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Daniel A. Bergquist

## Colonised Coasts

*Aquaculture and emergy flows in the  
world system: Cases from Sri Lanka  
and the Philippines*

Dissertation presented at Uppsala University to be publicly examined in Sal IV, Universitetshuset, Uppsala, Friday, February 15, 2008 at 10:15 for the degree of Doctor of Philosophy. The examination will be conducted in Swedish.

### **Abstract**

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This thesis conceives aquaculture as a transfer of resources within and between different parts of the world system. It is argued that due to inappropriate human-nature interactions, resources tend to flow from the South to the North, as a process of coastal colonisation. To study this resource transfer, coastal aquaculture is approached from a transdisciplinary perspective, integrating natural, social, economic and spatial aspects. By combining world system theory and general systems theory, a systems view is adopted to relate aquaculture to forces of global capitalism, and analyse interactions between social and ecological processes at local and global levels. Emergy (energy memory) synthesis and participatory research methodologies were applied to two cases of aquaculture in Sri Lanka and the Philippines; monoculture of the black tiger prawn (*Penaeus monodon*) and milkfish (*Chanos chanos*), and polyculture of the two species together with mudcrab (*Scylla serrata*). The study reveals that semi-intensive shrimp monoculture in Sri Lanka generates few benefits for poor local people, and depends much on external inputs such as fry, feed and fuels, which implies negative environmental effects at local as well as global levels. Extensive polyculture in the Philippines involves more local people, and implies lower dependence on external inputs. Still, since benefits accrue mostly to elites, and mangroves are negatively affected, neither case is viable for sustainable poverty alleviation. Nevertheless, the study offers several insights into how sustainability assessment may be more transdisciplinary, and points to several factors affecting sustainability and fairness in aquaculture; the most important being mangrove conversion, local people involvement, and dependence on external inputs. Given that mangrove conversion is counteracted, extensive polyculture practices may also prove more viable in times of decreasing resources availability, and if policies are developed that favour resource efficient polyculture, and local small-scale and re-source poor farmers, instead of the global North.

*Keywords:* Aquaculture, Capitalism, Socio-economic effects, Environmental effects, Benefit distribution, Sustainability, Sustainability assessment, Fairness, Development, Interdisciplinary, Transdisciplinary research, Geography, Emergy, World System Theory, General Systems Theory, Sustainable development, Sri Lanka, Philippines

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# Preface

This thesis deals with coastal aquaculture. This said, aquaculture is not the issue under study *per se*. Rather is aquaculture but one of many examples of interconnected human-nature complexity. However, as a production process driven by global demand, and with local and global consequences, it is an example that displays a range of interactions between human and environmental systems and scales. This makes aquaculture a particularly interesting case for probing wider issues such as patterns of production and consumption, development, sustainability, trade and fairness. In this context, albeit departing from a critical perspective on capitalism, the thesis neither aims to criticise capitalism *per se*. Rather, it attempts to analyse, visualise, and more importantly, operationalise sustainability, and discuss whether or not it is achievable under global capitalism as organised today. Bearing in mind what the thesis does not aim for, and turning to what it does aspire; the core ambition is to operationalise and quantify a feeling shared by many critics; *i.e.*, that global capitalism too often results in unfairness and environmental degradation. Equally important, however, is that this is aimed for by problematising how and why monetary measures of value so often underestimate human and environmental support to production. A crucial point of departure in this context is that conventional economic ways of establishing value are not enough to achieve sustainable development, and hence may benefit from complementing measures of value such as *emergy*. Here, the difference between money and *emergy* is highly critical. Money is basically symbolic – a conceptual means for negotiating and communicating value based on perceived utility. *Emergy*, on the other hand, is both symbolic and physical – it accounts for environmental and human support to production in concrete thermodynamic measures of energy, simultaneously as it considers theoretical principles of sustainability and fairness. A perhaps even more important difference between money and *emergy* is that money primarily aims forward in time, as a way to enable time to pass between moments of production and consumption. Meanwhile, *emergy* aims equally backwards as forwards; in that it maintains that all production requires that resources are taken from somewhere, and depends on biological and geological processes of resource accumulation during millennia. Put together, this means that all production implies appropriation of resources in time and space, and that resource use today simultaneously depends on the past, and reaches into the future.

# Acknowledgements

Among many other things, writing this thesis has taught me that few processes are linear, but rather cyclical – you start somewhere, moving back and forth, only to once again end up in something similar to where it all started. Similarly, my time as a PhD student has been a highly cyclical process. When it all started in early 2004, I didn't know anything of where it would take me (or my findings either for that matter). And here I find myself at the end, once again more or less clueless. But, as in all research, regardless of it is cyclical or not, many steps have to be taken to come back again. And on the way, many experiences and acquaintances are made without which it would not be possible to start nor to finish such a great endeavour as a PhD project. Therefore, many people deserve mentioning.

To start with, I would never have even imagined pursuing a PhD if it was not for my supervisor and mentor during my first years in academia. Thank you Dr Vesa-Matti Loiske at Södertörns högskola (University college), for opening the door to an intriguing world! Since pursuing the PhD also meant moving to Uppsala, several people there deserve my deepest gratitude. Starting with my numerous supervisors, thank you Professor Lennart Strömquist for taking me on, and for allowing me to think and work so freely! I am especially grateful to my extra-disciplinary supervisor, Docent Torbjörn Rydberg at the Swedish University of Agricultural Sciences (SLU) in Ulltuna, for tutoring me despite my limited knowledge and background in systems ecology – thank you for guiding me through the terminological hell (or heaven) of emergy, and putting up with all my silly questions. As a human geographer by training, grasping the complexities of systems was never easy, but so much more rewarding with you as my guide.

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In the Philippines, I am equally grateful to all the people in the municipalities of Numancia and Makato – thanks for your hospitality, help and cooperation. In Navitas, the village where I came to stay, I am especially indebted to Mr. Christian Deza, municipal extensionist, and Mr. Roy Bustamante, Barangay captain. Thank you both for becoming my friends, and for arranging accommodation, assisting during interviews, and last but not least, for introducing me to the fantastic people in your communities.

After ending the fieldwork, much work remained before completing this thesis. Back home, I feel privileged to have been part of such a thriving research community as Uppsala. Thank you all at Centre for Environment and Development (Cemus) and Cemus research forum (Cefo) for providing an inspiring and dynamic community for interdisciplinary discussions, seminars, courses and friendship. At my home department, similar support was provided by a range of compassionate colleagues; thank you all for helping me in a variety of ways on a day to day basis, but most of all for exposing me to your constructive critique and holding me back in my sometimes runaway quest towards transdisciplinarity. I am especially grateful to Dr Susanne Stenbacka, director of research studies, for taking so good care of all us PhD students, and Kerstin Edlund and Ewa Hodell, our excellent in-house administrators. And thank you Christian Abrahamson for your sharp-witted mind and comments on my evolving thesis, and not the least for all inspiring talks on the predicament of being in between. In chronological order, my two colleagues and roommates Flora Hajdu and Anna-Klara Nilsson also have my warmest appreciation – thank you for all energetic discussions, advice and gossip, and especially for making office work so much more fun.

Not only people in Uppsala, Sri Lanka and the Philippines have contributed to the completion of this thesis. My participation in a range of international conferences, field trips, and most importantly, my fieldwork, had never been possible without financial support from The Swedish Society for Anthropology and Geography, Centre for Environment and Development Studies and Smålands Nation in Uppsala, and Helge Ax:son Johnsons stiftelse in Stockholm.

In my immediate family: thank you Angela, my beloved wife, for always being so loving and supportive. And not the least for painting such a beautiful cover – I know it was really difficult for you to preserve your creativity while held back by all annoying systems principles! Last but not least a great deal of gratitude is extended to my parents, siblings and all other family members and friends, in Sweden and Colombia. Thank you for supporting me and providing a space for recovery on many, yet too few occasions of leisure and joy. Hopefully, we will see more of each other now when it is finally time to close this chapter of my life, and start on a new one together.

Bogotá Colombia, and Uppsala Sweden, January 2008

Daniel Alcalá Bergquist

# 1. Introduction

I say that those who eat shrimp – and only the rich people from the industrialized countries eat shrimp – I say that they are eating at the same time the blood, sweat and livelihood of the poor people of the Third World. (Banka Behary Das, Indian activist cited by Stonich and Vandergeest 2001).

If development is to be sustainable, degradation of the natural resource base should be minimised. Another requirement is that benefits from resource use are distributed based on principles of equity, or fairness<sup>1</sup>, benefiting also poor people. It is therefore crucial to diversify opportunities and facilitate access to resources for all individuals and communities, including women and the poor (Harrison *et al* 2002).

However, it is becoming increasingly apparent today that economic and environmental benefits and costs of development are not fairly shared. It is even argued (Hornborg 2001) that development has come to represent an exploitative process of production, consumption and exchange, where resources are increasingly being extracted in rural areas in poor countries and accumulated in urban areas, enriching the already rich (*c.f.* Hornborg 2007). In this sense the process of colonisation still lingers on, hence the title of this thesis: “Colonised coasts”. As will be shown, coastal aquaculture in the two studied cases results in unfair transfers of resources and benefits – a process with much in common with colonialism. And yet, aquaculture is often being referred to as a contributor to poverty alleviation (Lewis *et al* 2003) and promoted as an important generator of new livelihood opportunities for poor local people. Many governments have a strong belief in the potential of the industry to accelerate national economic growth and alleviate poverty (Dis-

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<sup>1</sup> A common interpretation of equity is that resources should be distributed among individuals in proportion to their efforts (*c.f.* Maiese 2003). From this follows, that people who produce more or better in the economic system are compensated more than those not equally successful. In this thesis however, it is argued that this may be problematic, since peoples’ opportunities to realise their full potential are seldom equally distributed, and therefore individuals may produce differently. Distributing resources based on equity hence potentially fails to meet the basic needs of all humans. Therefore, equity is hereon replaced by the term fairness, which is more context sensitive and acknowledges that needs and opportunities differ between individuals, and that therefore resource distribution should be democratically negotiated so that all people receive their morally “fair” share of resources, benefits and costs.

sayanake 2004; Thomas 2003). Based on this assumption, the Asian Development Bank and the World Bank have supported a large number of aquaculture projects in Asia, including Sri Lanka and the Philippines (Bailey 1988). International organisations and aid agencies, *e.g.* World Bank, NACA, WWF and FAO (2002) jointly confirm that aquaculture, and especially shrimp farming is an important contributor of employment opportunities, both in developing and developed countries. However, the emphasis on primarily large-scale and export oriented shrimp monoculture has reduced the potential of real improvement for poor people, when goals such as generating local employment and enhancing food security have been highly neglected (Stonich and Bailey 2000).

Aquaculture thus exemplifies how global trade relations result in unfair transfers of energy and other resources between different regions of the world, generating local as well as global effects of various kinds. Still, aquaculture undoubtedly contributes valuable foreign exchange in many countries throughout the South, including the two countries chosen for this study; Sri Lanka and the Philippines. However, this is mainly achieved at the price of adverse effects for both society and environment (Primavera 1997). At present, the industry itself is also experiencing difficulties worldwide. Due to disease outbreaks entire yields have been lost on many locations, and adverse environmental and social effects have been substantial. Whereas the environmental effects related to aquaculture are fairly well known, it is more uncertain what impact aquaculture has on the living conditions for local people. In some cases, aquaculture has even made the poor worse off (Viswanathan and Genio 2001). As will be illuminated in this thesis, the poorest individuals of coastal communities are in fact seldom involved in aquaculture at all, other than on rare occasions. Thus, benefits are often low for local communities, and especially for poor people in these communities. In this thesis, this phenomenon is analysed and compared by drawing on experiences from Sri Lanka and the island of Panay in the Philippines (figure 1).

When considering environmental effects from aquaculture, it is important to see the industry in a global, as well as local context. While some aquaculture depends mostly on local resources, others demand that inputs are brought in from outside the local area, for example by importing fry, feed, labour and knowledge etc. Especially the increasing dependence on artificial fry and feed is highly resource consuming, *e.g.* due to high rates of by-catches in off shore fisheries that supply raw materials. This means that environmental sustainability of production and acquisition of these inputs also has to be considered side by side with more direct impacts derived from activities at farm level.

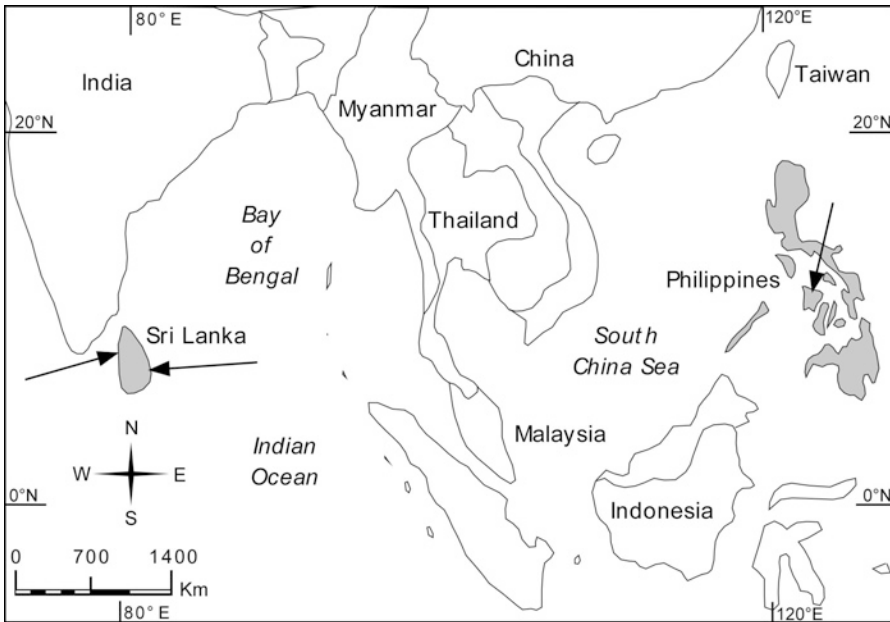


Figure 1. The study areas in Sri Lanka and on the island of Panay, the Philippines.

