endosomatic metabolism/ Harvest/PigNTFPconsump kcal

Variable NTFPdemandPig kcal
NTFPdemandPig kcal = FoodDemandPig_Village_kcal-CnDemandPig_kcal
Where:
CnDemandPig_kcal=CnDemandPig kcal
FoodDemandPig_Village_kcal=FoodDemandPig Village kcal

Variable Page 1
Page 1 = sum({ageclass1})
Where:
{ageclass1}=pig/Pig age classes/ageclass1

Variable Page 2
Page 2 = sum({ageclass2})
Where:
{ageclass2}=pig/Pig age classes/ageclass2

Variable Page 3
Page 3 = sum({ageclass3})
Where:
{ageclass3}=pig/Pig age classes/ageclass3

Variable Page 4
Page 4 = sum({ageclass4})
Where:
{ageclass4}=pig/Pig age classes/ageclass4

Variable buy new pigs
buy new pigs = if pig_pop<10 and Money>=1500 then 1 else 0
Where:
pig_pop=pig pop
Money=../cash economy/Money

Variable   durchschnitGW
    durchschnitGW = total_pig_weight/pig_pop
    Where:
        pig_pop=pig pop
        total_pig_weight=total pig weight

Variable   money spend   pigs
    money spend   pigs = if buy_new_pigs==1 then pigs_purchased*pig_price else 0
    Where:
        buy_new_pigs=buy new pigs
        pigs_purchased=pigs purchased
        pig_price=pig price

Variable   pig max pop
    pig max pop = if pig_pop>=minimum_pig_pop*2.5 then 0 else 1
    Where:
        minimum_pig_pop=../minimum pig pop
        pig_pop=pig pop

Variable   pig pop
    pig pop = count({index})
    Where:
        {index}=pig/index

Variable   pig price
    pig price = 500

Variable   pigfeeding
    pigfeeding = min(total_consumption__Pig_kcal/FoodDemandPig_Village_kcal*100,100)
    Where:
        total_consumption__Pig_kcal=total consumption Pig kcal
        FoodDemandPig_Village_kcal=FoodDemandPig Village kcal

Variable   pigs purchased
    pigs purchased = rand_var(5,15)

Variable   productive pigs
    productive pigs = Page_2+Page_3+Page_4
    Where:
        Page_2=Page 2
        Page_3=Page 3
        Page_4=Page 4

Variable   scen1 pig pop
    scen1 pig pop = if index(1)==1 then pig_pop else 0
    Where:
        pig_pop=pig pop

Variable   scen2 pig pop
    scen2 pig pop = if index(1)==2 then pig_pop else 0
    Where:
        pig_pop=pig pop

Variable   scen3 pig pop
    scen3 pig pop = if index(1)==3 then pig_pop else 0
    Where:
        pig_pop=pig pop

Variable   scen4 pig pop
    scen4 pig pop = if index(1)==4 then pig_pop else 0
    Where:
        pig_pop=pig pop

Variable time invested in pigs

time invested in pigs = if minimum_pig_pop==0 or pig_pop/minimum_pig_pop*100>150 then 0 elseif pig_pop/minimum_pig_pop*100>=100 then 1.2 elseif pig_pop/minimum_pig_pop*100<100 and pig_pop/minimum_pig_pop*100>=90 then 2 elseif pig_pop/minimum_ pig_pop*100<90 and pig_pop/minimum_pig_pop*100>=55 then 2.4 else 5

Where:

minimum_pig_pop=../minimum pig pop
pig_pop=pig pop

Variable total consumption Pig kcal

total consumption Pig kcal = CNkcal_fed_to_pigs+PigNTFPconsump_kcal

Where:

CNkcal_fed_to_pigs=CNkcal fed to pigs
PigNTFPconsump_kcal=../endosomatic metabolism/ Harvest/PigNTFPconsump kcal

Variable total pig weight

total pig weight = sum({singelpigweight})

Where:

{singelpigweight}=pig/pigweight/singelpigweight

Equations in cash economy

Compartment Money

Initial value = 30000
Rate of change = + moneyIn - rice - money - consumption - money

Flow rice money

rice money = if Money<=0 then 0 elseif money__demand_rice>=Money then money__demand_rice else Money

Where:

money__demand_rice=../endosomatic metabolism/ money demand rice

Flow consumption money

consumption money = if money__demand_rice>=rice_money then 0 elseif sum_IndMoney________need>=Money then sum_IndMoney________need else Money

Where:

sum_IndMoney________need=../sum IndMoney need
rice_money= rice money
money__demand_rice=../endosomatic metabolism/ money demand rice

Flow moneyIn

moneyIn = Copra_sold_in_CN_tot*Copra_Price*dt(1)

Where:

Copra_sold_in_CN_tot=Copra sold in CN tot
Copra_Price=../Copra Price

Variable Copra Demand

Copra Demand = if Money_Bilanz<0 then-(Money_Bilanz/Copra_Price)*1.5 elseif Money_Bilanz<30000 then(30000-Money_Bilanz)/Copra_Price else 0

Where:

Copra_Price=../Copra Price
Money_Bilanz=Money Bilanz

Variable Copra Demand in CNtot

Copra Demand in CNtot = Copra_Demand*rand_var(4,6)

Where:

Copra_Demand=Copra Demand

Variable Copra sold in CN tot

Copra sold in CN tot = if CN_for_copra>=Copra_Demand_in_CNtot then Copra_Demand_in_CNtot elseif CN_for_copra<Copra_Demand_in_CNtot then CN_for_copra else 0
Where:
CN_for_copra=../endosomatic metabolism/ Harvest/Coconut Distribution/CN for copra
Copra_Demand_in_CNtot=Copra Demand in CNtot

Variable Money Bilanz
Money Bilanz = Money-Tot_money__Demand
Where:
Tot_money__Demand=Tot money Demand

Variable Tot money Demand
Tot money Demand = sum_IndMoney________need+money__demand_rice
Where:
sum_IndMoney________need=../sum IndMoney need
money__demand_rice=../endosomatic metabolism/ money demand rice

Variable money for rice
money for rice = rice_money
Where:
rice_money= rice money

Variable money per capita
money per capita = Money/total_population
Where:
total_population=../total population

Variable moneyIn per capita
moneyIn per capita = moneyIn/total_population
Where:
total_population=../total population

Variable scen1 money
scen1 money = if index(1)==1 then Money else 0

Variable scen2 money
scen2 money = if index(1)==2 then Money else 0

Variable scen3 money
scen3 money = if index(1)==3 then Money else 0

Variable scen4 money
scen4 money = if index(1)==4 then Money else 0

Equations in per capita

Variable kcal CN per cap
kcal CN per cap = CN_consumption_kcal/total_population
Where:
CN_consumption_kcal=../CN consumption kcal
total_population=../../total population

Variable kcal fish per cap
kcal fish per cap = fish__consumption_kcal/total_population
Where:
total_population=../../total population
fish__consumption_kcal=../fish consumption kcal

Variable kcal ntfp per cap
kcal ntfp per cap = NTFP__consumption_kcal/total_population
Where:

total_population=../../total population
NTFP__consumption_kcal=../NTFP consumption kcal

Variable kcal pig percap
kcal pig percap = kcal_pigmeat/total_population
Where:
total_population=../../total population
kcal_pigmeat=../ Harvest/kcal pigmeat

Variable kcal rice per cap
kcal rice per cap = Rice______consumption_kcal/total_population
Where:
total_population=../../total population
Rice______consumption_kcal=../ Rice consumption kcal

Variable tot kcal per cap
tot kcal per cap = total_kcal__consumption/total_population
Where:
total_population=../../total population
total_kcal__consumption=../ total kcal consumption

Equations in consum per pig

Variable CN kcal per pig
CN kcal per pig = CNkcal_fed_to_pigs/pig_pop
Where:
pig_pop=../pig pop
CNkcal_fed_to_pigs=../CNkcal fed to pigs

Variable CNtot per pig
CNtot per pig = CNtot_fed_to_pigs/pig_pop
Where:
CNtot_fed_to_pigs=../../endosomatic metabolism/CNtot fed to pigs
pig_pop=../pig pop

Variable NTFP kcal per pig
NTFP kcal per pig = PigNTFPconsump_kcal/pig_pop
Where:
pig_pop=../pig pop
PigNTFPconsump_kcal=../../endosomatic metabolism/ Harvest/PigNTFPconsump kcal

Variable kcal per pig
kcal per pig = total_consumption__Pig_kcal/pig_pop
Where:
pig_pop=../pig pop
total_consumption__Pig_kcal=../total consumption Pig kcal

IX.
Curriculum Vitae

Martin Wildenberg

Date of birth: 19.3. 1977
Place of birth: Übelingen am Bodensee (Germany)

Education:

School:
1984 -1988 Primary schools in England, Puerto Rico and Germany
1988- 1997 High school in Germany and Austria
1997 Graduation ("Matura") at the BORG Murau, Austria

University:
Since 1997 studying Ecology at the University of Vienna

Major Projects, Training and Fieldwork:

- 2000 - 2001 Students Project "Mountains 2001 - Regional Perspectives" on the Technical University of Vienna

- Jul. 2002 TBA - (Tropical Biological Association), Course on Tropical-Ecology in Kibale National Park in Uganda. Project on the ecology of driver ants *(Dorylus sp.)*

- Jun. 2004 Summer Workshop on Participatory Integrated assessment of Sustainability organized by LIPHE4 and the IFF Vienna (http://www.liphe4.org/school.html).

- Jun-Aug. 2005 Young Scientist Summer Program at the International Institute for Applied System Analysis (IIASA) in Laxenburg (Austria) (http://www.iiasa.ac.at/). Working on the resilience of socio-ecological systems.

Publications:

? M. Wildenberg and S.Wibmer: *"Biological Diversity in the Hindu Kusch-Himalaya-Karakoram Range"*.
? M. Wildenberg and F. Ofner: *"Impressions collected during the Project Mountains 2001 – personal description about the situation of tourism and its impact on culture in Pakistan and Bhutan"*.
? G. Elimsteiner-Saxinger B. Marouschek and M. Wildenberg: *"Guidelines - Instrument of Power or Tool of Integration"*

All published in: *"Encounters, Integrated Regional Development in Pakistan Nepal, Bhutan"*. Published and edited by: Society Mountains_2001 - Regional Perspectives, 2001 Vienna.

X.

Danke!

Für die Betreuung Clemens, Simron und Helmut dem Institute für Sozial-Ökologie für den Arbeitsplatz und die nette Atmosphere am selbigen.

Vor allem möchte ich meiner Familie danken die mich immer wieder insperiert und motiviert hat. Danke Leonie danke Edith! (Auch für die Geduld).