Previous studies, (e.g. Jayasinghe 1995; Rönnbäck 2001a) indicate that less intensive and technologically demanding aquaculture tends to generate more employment opportunities locally than do more intensive production. Indigenous resource management systems have sometimes proven more sustainable (Berkes 2000), among other reasons due to their relatively high contribution to local economies, combined with relatively benign effects for the environment. Indigenous and less intensive aquaculture however seldom manage to accelerate economic growth on national levels. To achieve such growth, national governments often intervene by introducing science based innovations (*i.e.*, intensified production techniques) with the purpose of increasing productivity and targeting international markets (Abhayaratna 2001). The backside of this is that it often generates negative environmental effects without setting aside any of the natural resources for conservation (*c.f.* Blaikie 1985). However, recent strategies to come to terms with these problems are emerging, *e.g.* on the initiative of United Nations Environment Programme (UNEP). For example, in terms of mitigating the effects from aquaculture, natural resources are being increasingly protected and there are examples of setting aside resources for conservation (*c.f.* GPA 2007). However, a negative implication related to such a development is that high-tech production systems, though combined with conservation measures, are seldom designed to take advantage of local knowledge. Negative aspects of technical innovations and their impact on poor farmers is indeed an issue that has been poorly addressed in research (Abhayaratna 2001), perhaps

especially so in Sri Lanka. As argued by Norgaard (1994), new technologies therefore tend to determine social organisation today, since most societies adapt to technological breakthroughs, as opposed to adapting technology to societal needs and values.

## Aim, hypotheses and guiding questions

The overall ambition of this thesis is threefold.

1. First, it aims to study and compare spatial distribution of environmental effects and socio-economic benefits from coastal aquaculture under different conditions,
2. Second, it aims to use the two cases for applying and testing the concept of emergy, and explore its possibilities for more holistic and transdisciplinary sustainability assessment,
3. Third, it aims to use the results of the study to discuss and highlight implications for introducing more sustainable forms of aquaculture.

An important ambition is thus to test and develop a transdisciplinary approach that emphasises interactions and resource flows between different regions and peoples, or in other words, how global unfairness operates through time and space. With its roots in geography, where variations in time and space and relations in the interface between social and natural worlds are essential key elements (Whatmore 2002), such an approach may provide implications for more holistic and accurate sustainability assessment and planning for sustainable development. More importantly however, in terms of its epistemological aspirations, the thesis aims for increased theoretical integration and cross-fertilisation, by simultaneously applying world system theory, general systems theory, and emergy<sup>2</sup>, thereby contributing to increased holism in research on environment and development related phenomena.

In this context, it is also important to stress that, therefore, the primary object of study is not the local communities *per se*. Rather, it focuses on how local farmers and ecosystems are connected to processes at larger scales, and more explicitly to contemporary patterns of production, consumption, trade and development, as exemplified by local outcomes. For this purpose, case

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<sup>2</sup> Emergy expresses the different forms of energy and materials required, either directly or indirectly, to make another form of energy, product or service. In other words, emergy may be defined as “the previous work done to make something, whether the work was done by natural processes or by humans” (Odum and Odum 2001:6). The concept of emergy and its applicability in the context of sustainable development is further explored in chapter 5.

studies of aquaculture were conducted in Sri Lanka and the Philippines. However, the depth of the fieldwork was rather superficial, *e.g.* in terms of the number and character of informants included, and the emphasis on farm units as opposed to households. Therefore, it is important to point out here, that the primary aim of the fieldwork was to illuminate and relate local outcomes of aquaculture to larger scales, emphasising farmers' experiences and strategies, as opposed to that of the wider local communities.

Despite the geographical focus on Asian cases, the study's aspirations are global, both in terms of methodological development and problem analysis. Indeed, location specific studies, albeit especially of local relevance, as argued by Sen (1999), may also be of global interest. Still, this also means that findings do not necessarily apply to all other culture practices or national contexts. However, by highlighting differences between the two cases, important lessons may be learned on how sustainability varies between different culture practices, and how such differences can be assessed. Therefore, the two cases are used for discussing alternatives, challenges and opportunities for introducing sustainable aquaculture worldwide. In this context, sustainable implies aquaculture that improves living conditions for poor local people by increasing their involvement, reduce the risks of losing yields and degrading natural resources.

The cases of aquaculture studied are<sup>3</sup>; (1) semi-intensive shrimp monoculture in Sri Lanka, and (2) extensive (as the opposite to intensive) polyculture of milkfish, shrimp and mudcrab in the Philippines. Based on a review of literature on coastal aquaculture, the hypotheses used are as follows:

1. Semi-intensive shrimp monoculture results in high risks for losing yields and negative effects on the natural environment, and generates few benefits for local people.
2. Extensive polyculture reduces risks for losing yields and negative impacts on the natural environment, and generates positive socio-economic effects at local levels due to limited extraction of natural resources, high labour intensity and high level of local participation.

To test these hypotheses, the research questions are:

- [How] does natural resource use, socio-economic benefits, local and external participation change spatially, in relation to intensity in aquaculture? That is, from where and whom are resources taken, where and by whom are products consumed, and where and with whom do benefits from production end up?

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<sup>3</sup> See table 1 for definitions of aquaculture practices and intensities studied and referred to in this thesis.

- How does higher complexity in aquaculture and integration with natural ecosystems affect dependence on local versus external resources?
- Is there a difference between aquaculture in Sri Lanka and the Philippines in terms of their relative sustainability?

## Outline of the thesis

This thesis draws on several theoretical perspectives and methodological approaches. After introducing aquaculture and relating it to its larger context in chapter 1, chapter 2 more thoroughly accounts for past and present world trends in aquaculture. It also discusses what determines sustainability in aquaculture, and how this may be assessed. In chapter 3, several theoretical views and approaches to environment and development are explored. This entails discussing what development as a concept and strategy has meant in the past, as well as introducing some contemporary schools of thought. The chapter then turns to system theories in natural and social sciences, and explores prospects for integration. In chapter 4, the theoretical framework is operationalised in the methodology of the study, by proposing a transdisciplinary approach that can better handle interlinked society-nature phenomena. Remarks are made on how data was collected, and which methods and tools were used. Chapter 5 further elaborates on the emergy perspective, and introduces the main concepts and procedures of emergy evaluation. Chapter 6 then describes the situations in Sri Lanka and the Philippines, emphasising geographical settings, aquaculture practices and societal contexts. In chapter 7, these differences are analysed and compared as an example of regional variability in aquaculture. Aquaculture land-take, mangrove conversion, environmental effects and local people involvement in the two study areas is accounted for and compared. The chapter also contains the emergy evaluations, as well as interpretation of the results. In chapter 8, the results are related back to the theoretical framework of the thesis. The chapter also discusses prospects for epistemological and methodological cross-fertilisation and integration of the approaches applied throughout the thesis. Finally, in chapter 9, some concluding remarks are made on the results of the study, and the role of aquaculture in sustainable development. Readers may notice that in several passages throughout the thesis, empirical findings are mixed with theoretical starting points. This is not unintended. Although conventional scientific writing proposes that empiricism is accounted for towards the end, this thesis departs from a notion of self-organisation and feedback loops as generally beneficial for the whole. Therefore, empirical observations and findings are sometimes “fed back” to preceding chapters, with the explicit purpose of reinforcing theoretical arguments and starting points.



## 2. Coastal aquaculture

This thesis deals with coastal aquaculture in brackish waters. Pullin (1993:2) defines aquaculture as: “the farming of aquatic organisms, including fish, molluscs, crustaceans and aquatic plants”. Coastal here refers to land and associated water bodies in connection to the sea, estuaries and river mouths, since it is only in areas where brackish water abounds, that the aquaculture practices studied here can be found. Although narrowed down to “coastal”, this definition still encompasses a range of aquaculture practices, with varying effects for environment and society. This is why it is necessary to first define and account for some of the most common practices today, as well their history. This chapter therefore defines and discusses characteristics and differences of aquaculture practices in the two study areas, as well as world wide trends in aquaculture development. More importantly however, factors affecting economic viability, fairness and environmental impacts in aquaculture are identified and discussed<sup>4</sup>. These are later used to illuminate local and regional differences between aquaculture practices in Sri Lanka and the Philippines, and to discuss their relative sustainability.

### The emergence of aquaculture in Asia

Modern aquaculture is often considered one of the most destructive forms of agricultural activities (Gunawardena and Rowan 2005). However, historically more sustainable aquaculture has existed in Asia for several centuries. In China, the earliest known practice of fish culture can be traced back to some 4000 years ago (Schmidt 2000). In Java, Indonesia, traces have been found from the 1400s (Primavera 2000). Though, it was not until the 1980s that the activity started accelerating rapidly. The reason for this development was, among others, technological breakthroughs and increasing global demand for aquaculture products, which resulted in higher market prices and profits that further increased growth and public support (Shang *et al* 1998). However, since the early 1990s, the industry’s growth has slowed down, mainly due to disease outbreaks and environmental problems generated by the industry itself.

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<sup>4</sup> Parts of this chapter have also been published in Bergquist (2007).

Most coastal aquaculture has followed a trend which is similar to agriculture, where increased reliance on external inputs such as imported energy (e.g. diesel fuels), capital intensive technology, fertilisers and pesticides ultimately result in negative impacts on environment and rural communities (Altieri 2000). A feature more specific to aquaculture is that it is characterised by different phases, *i.e.*, “boom and bust”, where exponential growth is followed by near or total collapse due to disease outbreaks and environmental problems etc. One of the reasons for this trend is the failure to acknowledge the importance of mangroves as life-support areas to aquaculture (Gunawardena and Rowan 2005). Functional mangroves, by which is meant mangroves that are allowed to realise their full potential in terms of ecological productivity, are crucial for the well-being of aquaculture, but perhaps more importantly also for the coastal zone in its entirety. Aquaculture expansion at the expense of mangroves has led to a significant decrease in the extent and function of mangrove forests, which are important among other things as buffer zones and waste recipients from aquaculture and other human activities (more on this below). An alternative way to explain the boom and bust pattern of aquaculture development is that all systems tend to pulse, and always include phases of expansion and collapse/reorganisation (this trend is further described in chapter 3). In the case of aquaculture, new technology allows for economic expansion and further exploitation of natural resources, but after some time, increased resource extraction and competition results in saturated markets, as well as negative cumulative and environmental effects, which slows down growth until another cycle develops (Abel (2007). Hence, despite extensive efforts by researchers and practitioners to improve efficiency and reduce environmental impacts, collapse or serious recurrent setbacks of the aquaculture industry seem inevitable.

Many contemporary aquaculture practices threaten coastal resources, while at the same time the farmers incur considerable financial risks. Although probably underestimating the total value of goods and services provided by mangroves, economic evaluations have shown that shrimp aquaculture actually results in more economic harm than good (*c.f.* Khor 1995; Gunawardena and Rowan 2005). As argued by Gunawardena and Rowan (2005), there is general consensus that the true value of mangroves lost in aquaculture expansion is most often underestimated. One important reason for this is that most evaluations only consider marketed products such as yields from forestry and fisheries.

The severity of the negative effects from aquaculture depends much on production intensity and species selection, which vary greatly between a range of culture practices, by which is meant a particular aquaculture production system and its specific characteristics. The most common culture practices today are in this thesis classified as extensive, semi-intensive or intensive, based on technical and economic differences. Definitions of culture practices referred to henceforth are provided in table 1.

Table 1. Definitions and differences between culture practices studied and referred to in this thesis.

Parameter \ Culture practice	Extensive fish mono-culture	Extensive shrimp mono-culture	Extensive fish/shrimp polyculture	Semi-intensive shrimp monoculture	Intensive shrimp mono culture
Stocking density milkfish (fry/m <sup>2</sup> )	0.2-0.6	N/A	≈0.2	N/A	N/A
Stocking density shrimp (post larvae/m <sup>2</sup> )	N/A	≈2	≈2	≈15	≥ 20
Wild fry	Yes	Yes	Yes	No	No
Hatchery fry	Yes	Yes	Yes	Yes	Yes
Natural feed	Yes	Yes	Yes	No	No
Artificial feed	No	No	No	Yes	Yes
Average pond size	3ha	N/A	3/ha	0.5ha	0.5ha
Mechanical aeration	No	No	No	Yes	Yes
Water exchange	Tides	N/A	Tides	Pumping	Pumping

Over 90% of all undertakings in aquaculture in Asia employ either extensive or semi-intensive practices, whereas the remaining 10% use intensive practices, which are mostly prominent in Thailand (Shang *et al* 1998).

Although subject to minor changes through history, contemporary extensive aquaculture practises resemble the earliest versions. The cultured species is kept in earthen ponds or natural compounds at low stocking densities (*i.e.*, few specimens per unit area). Extensive aquaculture often relies on natural fry and feed brought in with tides (Schmidt 2000), and due to limited addition of artificial feeds, generates insignificant outflow of nutrients and waste to natural ecosystems.

When production is intensified through technology application, aquaculture is either semi-intensive or intensive. While management procedures may differ slightly between the two practices, actual stocking density determines whether a specific farm is to be categorised either as intensive or semi-intensive. Apart from stocking density, semi-intensive and intensive practices are thus similar in many ways, perhaps most importantly in terms of reliance on artificial aeration, feed and broodstock (Schmidt 2000). The higher stocking densities are enabled through precise control of pond environment, which however also results in higher stress for the cultured species and coastal resources. This is partly due to over-crowding in the ponds, fluctuating oxygen levels and escalating release rates of organic matter and nutrients. Furthermore, if mangrove that would otherwise take care of nutrients is removed to make room for ponds, natural filtration may fail, which further aggravates water quality.

Besides stressing natural ecosystems, self-pollution is the single most important cause to disease outbreaks and ultimately, to crop failure (Shang *et al* 1998). The most intensive farms hence have a total life span that seldom exceeds 5-10 years after which problems such as self-pollution, disease out-

breaks and acid-sulphate conditions (Gunawardena and Rowan 2005) forces farmers to abandon the land (Patil *et al* 2002). In some cases this has resulted in what Primavera (1997) calls a “rape-and-run” situation, where land is degraded only to be left useless when entrepreneurs move on to new and unexploited areas. For example, in Thailand, 70% of all intensive aquaculture ponds get abandoned, whereas in Sri Lanka, the figure is sometimes as high as 90% (Gunawardena and Rowan 2005). The increased use of intensified practices worldwide is thus one important reason for the escalating environmental and social controversies related to the industry.

To reduce environmental effects, and ensure survival of cultured species, controlling pond environment and effluents thus becomes increasingly important. When production is intensified, this however results in higher investment and maintenance costs. Production costs per kg subsequently become higher when intensity is increased. For example, according to a study conducted in 1994 and 1995 (Shang *et al* 1998), the cost for semi-intensive shrimp production in the Philippines was US\$ 4.01/kg, whereas extensive production was US\$ 2.61/kg. In the same study, production costs in Sri Lanka were US\$ 4.56/kg for semi-intensive and US\$ 3.45/kg for extensive production. Intensive aquaculture, due to its capital and knowledge intensity, is hence seldom a viable alternative for poor people in the South. Bernstein (1981) has earlier referred to this process as “the simple reproduction squeeze”, which shortly can be described as an intensification of productivity resulting in degradation of both natural resources and labour capacity. When higher demands are put on productivity, intensification inhibits traditional solutions such as fallow or crop rotation. This way natural resources are degraded and hence, productivity is reduced whereas more labour in-put is required despite the lowered returns. Simultaneously, more expensive means of production (*e.g.* artificial feed, fertilisers, high tech equipment, fuels etc.) aimed at increasing yields and reducing land degradation put higher demands on economic capital as well as scientific knowledge to manage the production, and also work as an entry barrier for the poor and less educated. When the capacity for economic investments is low at the local level, it is therefore common that investments are made by outsiders, either from urban areas on a national level or by multinational companies. If investors have the ambitions to initiate intensive aquaculture, high demands are also put on technological know-how of the employees. Especially in rural areas, this know-how is sometimes difficult to come by, which is why investors are often forced to bring in external labour. However, they may also use external labour due to other more personal reasons such as kinship. Still, due to the fact that both owners and employees are often outsiders, benefits and spin-off effects are dispersed over a large geographical area, thereby reducing positive socio-economic effects at local level.

More intensive aquaculture practices hence not only result in negative environmental effects, but are also expensive both to initiate and operate. They are therefore seldom a realistic alternative for people with low income. Subsequently, semi-intensive and intensive aquaculture is mostly run by urban entrepreneurs or members of local elites, but seldom poor local people. While this has obvious implications for fairness, it also means that profits from more intensive coastal aquaculture often leave the local communities, since the invested capital comes from outside (Primavera 1997). Extensive aquaculture on the other hand, is generally run as local household enterprises (Shang *et al* 1998), and hence tends to generate more employment opportunities and profits locally vis-à-vis more intensive practises (Rönnbäck 2001b).

Evidence has also shown (*c.f.* Shang *et al* 1998; Rönnbäck 2001b) that most employees at more intensive aquaculture farms are recruited from distant communities and urban areas and brought to the farm, rather than in the vicinity of the farm. In those instances when employees are indeed recruited locally, job opportunities are limited to low-paid, unskilled jobs, while more qualified positions are reserved for outsiders. As pointed out by Primavera (1997), economic benefits from more intensive aquaculture thus seldom trickle down to the residents but rather remain with a privileged few. Findings from the field studies conducted for this thesis further reinforce this argument, which will be further elaborated upon in chapter 7.

## Aquaculture appropriation of mangroves

Perhaps the most important effect related to aquaculture expansion is the depletion of mangrove vegetation. Mangrove forests provide marine and coastal ecosystems as well as humans with a range of ecosystem goods and services. With respect to aquaculture, among these, fry, feed, filtration and erosion control are perhaps the most crucial. Subsequently, if mangroves are removed to make room for aquaculture ponds, these goods and services are inevitably lost. Substituting ecosystem goods and services with technical solutions and imported resources require considerable amounts of money, and more importantly, energy (Gunawardena and Rowan 2005).

In terms of mangrove support to aquaculture, Rönnbäck *et al* (2003) estimated the extent of mangrove needed to sustain aquaculture with post larvae from natural ecosystems. The study included an ecological footprint analysis of shrimp hatcheries in Andhra Pradesh, India, that supply post larvae to semi-intensive shrimp farms similar to those studied in this thesis. For the hatcheries to produce enough post larvae for one hectare of shrimp production, they estimated the mangrove support area to 0.7 to 2.6 hectares. That is, for every hectare of shrimp production an additional 0.7 to 2.6 hectares of mangroves are necessary if the industry is to depend on natural fry produced

by local ecosystems. However, these estimates suppose that the only resource taken from the mangroves is shrimp post larvae. If also other species such as for example milkfish, tilapia and mud crab were to be included in the analysis, the mangrove support area would most probably be larger. Furthermore, mangroves also sustain both shrimp farms and the coastal communities with other goods and services (*e.g.* fish, firewood, and storm protection). If considered in totality, this means that the extent of functional mangroves necessary for sustainable aquaculture would be significantly larger than these estimates. This is also clearly underscored by Rönnbäck *et al* (2003). Still, the study is an illustrative example of the importance of functional mangroves for aquaculture as well as other human and ecological activities and processes in coastal zones. Considering and counteracting mangrove conversion is thus key to more sustainable aquaculture.

Also in terms of social impacts, the loss of mangroves is of importance. Stonich and Bailey (2000) argued that mangrove loss strikes especially hard on poor people and has resulted in displacement, human rights abuses, restricted access to previous common lands, as well as loss of livelihood opportunities (*e.g.* artisanal fishing, clam collection, fuel wood etc). However, mangrove loss has not only resulted in repercussions for poor local people. Simultaneously, increased effluents from aquaculture farms in combination with reduced filtration capacity due to mangrove loss has resulted in disease outbreaks and entire yields of shrimp have been lost in many places. Put together, these negative effects imply that low intensive harvesting of mangrove resources may in fact be of more value to local people and the wider community than conversion into aquaculture ponds, as is illustrated by *e.g.* Gunawardena and Rowan (2005).

## Aquaculture and sustainability

The biggest challenge for future aquaculture development is to find biotechnically feasible, environmentally friendly and socio-economically viable solutions. To achieve this, Patil and Krishnan (1998) argue that aquaculture needs to coexist with and adapt to local people and ecosystems. Appropriate culture practises for achieving this vary from one place to another, depending on geographical, societal and bio-physical preconditions. Furthermore, economic performance and environmental impacts vary from farm to farm, even when the same type of culture practice is applied. This is due to a complex relationship between technical, physical, institutional and socio-cultural/economic factors, all with regional (and local) differences which simultaneously affect farm performance and sustainability.

Shang *et al* (1998) mention several factors that affect economic performance and sustainability in aquaculture. In this thesis, these factors were used together with additional factors based on findings and observations during

the fieldwork, as well as the views of other scholars where specified. This way, a list was compiled, encompassing the most important factors affecting environmental impacts, economic viability and fairness in aquaculture. These are presented in table 2 (in no particular order).

*Table 2.* Factors affecting environmental impacts, economic viability and fairness in aquaculture. Based on Shang *et al* (1998), with modifications and additions by the author.

<b><i>Technical</i></b>	
1.	Water intake and drainage procedures
2.	Number of farms per unit area
3.	Water storage capacity
4.	Water treatment
5.	Water exchange rate
6.	Fallow
7.	Silt removal
8.	Pond area
9.	Aeration
10.	Crop rotation
11.	Feeding practices
12.	Brood stock quality
<b><i>Physical</i></b>	
13.	Mangrove conversion
14.	Soil type
15.	Tidal amplitude
16.	Salinity
17.	Temperature
<b><i>Institutional</i></b>	
18.	Credit cost and availability
19.	Market conditions
20.	Land tenure
21.	Legislation
22.	Mitigation
23.	Externalities
<b><i>Socio-economic</i></b>	
24.	Farmers' management abilities
25.	Empowerment
26.	Local and poor people participation
27.	Resource competition
28.	Poverty
29.	Cultural preferences

## Technical

Water intake and drainage procedures (1) affect water quality in the production ponds. On many farms intake and drainage share the same canal. This means that effluents from the farm may be reintroduced without treatment, thereby reducing water quality. If the total number of farms in one area (2) is high this problem is further amplified if the intake of one farm is located in direct connection to the drainage of another. In addition, excessive congregation of farms may result in cumulative effects that further increase pressure on coastal ecosystems. If considered individually, some effects might be of minor importance for the environment. However, the total consequences of a number of individually small projects might be highly significant when considered collectively (Mandelik *et al* 2005). One example is habitat loss and fragmentation of ecologically critical areas (*e.g.* mangroves) when many developments congregate in the same area. Pollution can also be a significant result from too many developments in the same area. Zubair (2001:474) provides an example of this;

[...] in Southern Sri Lanka, a refinery, a central tannery, a caustic soda processing plant, and prawn complex were all proposed in 1999 and were evaluated independently. The effluents from all of these enterprises led to a common estuary. The potential ecological damage to the estuary may not be evident when projects are considered in isolation.

By increasing water storage capacity (3), and keeping water in storage ponds for water treatment (4), *e.g.* pre-filling, biological treatment and sedimentation etc, these problems can be counteracted to some extent. By reducing water exchange rates (5), natural pond productivity, fuel consumption and costs for pumping water can also be saved. Another solution is to fallow (6) the ponds after harvest, which reduces the need for chemicals. A period of fallow also enables manual silt removal (7) since the remaining crust can easily be removed to reduce the amount of chemicals and other waste remnants before the next production cycle. Regarding water quality, also individual pond area (8) is of importance, since larger ponds are more difficult to manage and control.

With higher stocking densities artificial aeration (9) becomes necessary, which increases management costs and dependence on non-renewable energies (*e.g.* diesel fuels). This is seldom considered in sustainability assessments of aquaculture, but turned out crucial based on testimonies of farmers in the study areas. According to them, artificial aeration has become of more serious concern lately, since fuel prices have escalated significantly, resulting in increased production costs. Crop rotation (10) or polyculture can be used to further reduce costs and improve efficiency (Schmidt 2000). For example, experiences from polyculture of shrimp and milkfish in the Philippines have shown that it is an effective way to maximise natural aeration and



use of algal production. Milkfish is an herbivore species primarily feeding on algae, and similarly to other finfish stir the water when swimming, hence aerating water and minimising accumulation of organic matter (Shang *et al* 1998). If combined with animal husbandry and agriculture, production costs can be further reduced by using by-products and other services from different farm activities for aquaculture, *e.g.* erosion control, filtration and making feed and fertilisers (Hilbrands and Yzerman 1998). By improving feed formulation and feeding practices (11), also the total amount of added feed can be reduced, thereby limiting feed amounts, costs and water pollution. Broodstock quality (12) from hatcheries is also of importance, since it affects growth-, survival- and profit rates.

### **Physical**

As discussed earlier in this chapter, mangrove conversion (13) is perhaps the most important factor affecting the sustainability of aquaculture. Mangroves supply both humans and nature with a range of ecosystem goods and services. Consequently, conversion into aquaculture facilities severely degrades the coastal ecosystem. Soil type (14) is of importance for farm performance. For example, acid-sulphate and sandy soils reduce profitability and increase the risk of disease outbreaks. Observations and findings from the fieldwork also indicate that production costs and dependence on fossil fuels are directly linked to tidal amplitude (15) of the farm's water source. With higher amplitudes, tides can be used for water exchange. Lower amplitudes means this work has to be performed by mechanical pumping, thereby increasing energy consumption and costs. Salinity (16) and temperature (17) are other factors that affect crop growth- and survival rates, since pond environment has to mimic natural living conditions of the cultured species.

### **Institutional**

In previous studies of aquaculture, institutional factors have often been underestimated in terms of their effects on farm performance, and more importantly on fairness. The possibilities and conditions for being granted loans for aquaculture developments, *i.e.*, credit costs and availability (18) affect both production costs and fairness. Apart from the obvious increment in production costs if interest rates are high, loan conditions often inhibit less empowered socio-economic groups of society (*e.g.* poor people) from being granted credits for new investments. For example, results from field studies in Eastern Sri Lanka<sup>5</sup> indicate that, according to local shrimp farmers, the most important problem associated with aquaculture in the area was the

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<sup>5</sup> In addition to the main field study area in North-Western Sri Lanka, in October 2005, a pilot study was conducted in the Eastern Province, mainly in the vicinity of Batticaloa. However, this study included visits only to 5 farms. Although the pilot study provided some interesting results contrasting the situation in the North-Western Province, plans to conduct a more thorough study had to be abandoned due to the worsening security situation in late 2005.

[un]availability of loans. Similar problems can be derived from market conditions (19), since high prices on input goods and services, technology and education etc, further restrict access to the industry, especially for the poor. Another factor that affect who is to engage in aquaculture is that of land tenure (20). Fair entitlement to land, ownership, procurement procedures and access can be hard both to define and regulate. In India for example, aquaculture developments have reduced access to previously communal lands to such an extent that it was regarded as the most important social impact in the affected district (Hein 2002). This is of course dependent on legislation (21) and policies proposed in *e.g.* planning and coastal management schemes. One way of reducing social impacts of aquaculture is therefore to apply measures such as mitigation (22) to ensure compensation and fair sharing of coastal resources. This becomes even more crucial when considering the externalities (23), *i.e.*, indirect costs, of aquaculture. These are not normally included when valuing economic viability, since they are not directly perceived by farmers and hence not experienced as real costs. Externalities from aquaculture include *e.g.* negative effects on surrounding agriculture, reduced drinking water quality (due to salt intrusion), lower natural fish production (affecting coastal fisheries), and increased vulnerability to natural disasters such as typhoons, storm surges and tsunamis. Especially the latter two are due to loss of mangrove that would otherwise provide coastal protection and other mangrove related goods and services. The externalities from aquaculture are thus the true production costs, in contrast to the directly apparent (Primavera 1997). When considering aquaculture viability and sustainability, externalities are hence not only crucial to account for, but they should also be integrated in mitigation strategies, though this is hardly ever the case.

### **Socio-economic**

The farmers' management abilities (24) affect chances to successfully run the farms in an economically viable and environmentally sustainable manner. Management abilities depend much on the farmers' economic standing and empowerment (25), since this sets the conditions for accessing new technology and information (Abhayaratna 2001), and also, how institutional factors (especially 20-21) are coped with. Another factor affecting fairness is the level of local and poor people participation (26), *i.e.*, who (*e.g.* locals, non-locals, poor, middleclass, rich etc) are benefiting from the activity (Pullin 1993). In addition, when mangroves or coastal wetlands are converted into aquaculture ponds, unemployment for unskilled labourers in the local area increases since their livelihoods (*e.g.* small-scale fishing and crab collection on communal marsh lands) are negatively affected. To ensure fairness, *i.e.*, to enable fair sharing of resources, costs and benefits, it is therefore important to strive for local-, and poor people involvement, but also to consider resource competition (27) with other people and economic activities in the farm vicinity. If poverty (28) is widespread in regions where

luxury food products (*i.e.*, where the value is determined more by social/cultural demand than nutritional content) are the main crop, it also means there will be few opportunities to sell the products to local consumers, buyers and middlemen. Apart from missing out of the nutritional value of local consumption, this further reduces trickle-down effects that would otherwise stimulate the local economy. These market issues are also dependent on cultural preferences (29), *e.g.* which species are preferred for consumption on the local market and choice of species to culture. For example, in the Philippines, milkfish (*Chanos chanos* Forskål) is the most preferred species both for culture and consumption, which facilitates inclusion of local middlemen, marketing and increases sales price, and hence, potential profit and spin-off effects from commerce at local and national markets.

### 3. Views and approaches to environment and development

There is an unequal exchange of biophysical resources between distant segments of the global socioecological [...] system, facilitating development and infrastructural accumulation in some regions at the expense of other, economically and ecologically impoverished ones” (Hornborg 2007:11).

Humankind as a species tends to think and act locally. However, today it is apparent that cumulative local human activities have come to generate effects of global proportions (Moran 2007). Simultaneously, it is increasingly obvious that most processes in society and nature are intertwined. Still, most people are involved and embedded in everyday activities and ideas that are mentally disconnected from humankind’s dependence on natural resources, and more importantly, our destruction of nature (Atkinson 1991). While Odum and Odum (2001) explain this unawareness as a result of people staring them blind at detail, Hornborg (2001) argues that this disconnectedness is a result of our Cartesian way of compartmentalising knowledge, which produces an illusion of humankind’s independence from nature, and thus renders environmental management issues unimportant.

There are many ways of explaining humankind’s conceptual disconnectedness from nature, and they have changed substantially through time. Therefore, this chapter provides an overview of some of the most important schools of thought and theoretical perspectives within the environment and development discourse, with the purpose of putting aquaculture under scrutiny in such a context.

#### Development conceptualised

Many schools of thought have emerged throughout the latter decades, all aspiring to explain and/or trigger development, and explain the opposite, *i.e.*, under-development. Most of these development theories emerged during a few decades following WWII. Today, grand all-inclusive development theories are often viewed as insufficient and outdated. Thus, asking questions about unfair exchange and exploitation would today by many seem obsolete (Hornborg 2001). This is perhaps especially true in the context of aquacul-

ture and its contribution to development, where positive effects are often taken for granted without consideration of existing theories, trends and empirical evidence. However, some contemporary scholars (*e.g.* Eisenmenger and Giljum 2007; Hannerz 2004; Hornborg 2001, 2007) argue that at least some aspects of development theories may still be valid today, and offer a means for more theoretically and empirically based strategies for development. Therefore, some of the theoretical perspectives mentioned here will ultimately be used as a framework for relating the remaining chapters of the thesis to discourses of environment and development.

During the past centuries, some countries have experienced unprecedented growth and concentration of wealth, while others have suffered from decreasing living standards, mainly for the poor and middle classes, as well as environmental degradation (*c.f.* Moran 2007). From a wider perspective, wealth is not equal only to monetary assets. As argued by Odum and Odum (2001) real wealth is *e.g.* food and livelihood security, shelter, fuels, forests, fisheries, land, buildings, art, music and information. Hence, money alone is not wealth, but rather a means for accessing real wealth.

To explain the trend of uneven distribution of wealth and development, Perez (2004) argues that there are centrifugal forces in motion worldwide, which reinforce the uneven patterns of resource allocation and wealth distribution. Despite the wide variety of perspectives, all aspiring to explain and illuminate the reasons and processes that lie behind this unfairness, the uneven pattern of resource allocation and consumption has not come to a halt. As noted by Binns and Nel (1999), development theory therefore seems to have come to a dead end, at least in terms of its ability to come up with viable solutions for creating a fairer world. To understand why, it is therefore important to consider the various applications and meanings of development as a concept through history, which have led to the current situation.

## Dichotomies of development

During the Enlightenment it was believed that to make humankind happier and free from cruelty and injustice, it is necessary to apply reason and empirically based knowledge to ultimately achieve progress (Hamilton 1992). At the time, the main task of science, and overall aim of progress was to increase humankind's control over nature, thereby making it possible to eliminate those aspects of nature that were harmful to humans. Whereas this overly anthropocentric and dominant attitude towards nature was shared by many philosophers, they however strongly opposed domination and exploitation of non-western cultures and peoples, which was during the latter half of the colonial era a common practice in the name of progress (Hamilton 1992).

Much as a result of colonialism, the increasing polarisation of different peoples ultimately led to a division of cultures and states into the West, and as Hall (1992) puts it: "the Rest". This dualistic view is not entirely problem

free. Since the two terms do not contain any single meanings, but rather represent a complex mix of ideas of what is western and non-western, they become highly subjective and difficult to apply to real situations. Furthermore, how the West and the Rest are defined today, and what terms are used to describe them, is in fact highly dependent on power relationships that were established long ago, especially during colonial times (Hall 1992). Therefore, it is important to bear in mind that the “West” is more a historical construct than geographical classification (Hall 1992). Still, it is a construct that, due to it being based on power relations, is being reproduced as social and economic relations build on asymmetrical resources and risks distribution (Hornborg 2001).

The most important difference today is perhaps that properties that are commonly conceived of as western (*e.g.* developed, modern, industrialised, secular etc.) are not anymore limited to particular geographic areas, but are rather life styles and ways of organising society that can be found worldwide, in the North as well as in the South, and in rural as well as urban areas. During colonial times, the distinction between North and South was indeed more conceivable in an explicitly geographical sense. But in today’s globalised world, where people and capital move both faster and more freely around the world, almost regardless of national boundaries, referring to development and relationships between people, states and economies by using dichotomies such as West-Rest, North-South, Developed-Underdeveloped etc. becomes arbitrary. Instead, it may be more appropriate to refer to a “global North”. Although it is unclear who coined this concept, it is today widely used in the development discourse. As opposed to the concept “North”, which implies a defined and delimited geographical area, the concept of global North stems from the notion that characteristics normally associated with countries pertaining to the North can be found worldwide, regardless of them being located in the North or South. That is, it refers to clusters of wealthy and westernised people and ideas that are dispersed globally, hence transcending geographical boundaries. One example are the elites and growing middle classes in the South, whose living conditions and consumption patterns far more resemble those of the West than those commonly associated with developing countries. Despite that these people are geographically located within the South; they are as dependent on uneven transfers between cores and peripheries<sup>6</sup> as are the peoples in the North.

Similarly, it is possible to refer to a “global South”, as a counterpart to global North, represented by poor and marginalised groups of people, who in a similar fashion may be found worldwide, in the South as well as the North. Indeed, there is growing consensus, that political boundaries are therefore no longer appropriate to conceptualise such dynamic and cross-boundary relationships (Hornborg 2007) as North-South relations. Rather such definitions

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<sup>6</sup> The concepts of cores and peripheries are defined and further explored on page 39.

are to be used in an abstract sense, denoting structural relationships between different segments of the world, as opposed to absolute geographical or political units (Hornborg 2001).

Henceforth in this thesis, it is argued that the western way of living can be found anywhere, in the North as well as in pockets located within countries otherwise referred to as the South, and that what is important to emphasise and study is the characteristics of interactions cross local and global scales. Thus, when referred to in this thesis, the term West is substituted by the global North. However, when referring to specific geographic regions that are commonly perceived as developed, the term used is simply the North, defined as comprising the wealthiest states and regions, *i.e.*, North America, Europe, Japan, Australia and New Zealand.

Drawing on what has been discussed above, and on Sachs (1992) definition of the industrialised society, the global North thus hereon implies a geographically un-specific life style that promotes exponential economic growth and consumption, supported by increasing throughput of energy, *i.e.*, escalating rates of energy input and resulting output of waste. In this context, exponential growth implies that as the economy grows, so does the rate of further expansion. However, since ultimately all economic processes depend on energy, this is problematic, because the global resource base simply does not grow following the same exponential trend. That is, since natural resources are either stock or flow limited<sup>7</sup>, as opposed to growing exponentially, it seems only logical to assume that energy consumption rates may not be exponential for too long. The problem is that that the growth based notion of development that is being promoted by the global North conveys an illusion of ever escalating growth as plausible, although it contradicts the very notion of “sustainable” development. Similarly, Hornborg (2001) therefore argues, that to believe in the feasibility of infinite industrial expansion, is to disregard the fact that as the industrialised society grows so do the costs of its maintenance (*i.e.*, needs for energy inputs). As pointed out by Sachs (1992), the goal of the global North therefore needs to be questioned, since the world’s resources are probably not enough if all nations and people were to follow the industrial example promoted by the global North.

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<sup>7</sup> By stock limited resources are meant those resources that have been accumulated and stored during longer periods of gradual environmental production, resulting in accumulation of for example minerals, water, biomass, oil etc. When a stock limited resource is used faster than it is restored by environmental processes, it is hence limited in terms of the stocked amount available for extraction. Meanwhile, flow limited resources are those flowing continuously without resulting in storage, such as sunlight, rain, winds, tidal force etc. The work potential of flow limited resources is limited in terms of the rate of inflow and how much can be harnessed, whereas the work potential of stock limited resources are thus limited by the quantity already stored, and available for use by humankind (*c.f.* Odum 1996a).

## Defining sustainable development

Sustainable development has become a major buzz word in latter decades. However, it is not as self-evident as it may appear *prima facie*. On the contrary, there are several competing and sometimes contradicting definitions, which, depending on context, withhold highly different meanings.

Most contemporary definitions draw upon the formulation of sustainable development coined by the World Commission on Environment and Development (WCED) from 1987, in the report entitled “Our common future”, commonly referred to as the Brundtland report. In the report, sustainable development is defined as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (WCED 1987:43). It thus entails challenges such as sustainable, long-term use of limited resources and fair sharing and distribution between different social groups, as well as generations to come (Eisenmenger and Giljum 2007). However, such vague definitions leave much room for personal interpretation, and thus accommodate several objectives and proposals (de Vries 2007). They also imply that sustainability is something that can be intuitively appreciated.

Another flaw of contemporary definitions of sustainable development is that the concept implies a “business as usual” situation, or in other words, that development can go on as before, *i.e.*, in terms of economic growth based on exponential increase of resource extraction and consumption. Paradoxically, already at the 1972 United Nations conference in Stockholm, there was consensus that the North was actually building their development at the expense of the South, and therefore, there may be reason to question growth based approaches to development. However, this notion had disappeared when the United Nations reunited 20 years later at the 1992 WCED conference in Rio. Then it was instead established that there is no contradiction between exponential growth and sustainability (Hornborg 2001). To explain part of this paradox, Eisenmenger and Giljum (2007) argue that when embracing policies of sustainable development, the richer countries have been able to hide the true costs and basis of their development through outsourcing material intensive production, and thereby “dematerializ[ing] their economy without changing their lifestyles and consumption patterns” (Eisenmenger and Giljum 2007:290). Consequently, the quest for sustainable development has come to represent a world view that, as Hornborg (2001:29) puts it: “declares capital accumulation in the core completely innocent with regard to poverty and environmental problems in the South”.

Failure to define and clarify what is meant by sustainable development thus far too often has resulted in inappropriate measures, since it makes people believe that it is possible to go on as usual. Another reason is that many approaches to assess impacts from development initiatives fail to consider distributive aspects of development, as well as interactions between activi-



ties at local and global levels. Focussing on flows of energy and materials within and between different regions is an alternative approach that makes it possible to evaluate the behaviour of systems and interactions with natural and societal process at local and global levels, hence making it possible to predict best alternatives (Ulgiati *et al* 1995). In this thesis, distributive aspects and interactions between local and global levels are therefore exemplified by aquaculture development, but with the more general aim of exploring ways for assessing, monitoring and enabling more appropriate patterns of production and consumption at par with a more realistic definition of sustainable development.

Perhaps the two most influential perspectives in terms of defining and negotiating the significance of sustainable development are those found within economic and ecological disciplines. Within economic sciences, the belief in infinite economic growth as the exclusive remedy for development problems stems from notions of the world that are rooted and highly influenced by global North ideologies, which often fail to acknowledge the dependence of economic processes on natural resources and energy. Other sciences such as ecological economics and human ecology, promote a more ecological approach to development. There is significant tension between these two paradigms, within science as well as politics. This tension may to a certain extent be explained by a discrepancy between ecological and economic world views, and resulting differences in terms of how the world should be studied and managed. This gap also depends much on whether development is seen as a linear or cyclical process. For example, most economic perspectives tend to view production processes as linear, in the sense that resources are transformed into products and waste. Products are then sold to consumers who produce even more waste when the products have been consumed. The economic perspective stops there, whereas the ecological perspective provides a perhaps more complete view. In nature, there is no waste, since all materials are re-used, re-cycled and re-organised through feedback mechanisms, and are therefore not considered as waste, but as inputs that are fed back to other parts of the system. Recycling materials is common practice in nature and may therefore serve as an example of how society may be better organised. Hence, reaching sustainability in production and consumption ultimately means mimicking the processes of nature, which are highly integrative and cyclical. Therefore, in any study or policy relating to sustainable development, adopting cyclical views and solutions is key (Capra 1996).

To understand the internal contradictions of sustainable development as a concept, it is however first necessary to define the concept of development, since this affects what is focused upon in development related research and policy, and how research findings are related to the general discourse of development, including goals such as poverty alleviation, sustainable development etc. So what is then meant by development? Hagberg (2006) appropriately points out that the concept has been defined in several ways; as eco-

conomic growth, modernisation, distributive justice, and socio-economic transformation etc. Out of these, economic growth is the interpretation that has impacted most on the contemporary development discourse, and as Norgaard (1994:90) puts it, represents “the hard core of development”. A definition of development as economic growth entails that non-growing economies are depicted as stagnating, backwards and un-wanted, and that a high GDP is seen as a prerequisite for realising development (Friman 2002).

As pointed out by Nobel Prize winner Amartya Sen in 1989, growth based development approaches are especially strong within the economic sciences, and more specifically so in neo-classical economics. Sen (1989) therefore argued that although standard economics often neglect issues such as poverty, misery and well-being, enhancing living conditions for people remains an essential part of development, and therefore needs to be the goal of all economic exercise. There are, however, other factors than economic growth that influence living conditions, such as capabilities, well-being, livelihood security and fairness (*c.f.* Chambers 1997). As argued by Eisenmenger and Giljum (2007), measuring social and economic well-being by using economic indicators only, has therefore resulted in major shortcomings. In fact, much evidence suggests that there are no correlations between material prosperity, welfare and happiness (*c.f.* Sen 1989; Bäckstrand and Ingelstam 2006). Therefore, the development concept needs to include more variables than mere economic growth.

Still, and regardless of what variables or definitions one chooses, there is most often a discrepancy between discourse and practice, *i.e.*, what is aimed for in development efforts is rarely reflected in reality when those ideas are implemented (Olivier de Sardan 2005). This may in part be explained by the fact that people formulating development policies, and those individuals who are to implement them, are seldom the same, and hence may carry different perspectives, abilities and agendas.

Norgaard (1994) further argues that the multitude of definitions and practices of development have meant that a combination of several beliefs have been merged into a single whole, which of course has resulted in internal contradictions. Still, the wide-spread belief in development (and the implicit emphasis on economic growth) creates what Norgaard (1994) calls a collective certainty, *i.e.*, a shared social belief that is seldom criticised or debated in mainstream circles. From this follows that although concrete aspects of development may be debatable, it is highly improper to question the validity of development *per se*. Rist (2006) therefore argues that development can be seen as the religion of modernity. He does so by drawing on a Durkheimian definition of religion, *i.e.*, as an indisputable truth that transcends ideological divisions and binds society together (Rist 2006). The near to global consensus of economic growth as a remedy for development has therefore resulted in that opponents to growth-based development strategies are pointed out as bad citizens, and that although individually one may not be convinced of

economic growth as a solution to all development problems, in public it is necessary at least to agree to its plausibility (Norgaard 1994).

Whilst development is a concept with many interpretations, sustainability is not less complicated a concept. Ulgiati and Brown (1998b) list the main interpretations of sustainability and its linkages to: (a) resources availability, and (b) resource use efficiency, (c) fairness in terms of how resources are shared between populations today, and (d) how they should be conserved for future generations, and (e) how resources are constrained by environmental dynamics. What makes sustainability complicated as a concept, in addition to it accommodating various interpretations, is that most approaches to assess sustainability concentrate on only one or a few of the above mentioned aspects.

The inherent paradox of sustainable development may thus be summarised as follows: whereas sustainability implies levelling off global use of energy and resources, development implies continued expansion of production and consumption. The question is, therefore, from where a society that prioritises growth is to draw its resources? As argued by Eisenmenger and Giljum (2007), any realistic definition of sustainable development should therefore encourage decreased rather than increased resources extraction and use, which is only possible by decreasing global average consumption and expansion rates. Indeed, this need for adapting society to resource scarcity is increasingly stressed, especially by advocates of alternative definitions of sustainable development, such as resilience (*c.f.* Walker *et al* 2006) and the pulsing paradigm (*c.f.* Odum 2007).

Drawing on what has been discussed above, whenever sustainable development is referred to in this thesis (apart from where otherwise stated) it implies a process of production and consumption that is not linear but rather pulses, yet includes transition into a socio-ecological world system that promotes well-being, social, political and economic fairness, fair distribution and sharing of resources, and long term (if oscillating) ecological equilibrium<sup>8</sup>. However, using terms such as equilibrium in this context may be confusing since it implies a steady state. Living systems in fact never reach equilibrium, but flux continuously. A completely steady state, *i.e.*, equilibrium is only reached when all energy transformation processes come to a halt, which is in fact a common definition of death (Capra 1996). As noticed by Odum and Odum (2001), pulsing patterns are indeed apparently better at enabling long term efficiency and overall productivity, and therefore, policies need to abandon steady state conceptualisations.

Equilibrium in this thesis therefore implies a pulsing “steady” state that maintains a desirable structure and function, yet characterised by continuous oscillations of energy and material flows. The most important difference

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<sup>8</sup> See the discussion on pages 60-61 for a definition and explanation of the pulsing paradigm that has inspired this definition.

between this definition of sustainable development and that coined by the Brundtland commission, is thus that it suggests pulses of increasing and decreasing levels of energy consumption, and acknowledges that ever increasing consumption is neither wanted nor possible.

In reality however, many development initiatives are based on a vision of global industrialisation and societal development after a western model, *i.e.*, through economic growth driven by top-down approaches and external aid and investments. This way of thinking of development is still central within economics and politics, and today constitutes the mainstream of international aid and strategies for sustainable development worldwide. However, this vision has not been fulfilled (Stiglitz 2002). Some scholars have therefore come to criticise this view, and failure, of development (*e.g.* Binns and Nel 1999; Stiglitz 2002). Binns and Nel (1999) also argue that one of the reasons for this failure is the free-market ideology on which contemporary society is based. As Hornborg (2001) points out, the market has proven a successful institution because it makes the exploitative nature of resource extraction and exchange less obvious, than for example, by having colonies of slaves with the purpose of keeping the modern industrialised society running. Though slavery and other obvious forms of domination and exploitation are on the decrease today, resources still need to be taken from somewhere if growth is to continue exponentially. Therefore, it may be argued that exploitation needs to find other ways that at least at a glance appear more ethical.

One explanation to why exploitation is always necessary, at least if development is to be based on infinite growth, can be found in the field of thermodynamics, which is one way to study production and consumption in terms of energy transformations. According to the second law of thermodynamics, all production (*i.e.*, energy transformation) is a dissipative process that converts raw materials into finished products and produces entropy (disorder) in the process. The second law of thermodynamics dictates that all energy transformation processes move towards increasing entropy, *i.e.*, from order to disorder (Capra 1996). This disorder is then necessarily transferred somewhere else through dissipation. It can however be transferred in different ways; for example in space, *i.e.*, from one place to another, or in time – *e.g.* from one generation to another. The concept of entropy was initially coined with the purpose of measuring the dissipation of energy into heat (Capra 1996). Eventually however, the concept was refined and incorporated into other natural but also social science disciplines (*c.f.* Hornborg 2001).

Although hitherto more used metaphorically, the concept of entropy has also been applied to social contexts. For example, among others Hornborg (2001:11) argues that “industrialism implies a social transfer of entropy”. Similarly, Capra (1996), points out that creating world order always means simultaneous creation of disorder. Furthermore, the generation and transfer

of disorder may be seen as exacerbated by capitalism<sup>9</sup>, and international trade as a system of intergenerational and spatial transfer of entropy. Therefore, Hornborg (2001) argues, criticising production and trade as it commonly takes place under capitalism is not as much a value judgement as it seems, since there is in fact a natural law suggesting that the generation of order in one place can only be achieved by creating disorder elsewhere (in time or space). This argument may be exemplified by the current organisation of world trade. The ability of a majority of the world's population to participate in international trade is limited. Consequently, this has resulted in poor people being seemingly abandoned by the Western-dominated global economy, and some countries are therefore today even more economically marginalised than before (Stiglitz 2002). In this way, some peoples and regions have been appointed losers, or in other words, receivers of entropy, by some societal mechanism, such as for example war, colonisation or imperialism etc. The market may thus be seen as yet another such mechanism, albeit with less visible un-ethical connotations.



*Figure 2.* Harvesting aquaculture products in the Philippines. Global capitalism and trade relations make local indigenous and scientific knowledge systems merge with the purpose of bringing local aquaculture products to the global market, affecting environment and development at global as well as local levels. Photo: Daniel A. Bergquist, Alibagon, Makato, Philippines, 2006-01-26.

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<sup>9</sup> Drawing on Giddens (1997) definition, capitalism in this thesis refers to an economic system that encourages eternal expansion of production, consumption and accumulation of wealth.

In other words, the South may be seen as forced to absorb entropy due to existing trade relations. Thus it seems, that poor people in the South themselves have to take responsibility for their own situation and future. Binns and Nel (1999) therefore argue that local initiatives are among the few realistic options for local development to actually take place. This is one reason why locally based development strategies have gained such popularity and support lately. Concepts such as local economic development, self reliance, local governance and community based management are all based on this the latest paradigm in development; where the dominating view is that development can only be achieved by local people themselves, and consequently has to be initiated and driven from the local level.

### The importance of benefit distribution for local development

Money is merely one of many assets to improve individual living conditions in terms of capabilities and access to utilities etc. It is however one of the most important assets in terms of contribution to local livelihoods (*c.f.* Hajdu 2006). For analysing development, it is therefore crucial to understand income generation and distribution, and linkages to local, regional, and global processes. In comparison to other forms of capital, analysing income generated from aquaculture was therefore prioritised in the fieldwork for this thesis, *e.g.* by emphasising spatial distribution of income and expenditures.

Anand and Sen (2003) confirm the importance of distributive aspects of income for understanding fairness and poverty issues in development. In terms of aquaculture contribution to the local economies, how and where farmers spend their incomes, that is, how profits and other benefits are distributed in space is therefore of significance (Bailey 1988). Anand and Sen (2003) further argue that many efforts to analyse and measure income fail to be distribution sensitive. This is partly because most contemporary income assessment tools aim at producing generalised results, *i.e.*, by calculating average values of income, which means distributional aspects are lost. A more appropriate approach to assessing income distribution would thus demand explicit focus on individual incomes (Anand and Sen 2003). However, individual data is most often un-available when assessing incomes on larger scales, especially in rural areas of the South, which results in limitations in terms of practical feasibility. In this thesis, spatial distribution of income, profits and expenditures, were therefore studied on individual levels, the aim being to estimate how much of the farmers' incomes stays within the local areas, and how much is dispersed elsewhere.

## Dependency and neo-colonialism

Albeit seldom referred to today, dependency theory is an alternative perspective that offers opportunities for concentrating on distributional aspects of development. As suggested by Hornborg (2001), one possible way of constructing a more empirically based argument inspired by dependency theory may be to draw upon experiences and concepts from natural sciences, such as energy, or *emergy*, as will be argued later in this thesis. Here, an introduction is therefore provided to dependency theory, and its opportunities and constraints, which will later be used for proposing a more rigorous approach that incorporates dependency theory with *emergy*.

Dependency theory proposes that most development problems stem from exploitative relations and resource transfers between regions. Such interactions across state boundaries have been increasingly easy since the time of colonialism, mainly due to new transportation possibilities and, as argued by Blaut (1977), the establishment of global capitalism, which has made national boundaries increasingly porous. As Bardhan (1989) puts it, dependency theorists argue that capitalism in this sense opened for un-even transfers of value between capital-poor peripheries and capital-rich cores, or in other words, accumulation of capital in one place at the expense of another.

Eisenmenger and Giljum (2007) list three geographical categories that, according to dependency advocates, have resulted from the global division of labour and trade. These are: (1) cores – defined as countries or regions engaged in high-tech, capital intensive, and high profit production, (2) peripheries – which are mainly engaged in low-tech, labour intensive production, and (3) semi-peripheries – countries that prevent excessive polarisation between the cores and peripheries by maintaining trade flows in both directions, that is, to and from both cores and peripheries. Semi-peripheries are otherwise characterised by similar modes of production as core countries, whereas other features resemble more those of peripheries.

In capitalist trade, periphery countries (*i.e.*, those not at the centre of the global market economy) are pointed out as losers, since they are subject to expropriation by foreign capital in alliance with elite minorities from within their own countries (Bardhan 1989). Meanwhile, the core (or rather, global North) imposes unfair terms of trade on the periphery, due to which exploitation is rendered possible (Griffin and Gurley 1985). In this view, peripheries are seen as dependent on the cores, who dictate terms of trade and influence opportunities in the peripheries. However, it may also be argued that dependence is rather reversed, in that cores depend on having peripheries to exploit. This is perhaps especially apparent in the case of export-oriented aquaculture, where local coastal socio-ecological systems (as a representative of the South) support foreign buyers, middlemen and consumers (the core) with environmental resources and cheap labour, thereby enabling wealth accumulation in the core.

As pointed out by Hannerz (2004), an important concern within dependency theory, other than economic and political domination, is therefore increasing control and exploitation of natural resources in the peripheries. Today, core-periphery conceptualisations include political, economic and material domination and exploitation, as well as cultural aspects, *i.e.*, cultural imperialism that imposes an ideal (western) way of living on previously non-western cultures/societies, thereby diminishing also cultural diversity (Hannerz 2004).

Proponents of the neo-colonial perspective take this argument further and theorises the relationship between previously colonised states and their colonisers. The argument is that although Western domination of the South in a political sense is over since the fall of colonialism, indirect control is still apparent in most North-South relations (Jentsch and Pilley 2003). That is, despite formally independent and de-colonised, the former colonies, as well as other countries in the South, remain dominated (Hall 1992). Neo-colonialism is thus sometimes referred to as “imperialism without colonies” (Griffin and Gurley 1985:1092). The argument that colonialism in this sense has a “modern dress” was first argued by the Indonesian president Ahmed Sukarno in 1955 (cited in Hodder-Williams 2001:2239), who claimed that this new form of colonialism is based on economic or intellectual control, and is materialised in unfair relations between, and within, nations. Control is thus performed in other ways than political, such as in research collaboration (Jentsch and Pilley 2003), aid, trade (Potter *et al* 2004) and other forms of economic, technological, and cultural dominance (Hodder-Williams 2001). This said, according to Cohen (1974) it is still possible to distinguish two main ways by which neo-colonialism operates; (1) by generating unfair resource allocation, and (2) by promoting tastes and consumption cultures based on western values. However, economic dominance remains as perhaps the most important manifestation of neo-colonialism, since the world consists of several political systems, but is integrated only by one economic market. Regardless of which, the outcome of neo-colonialism is, according to the 1960s Ghanaian leader, Kwame Nkrumah (cited in Young 2001:47):

that foreign capital is used for the exploitation rather than for the development of the less developed parts of the world. Investment under neo-colonialism increases rather than decreases the gap between the rich and the poor countries of the world.

## Critique and opportunities of the neo-colonial perspective

Proponents of dependency theory and the neo-colonial perspective have received significant critique for being too one-sided and narrow-minded, since many described the core-periphery conflict in geographical terms only. That is, as a conflict between nations, rather than between groups of people



and classes, and/or regions. Some dependency theorists also used tautological explanations of what processes are typical for cores and peripheries, *e.g.* by defining accumulation as what goes on in the core, and the core as the place where accumulation occurs (Hornborg 2001). Also, they argued too strongly that, under capitalism, it is impossible to achieve development in peripheral countries. This, however, has been refuted in latter decades, since some South nations have experienced improvement despite connecting to the global capitalist economy (Griffin and Gurley 1985). As pointed out by Amsden (1979), there are indeed examples of economic “miracles” (*e.g.* Taiwan) that strongly contradict the radical standpoint of dependency theory.

Despite this criticism and the fact that these arguments were formulated some 30 years ago and are largely neglected today, among others Hannerz (2004) and Rist (2006) claim that they still offer some opportunities. Furthermore, the notion of unfair relationships between cores and peripheries, as exacerbated by international trade, has also recently been recognised within other fields, such as systems ecology (*c.f.* Rydberg and Salomonsson 2004) and world systems theory (*c.f.* Hornborg 2007). As argued by Gunder Frank (2007), these fields offer alternative approaches for improving the neo-colonial perspective, in that they emphasise flows of absolute and relative contents of energy, and how entropy displacement works in detail. Even more so today than when dependency theory was formulated, resources continue to flow between regions and new cores and peripheries are emerging. Put together, this implies that rather than completely rejecting core-periphery conceptualisations and neo-colonial processes, they deserve further refinement and scrutiny (Hannerz 2004).

## Neo-colonial transfer of resources and costs

Much that has been discussed above can be traced back to the Marxist argument that capitalism inevitably results in inequality. Peet (1977) early noted that capitalism seems capable only of generating wealth for a few, and poverty for many. Although such Marxist ideas admittedly have inspired this thesis to some extent, it is also important to underscore here that such simplified explanatory models simply do not suffice. Rather, it is crucial to realise that the shortcomings of most development approaches and theories (including many Marxist perspectives) can be derived from the failure to recognise that all economic and production processes ultimately depend on natural resources (Bunker 1985), and that human activity hence simultaneously depend on, and affect, social and natural processes on a variety of temporal and spatial levels. As clearly pointed out by *e.g.* Harvey (1996a), the geographic and temporal dimensions of accumulation have far too often been ignored. Also within Marxist theory, time-space dimensions have only been fragmentarily addressed.

However, some scholars (*e.g.* Bunker 1985; Hornborg 2007) have emphasised the way in which resource and energy extraction and use is organised, and how this affects development possibilities, the environment, and specific regions or nations. As argued by Bunker (1985), the use, transfer and distribution of human and non-human energies, may indeed provide insight into development and fairness, and is also crucial for expanding the time-space dimension of production and accumulation. Across the world, resources are being extracted, transformed and traded in exchange for energies derived from or transformed in other regions (Bunker 1985). Therefore, one way to strengthen the spatial and temporal emphasis of accumulation may be to study resource transfers between the North and South, or in other words, energy flows between regions, (*c.f.* Bunker 1985; Odum and Odum 2001).

As noted by Odum and Odum (2001), investments by agents of global capitalism rapidly transport resources such as minerals, forestry, fisheries and agricultural products from peripheries to cores. This concern has earlier been expressed by *e.g.* Cohen (1974), who stated that natural resources such as minerals and fuels are being exploited, and due to their finite character, may ultimately be drained, thereby resulting in an even worse situation for the peripheries. The periphery is thus in a way forced by capitalism to waste their assets. This exploitation process is further reinforced by the ruling elites of poorer countries (*i.e.*, pockets of global North), who, due to *e.g.* western educations have contracted western values and often identify less with their own people than with the North (Young 2001). In this way, the global North retains substantial influence in the South (Altbach 1995). As pointed out by Cohen (1974), exploitation is sometimes even further reinforced by multinational corporations, in that they enable foreign investments mainly in the exporting sector, which creates independent enclaves within the peripheries. Since workers employed in such enclaves are often foreign, and most capital goods used for production are bought from abroad, consequently most payments for goods and labour go abroad. This, Cohen (1974) argues, creates relatively independent sectors where little of the benefits reaches the host country or region, but rather flows back to that of the investors.

As will be shown in this thesis, such polarisation of investors and local people also exists in many cases of aquaculture development, where people working or benefiting from the activities are often external (see chapter 7). This ultimately results in that activities in such enclaves are run mainly by external people and imported resources, and that benefits are rarely used for improving conditions outside of the enclave, *i.e.*, in the host country or area. As concluded by Cohen (1974), the net benefit in terms of foreign capital investments may thus be quite small when seen in totality. However, in this thesis, it is also argued that this does not apply only to relations between nations, but also between rural and urban parts within single nations. For example, as will be shown in chapter 7, aquaculture aimed for export seldom

involves or benefits the poor rural societies to a large extent, but rather enrich the global North, as represented by local elites and urban entrepreneurs.

However, the neo-colonial perspective is also problematic, since it is far too simplistic and does not specify what change can be derived from neo-colonial forces (Cooper 2005). According to Griffin and Gurley (1985) this critique is justifiable, since proponents of neo-colonialism have not appropriately enriched their definitions, and have failed to address the fact that some peripheries have benefited from capitalism, and that not all nations in the North are necessarily imperialistic. According to them, a better way of understanding neo-colonialism is therefore to refer to it as an era rather than a process or school of thought.

In this thesis, the most relevant aspect highlighted by neo-colonialism is the transfer of natural and human (*e.g.* labour) resources, or benefits from extraction, from the South to the global North. Local elites in the South often facilitate neo-colonial processes (Bardhan 1989), and hence, some nations and people benefit at the expense of others. This is also an important critique to aquaculture development, since it is often financed by external capital and run by local elites, and hence generates few positive effects for poor local people.

Recent studies of biophysical resource flows (Eisenmenger and Giljum 2007) further acknowledge that the South supports the North with great quantities of raw materials at low prices, only to receive small quantities of value added products in exchange for these materials. That is, great quantities of raw materials are exchanged for small quantities of materials with high economic value. This process is further reinforced through current trade relations, which “encourages relocation of material-intensive production processes from industrialized countries to less developed countries in the global South” (Eisenmenger and Giljum 2007:290). In this view, the South allocates large shares of their natural resource base for use elsewhere. Whereas consumption occurs mainly in the global North, natural resources are thus increasingly extracted in the peripheries, and hence the South is left bearing the ecological costs of development (Eisenmenger and Giljum 2007). As expressed by (Gunder Frank 2007:305), in this way “human beings are very skilful at exporting the costs of their own behaviour to others”. Furthermore, some scholars (*c.f.* Eisenmenger and Giljum 2007; Gunder Frank 2007) claim that it is only by exporting the economic and ecological costs, that development can reach the levels yet only to be enjoyed by the global North. Therefore, under current capitalist premises, some regions per definition will always have to step back for others to rise. From this standpoint stems the notion that development in the global North, and “accelerated ecological damage, war, civil strife and political conflict” (Gunder Frank 2007:304) in the South, are two sides of the same coin.

In explaining this process further, Gunder Frank (2007) refers to it as displacement of entropy. That is, physical/ecological and social entropy generated by economic growth is displaced from cores to peripheries as a result of the second law of thermodynamics. Displacement of entropy thus occurs:

when one system has the will and the ability to force others to absorb the costs of its own growth and prosperity [...] through impersonal market mechanisms so the victims on the periphery [...] are not aware of what is being done to them. (Gunder Frank 2007:305).

Gunder Frank (2007) further argues that entropy displacement is a result of the multilateral system that determines how much benefit (or dis-benefit) a region, country, or even individual can derive from the global resource base, and that this is determined by the social-structural and geographical position in the global economy. This process is often facilitated by exercising political, and more importantly, military power. Therefore, Gunder Frank (2007:305) argues:

Entropy may be regarded as the cost of participation in the system and its economic production and growth. Displacement of entropy then is the transfer or export of this entropic cost from here to there, and in the world from the rich North that generates or causes the generation of much of it to the poor South, which is obliged to absorb this displaced entropy at its own cost.

An important thing with entropy displacement, especially in the context of this thesis, is that it occurs along multilateral paths and networks, often via one or more third parties (Gunder Frank 2007). This makes the process less visible and obvious, and hence it has often been surpassed in many sciences. For example, Hornborg (2001) points out that this way of not seeing the whole picture is what made it possible for the economist Marian Radetzki to conclude that environmental damage decreases as GDP increases. Radetzki's argument was that since richer countries tend to replace material intensive production with service industry, they can enjoy a cleaner environment – landscapes are indeed reverting to something similar to a “natural” state in the richer countries, and *e.g.* forests are not decreasing, but rather regenerating. Therefore, Radetzki argues, there is evidence enough that growth and technological development auto-generate clean activities, such as plantations instead of exploitation of natural forests, and aquaculture instead of coastal fisheries that deplete wild fish stocks.

This view of economic growth as automatically limiting negative effects of economic activities is shared by many environmental economists. By concentrating on correlations between economic growth and pollutants, *e.g.* Grossman and Krueger (1991) argued that higher GDP triggers investments in green technology and changed consumer habits, which to a certain extent ultimately decreases the discharge of pollutants. Similarly, economists at the

World Bank (1992) have contributed to this view of economic development and sound environmental management as complementary processes. By using several examples of how water pollution, particle emissions, lead and sulphur dioxide concentrations have decreased at par with economic growth, they all argue that increasing incomes ultimately enable countries to alleviate environmental degradation. Hence, they conclude, the counter argument, *i.e.*, that development unavoidably results in degradation of environmental resources, is a false dichotomy.

These arguments owe much to the work of the economist and 1971 Nobel Prize winner Simon Kuznet, and the formulation of the Environmental Kuznet Curve (EKC). Deacon and Norman (2006:291) shortly describe the EKC as the notion that: “as a country’s income grows, its pollution will initially rise, but will eventually decline if growth proceeds far enough, tracing out an inverted-U relationship”. That is, at the early stages of development, when economic activity is low, little attention is paid to environmental issues. While economic activities grow, so do environmental impacts, resulting from increased industrialisation and resource consumption. After some time, a threshold is reached, when negative environmental effects of growth are no longer acceptable, which triggers increased environmental concern. The EKC thus suggests that after a time of accumulating wealth and ignoring the environment, society will be willing and rich enough to direct part of the economy to environmental conservation and restoration measures, thus decreasing environmental pressure derived from growth.

As mentioned above, the EKC hypothesis primarily draws on analyses of a few pollutants, while there is little evidence that the U-shaped trend applies to development and environment on aggregate levels. For example, whereas the concentration of some pollutants have indeed decreased in richer countries, the total use of energy and materials within nations has not fallen with rising incomes, but rather increased exponentially alongside economic growth. In contrast to the EKC, this implies that negative effects of growth do not necessarily decrease after a threshold of wealth is reached, mainly since the total energy use is rising on aggregate levels, in the North as well as in the South, which increases rather than decreases pressure on environmental and other resources.

From a critical standpoint, the most important problem with the argument that negative environmental effects decrease as GDP grows, is that it originates from the assumption that economic activities and their environmental effects coincide geographically. What is left out in this picture is that a “clean” environment alongside increasing economic activities is only possible by exporting entropy. Also when substitution results from new technologies emerging as a response to depletion of resources, the process is ultimately finite, since substitutes also require resources that need to be drawn from what is ultimately a limited stock (Bunker 1985). Therefore, Hornborg (2001) argues, it becomes necessary to always pose the question: where?

Where is the environment improved? And where are resources procured for making this possible? Indeed, relating human organisation and resource use to place is a central issue in geography. Hence, to gain knowledge of the environmental consequences of economic activities, it becomes crucial to trace resources and interactions back to their origin. This, Hornborg (2001) claims, is the only way to understand the true costs and underlying processes of economic activities, and to reveal the unfair exchange of resources.

Tracing flows between systems is the mainstay of energy accounting, which is also why it was chosen as a methodology in this study. However, the approach should not stop here, since “who” as well as “where” is of significance, and especially so in the context of development and fairness. Therefore, this study takes on an explicitly spatial approach, by questioning from where and whom resources are taken, and ultimately where and with whom these resources, and benefits from extraction, end up.

Although exemplified by the relationship between towns and countryside, the transfer of resources between different localities was pointed out by Adam Smith as early as in 1776. He wrote:

The town, indeed, may not always derive its whole subsistence from the country in its neighbourhood, or even from the territory to which it belongs, but from very distant countries; and this, [...] has occasioned considerable variations in the progress of opulence in different ages and nations. (Smith 1776:171).

Also Giddens (1997) concur with the notion that exploitative North-South relations are enabled and reinforced under capitalism, *i.e.*, the economic system that implies an eternal expansion of production and accumulation of wealth that often only benefits a few due to inappropriate inter-group redistribution of gains. This is much a result of prioritising endless accumulation of capital, which according to Wallerstein (2007) is the primary aim of capitalism. Endless accumulation, he argues, implies that people and corporations strive towards accumulating capital merely for the sake of further accumulation, and that accumulation in this sense is ascribed an intrinsic value, as being both the goal and means of capitalism.

Wallerstein (2007) further argues, that for accumulation to occur under capitalism, several institutions are needed, such as corporations, states, households, classes, and most importantly, markets. Capitalists themselves often promote a free market ideology, *i.e.*, goods, services and information should be allowed to flow freely and made equally accessible to everybody, limited only by supply and demand. However, Wallerstein (2007) also claims that a totally free market is nothing but an illusion, and that for incentives for exchange to exist, markets are necessarily only partly free. For if markets were indeed truly free, and information equally accessible to all, it follows that all consumers would have total knowledge of all production

processes and costs, hence capable of negotiating prices so as to eliminate profit margins, and thus also incentives for exchange. Therefore, if exchange and accumulation is to take place, markets need only be free to a certain extent, and costs and production processes kept hidden. Only then may surplus value be created, and hence accumulation occur.

According to Wallerstein (2007), capitalism therefore always means that there are net winners and losers. Hornborg (2001) similarly argues that capitalism is reliant on internal mechanisms that enable creation of surplus value in production and consumption. In this context, Hornborg (2001:57) lists five ways of appropriating resources, or “modes of accumulation”. The first is *plunder*. The second, *merchant capitalism* means to exploit cultural asymmetries between geographically and culturally distant regions, which generate differences in the perceived value of things. The third, *financial capitalism, i.e.*, to loan money for the exchange of interest, is one of the most important means by which the North today appropriates wealth from the South via international lending institutions such as the World Bank. Hornborg’s fourth way to accumulate wealth is by under-compensating labour. That is, by creating an unfair relation that enables a discrepancy between what labourers get in return and the true value of the labour effort, *i.e.*, in terms of time, money, energy or other assets. Therefore, localising labour intensive activities in peripheral countries is increasingly common, since salaries there are low among other things due to weak negotiation power by the workers. Long working hours, poor working conditions and low salaries, may all be seen as a means to enable under-compensation of labour. Hornborg’s fifth and final way to accumulate wealth is similar to the fourth, but emphasises resources, that is, other forms of energy than labour. Here, he refers to a discrepancy between the quantity and/or quality of resources obtained by one party and those that are left in exchange, that is, paid to the other party. All these modes of accumulation are dependent on power relations, and hence owe much to the colonial heritage. That is, none would be possible if there was no difference in terms of who has more or less power to affect terms of interactions. Hence, power and fairness need always be emphasised when analysing the history and organisation of trade and capitalism.

In the context of this thesis, the most relevant of Hornborg’s (2001) modes of accumulation are the latter two, *i.e.*, under-compensation of labour, and resources. Or in other words: the failure of trade to acknowledge and compensate fully human and environmental support to production. This way of reasoning is similar to that of Odum and Odum (2001), who illustrate appropriation and distribution of resources by analysing the emergy inherent in exchanged goods and services. They do so for example by calculating the emdollar value (emergy to dollar ratio), defined as the amount of emergy that goes into one dollar of the gross economic product of the country in question. In this way, emdollar may be used for comparing the emergy sup-

port of nations, and reveal advantages and disadvantages in terms of net transfer of resources (emergy) in trade between nations. Studies of emergy support to nations worldwide have showed that countries with large amounts of money in circulation in the national economy, and low emergy support with national origin (*e.g.* western Europe, US and Japan) enjoy significant advantages in trade relations, since the money paid for goods and services is supported by relatively less domestic emergy than the amount of emergy received in the transaction (*c.f.* Rydberg and Salomonsson 2004). All in all, these arguments point to the same; *i.e.*, that trade under capitalism seems to inevitably result in unfair exchange (accumulation) that only works due to asymmetric relationships between people and regions. Thus, as concluded by Hornborg (2001:63):

the entire rationale of trade is the asymmetric transfer of labor time [and emergy, and hence] if invested energy or hectares were counted instead of dollars, the significance of imports from the South would be recognized as much greater than that suggested by monetary measures.

As noted by Griffin and Gurley (1985), this view has been shared by many theorists (*e.g.* Andre Gunder Frank, Celso Furtado, Fernando Cardoso, and Osvaldo Sunkel) who all agree “that capitalism is a powerful engine of growth in the center, but in the peripheral countries it tends inevitably to produce under-development and poverty” (Griffin and Gurley 1985:1111). Capitalism has therefore received extensive criticism during recent decades, based on the argument that capitalism creates class structures that seriously impede developing countries in improving living conditions of their populations, and especially, of the working classes (Griffin and Gurley 1985). Thus it seems unavoidable, that in capitalist societies, gains from economic growth and international trade accrue only to certain powerful classes, whereas a majority of the populations are appointed losers (Bardhan 1989). Gunder Frank (2007), as well as Rasmussen (2001:10) therefore resemble global capitalism to “a game of musical chairs [... where] someone has to be left without a chair if the game is going to work”. Perhaps the biggest problem here is that this “someone” is not a negligible part of the global population, but rather is constituted by a majority. Still, this unfairness has continued for the last 150 years, much due to a clouded perception of limits derived from economic growth and fossil fuel use (Abel 2007), as an illusory emancipation from dependence on natural resources. This has hence given us the false impression that infinite economic expansion is possible, and that “development” will spread everywhere, and ultimately also counteract environmental degradation. This however, would go against fundamental ecological principles saying that nothing can ever grow exponentially for too long, since sooner or later a point is reached where the resource base is over-exploited and hence will inevitably restrain further growth (*c.f.* Malm 2007).



This point is sometimes referred to as carrying capacity, or resilience. Hence, as argued by Gunder Frank (2007:307-308):

it is vain to claim or even hope to [...] industrial[ise] the entire Third World [...] by replacing dirty industrial technology with, for example, clean green but more expensive informatics. Indeed, raising the income of the Rest to that of the West would require three extra planets”.

Many scholars (*e.g.* Giddens 1997; Abel 2007; Gunder Frank 2007) have indeed argued that since the worlds' resources are finite, infinite expansion of the capitalist system is not possible. That is, there are real physical limits to global capitalism and economic growth (Abel 2007). Furthermore, available resources on Earth are not only decreasing, but each year it also takes more and more effort for concentrating what resources remain. This means that an increasing part of the economy goes into resource extraction and concentration, and hence, each year less of the economy is left for improving real conditions for people (Odum and Odum 2001). In addition, more of the resources supporting poorer nations (*i.e.*, the South) are being diverted through global trade to benefit the richer countries. Thus, environmental costs associated with production increase faster than benefits, in the North as well as in the South (*c.f.* Hornborg 2001; Daly and Farley 2004; Eisenmenger and Giljum 2007). This means that the cost of extracting or producing each additional unit will be more than the previous one (Eisenmenger and Giljum (2007). This trend is visible also in export-oriented aquaculture, where the costs for producing *e.g.* one kilo of shrimp are increasing each year.

Solving the problems of environment and development therefore will not only involve how to limit environmental degradation, but will ultimately also demand reduction of levels and rates of resources consumption, and also, fairer sharing of resources and costs. In other words, in order to prevent development from leading to a growing consumption culture that ultimately speeds up resource extraction and exponentially hasten the restrictive character of resource limits (Abel 2007), reflexive modernisation through rethinking the life styles proposed by the global North is necessary (*c.f.* Odum and Odum 2001). Otherwise, as argued by Norgaard (1994:3) the “pursuit of trivial materialism” in the global North will ultimately consume *e.g.* fossil fuels and transform the planet well before even the most basic needs have been met for the majority of people in the South. However, abandoning the aim of continuous economic growth based on increasing resource consumption will only be possible by creating new social institutions (Giddens 1997).

## Systems thinking – merging the social and the physical

Drawing on what has been discussed above, an important aim of this thesis is to study interactions and resource flows between different regions and peoples. To enable this, Bunker (1985) argued that theoretical and analytical approaches are needed that simultaneously consider physical dependence on resources and societal interactions between local, regional and global systems. This way of thinking of the world in terms of a socio-ecological system has gained increased interest lately. From a transdisciplinary perspective, system thinking is thus particularly useful due to its ability to conceptualise fairness and physical resource flows between systems. This opportunity is perhaps most visible within the fields of world- and general systems theories, two perspectives that will therefore be further discussed in the following sections.

Thinking of the world in terms of systems of nature-society interactions is not new. For example, it has long since been a key issue of geography where dependencies on climate, soils, topography and vegetation have set the scene for analysing human resource use potential and effects. In physical and social sciences, system thinking emerged more or less simultaneously in the 1920s (Capra 1996). What all perspectives pertaining to systems thinking have in common is that they depart from the conviction that the essential properties and overall functions of a system are only visible when observing the whole, and that these properties cannot be found in the individual parts of the system. Therefore, these properties will always be overlooked if the system is dissected and isolated into individual parts for analysis (Capra 1996).

This notion shook 20<sup>th</sup> century academia, since it implies that systems cannot be understood by analysis within single and sectorised academic disciplines. On the contrary, systems need to be studied through synthesis as opposed to analysis, and related to contexts at larger scales (Capra 1996). In this sense, system thinking is always contextual and synthetic, as opposed to conventional analysis, which is only partial in that it only generates partial knowledge, whereas intrinsic properties of systems and relations to other scales are overlooked. In this context, however, the concept “scale” deserves some elaboration. As pointed out by Marston *et al* (2005), there is no consensus in terms of how scale is to be defined, nor operationalised in research. Drawing on Swyngedouw’s (2004) work, Marston *et al* (2005) argue that since nature and society are connected in networks of interwoven processes, delimitating a part of reality is arbitrary at best. That is, if it is accepted that everything is connected to everything else, how does one go about delimitating a specific scale? And how are the boundaries between scales to be identified and defined? In the context of this thesis, this implies that defining what is local, regional and global becomes difficult, since scale does not exist anywhere but in our minds. Even so, when studying interactions and

flows within and across scales (here defined as systems) some delimitation is still necessary. One way to do this is to follow geobiophysical, *i.e.*, naturally occurring yet porous boundaries in nature, such as river basins, catchment areas or islands, and to define scale based on interactions between these and geographically larger and/or smaller spatial entities. This way, a hierarchy is soon identified, which enables, at least conceptually, the study of inter-scalar relations. Systems thinking is based on such a definition of scale, *i.e.*, in terms of hierarchies that emerge through self-organisational principles with the purpose of maximising energy transformation to the benefit of larger scales, that is, higher up in the energy hierarchy. This is further elaborated in chapter 5.

A shift to systems thinking thus means shifting from the parts to the whole (Capra 1996). However, this is not entirely unproblematic. If the whole is what is important, it is necessary to study all parts together. Furthermore, if everything is connected to everything else, it obviously leads to the question whether we can ever understand anything. Systems theorists respond to this question by arguing that precisely because everything is connected, the infinite complexity of the socio-ecological world system can indeed never be completely understood. However, there is approximate knowledge. As an opposite to the Cartesian paradigm, in which scientific knowledge is taken for certain, systems thinking stresses that science can never generate absolute knowledge (Capra 1996). Nevertheless, this is not the same as to say that science may not be used for increasing our understanding of the world, although it is necessary to bear in mind that scientific knowledge will always be an approximation of reality.

From a social science perspective, world system theorists have come to emphasise social and economic interactions and the interconnectedness of global human societies. Meanwhile, physical scientists have mainly focused on how ecosystems are connected in terms of a planetary earth system (Hornborg 2007). However, both sides are increasingly realising that the world and earth systems are intricately linked to each other. Therefore, there is a growing conviction that the problems related to sustainable development may only be fully understood through interdisciplinary approaches, and that this is best achieved by applying a systems view (*c.f.* Hornborg 2007; Odum and Odum 2001). Therefore, natural as well as social science based system thinking are becoming more and more integrative.

A notion shared by both perspectives, is that all complex systems (*e.g.* the biosphere as a socio-ecological system) are characterised by emergent properties – they all self-organise in hierarchical structures that dissipate energy, create entropy, pulse and collapse, which leads to nonlinearity and multiple steady states (*c.f.* Odum and Odum 2001; Abel 2007; Chase-Dunn *et al* 2007). The concept of self-organisation here implies that things and processes that require much energy will only be re-produced if they have some positive effect on lower levels of the hierarchy, that is, by providing feed-

back that reinforces the system as a whole (Odum and Odum 2001). By feedback is here meant the circular arrangement of several interconnected elements that are causally connected so that each element affects the next, until ultimately the last element feeds back again to the first (Capra 1996). An example of a feedback mechanism is the controlling function performed by predators feeding on species lower down in the food chain (hierarchy), who in this way limits excessive population growth of prey species so that thresholds are not surpassed. In this way, both species have different yet equally important roles, in that both maintain overall stability of the system, thus benefiting the system as a whole. Although feedback loops are one of the most important characteristics of self-organising systems, it is important to note that feedback needs not only be positive, but can also exist as a negative or self-balancing mechanism (*e.g.* by counteracting efficiency or generating exaggerated polarisation of system components). Whether a feedback is perceived as positive or negative also depends much on the position of the beholder, since what is good for one species may be bad for another, although it remains positive for the system as a whole. The only thing that is certain, therefore, is that all systems have some feedback mechanism, especially considering that no relation can exist in but one single direction (*c.f.* Abrahamsson forthcoming).

The organisation of feedback mechanisms between elements may thus be conceived of as nested hierarchies. However, as argued by Capra (1996) the term hierarchy may be misleading here, since the patterns of self-organisation and interactions between parts are more like networks, and therefore may be more accurately described as a web of life. Thus, it is important to point out that the meaning of hierarchy is sometimes more metaphorical. Still, identifying hierarchies is one approach that may aid the human mind in conceptualising interactions and relationships within systems, although in reality, no systems are organised as pure hierarchies in the sense that there is an “above” or “below”. Rather, is hierarchy to be seen as a human projection of the yet more complex organisation in the web of life (Capra 1996). As will be shown in chapter 5, from a thermodynamic point of view, the study of systems may however be operationalised as hierarchies, where the concept of transformity may be used for determining the position of particular parts of interest.

Looking upon systems as self-organising living organisms may be traced back to the time of Immanuel Kant. According to Capra (1996), Kant argued that the parts in any organism (*i.e.*, system) self-organise and reproduce by enforcing each other. In other words, they exist not only for each other, but also by means of each other. For this to work, systems need not only be organised, but they may only achieve this by the means of self-organisation. Thereby, Kant was not only the first to use the term self-organisation, but also did so in ways that are very similar to contemporary use and definitions of the concept (Capra 1996).

Self-organisation is apparent in systems at all scales, from biological organisms to global trade. In the context of aquaculture, self-organisation is primarily represented by indigenous knowledge systems that through trial and error have resulted in aquaculture practices of high complexity. Polyculture is one such example of a system of aquaculture with relatively high levels of self-organisation (see figure 3). By simultaneously farming multiple species that contribute services to each other, they mutually reinforce efficiency of the system as a whole. As an opposite, by applying monoculture practices (figure 4), such mutually beneficial processes are lost. Low levels of self-organisation in this case results in increasing need for external inputs (*e.g.* artificial fry, feed and fuels) and stabilisation of pond walls (manual labour), that is otherwise contributed through internal processes and feedback loops. For example, polyculture systems often include keeping trees on pond walls for stabilisation and maintenance, instead of providing this service through manual labour. Other aspects in terms of self-organisation and differences between monoculture and polyculture are accounted for in chapter 7. Here however, the two cases are used for exemplifying how varying degrees of self-organisation may look like, and what implications this may have for sustainability and efficiency of systems.



*Figure 3.* Polyculture in the Philippines. Photo: Daniel A. Bergquist, Tugas, Makato, Philippines, 2006-01-17. Figures 3 and 4 (next page) show two examples of varying degrees of self-organisation in aquaculture, resulting from different kinds of human-nature interactions. Figure 3 shows polyculture in the Philippines, a system with relatively high level of self-organisation. Trees on pond walls provide stabilisation

and storm protection. Herbivorous fish in the ponds feeds on algae, which reduces the need for artificial feeds. Simultaneously, the fish aerates water to the benefit of the shrimp. Meanwhile in Sri Lanka (Figure 4), the pond environment in monoculture is not allowed to self-organise to such an extent. Instead, production is strictly controlled by artificial means to substitute services otherwise provided internally in systems with higher degrees of self-organisation.



*Figure 4.* Monoculture in Sri Lanka. Photo: Daniel A. Bergquist, Iranawila, Sri Lanka, 2005-03-08.

In nature, wasteful processes and items tend to disappear through the process of trial and error, and therefore should do so also in systems subject to human control. However, the concept of self-organisation also means ascribing both the material and human world teleological aspirations, something that by many is considered controversial. Many have difficulties believing that there may be general principles controlling the overall socio-ecological system, and especially that the human economic sub-system would be subject to other regulating principles than those of the free market (Odum and Odum 2001). This, however, is precisely what systems thinking suggest. This view is particularly strong within world system theory and general systems theory, which is also why these two perspectives are discussed more in detail below.

## World system theory

The concept of a world system was first coined in the 1970s by Immanuel Wallerstein (Abel 2007, following Wallerstein 1974). He argued that the world was organised as “a multi-state system of capitalist countries bounded in time and space, with a division of labor and trade relations that favored a core of one or several nations over a surrounding periphery of other nations“ (Abel 2007:57). In this sense, core-periphery relations as discussed earlier in this chapter can be defined as a hierarchical structure, where one society (system) dominates and/or exploits another (Chase-Dunn *et al* 2007). However, since the division of labour and world trade is not confined to specific countries (*c.f.* the discussion on global North earlier), contemporary world-system theory has expanded the concept, much inspired by progress in system thinking in physical sciences (*e.g.* systems ecology). Because similarly to ecosystems, world systems (conceptualised as complex human-ecological systems) organise in hierarchical structures (*e.g.* core, periphery, semi-periphery), they pulse, collapse, cycle, and are characterised by high degrees of complexity and chaos (Abel 2007). The world system may thus be conceptualised as interlinked spatial entities that appropriate, use and cycle energy and materials and information, and exercise power and control at several scales. Abel (2007) further argues, that by this conceptualisation, today there is a single hegemonic U.S.-E.U.-Japan world system that dominates the remaining countries as peripheries and semi-peripheries, thereby converging energy in the core.

Hornborg (2001), as well as geographers (*e.g.* Harvey 1996b), argue that it is this very socio-ecological and political-economic structure that generates social and economic unfairness, and the various experiences and understandings of what constitutes justice. According to Harvey (1996b), this process is further reinforced by new transport and communication technologies that renders geographic and temporal distance negligible, or in other words, that compress time and space with the purpose of increasing velocities and reducing distances for people, goods and capital to flow more smoothly. This has had a major impact on how societies and markets are organised and interact in space. However, as argued by Hornborg (2001), Harvey fails to acknowledge that time-space compression can only be made possible through time-space appropriation, which, Hornborg argues, results from the global market working as an institution for redistributing time and space. As mentioned earlier, Hornborg (2001) and Gunder Frank (2007) refer to this process as environmental load- or entropy displacement. Whether referred to as time-space appropriation or entropy displacement, this processes is in many ways similar to the metabolism of living organisms, which appropriate resources (*e.g.* food), and return it as waste (excrements) in a less orderly state, and in the process, dissipate energy as heat. By appropriating resources and consuming them in the cores with the purpose of generat-

ing wealth and order, waste and disorder is dissipated, that is, created in the process, and often returned back to the peripheries, from where the resources were taken in the first place (*c.f.* Schmidt 2006).

Some authors (*e.g.* Eisenmenger and Giljum 2007) therefore refer to the process of transferring energy and materials between cores and peripheries as societal metabolism. In this view, societal metabolism entails the notion that societies exchange energy and materials with the natural environment. That is, human society is dependent on continuous inflow of energy and materials from the environment, and out-flows of waste when resources have served their purpose for humankind (Giampietro *et al* 2000). From this view stems the notion that society-nature interactions can be studied in terms of material flows there between, *i.e.*, as societal metabolism. Due to the processes of time-space appropriation and global capitalism, countries therefore tend to go from dependence on mainly local resources, to increasing dependence on resources from other regions, or in other words, towards accelerated societal metabolism over increasingly extensive geographical distances.

To operationalise the concept of societal metabolism, Eisenmenger and Giljum (2007) therefore argue that methodologies emphasising other values than money be used, for example weight. However, although this is one approach to compare and analyse flows and interactions within and between systems, using weight as the analytical unit may neither be completely appropriate. Different materials and energies exhibit different qualities, which may remain hidden if the only measured parameter is weight. The value of different kinds of energies and materials may therefore be better analysed using another unit, for example emergy, as will be argued in chapter 5.

Some scholars (*c.f.* Gunder Frank 2007; Eisenmenger and Giljum 2007) have analysed this ecological exchange through which the global North is able to consume more by displacing ecological costs elsewhere. For example, results from a study conducted by Eisenmenger and Giljum (2007) revealed that energy convergence in the E.U. (as a representative of a core region) has resulted in them being able to refrain from intensifying the use of local resources, but only by increasing the use of materials from abroad. In this perspective, it is interesting to note that *e.g.* China is emerging as a new core, thus changing the constitution of the world-system. However, the natural resource base of the world will most probably not be enough for yet another core, since all resources are either flow or stock limited, as has been discussed earlier. Thus, it is more plausible to expect decomposition (or collapse) of the existing world-system, rather than the formation of new cores (Abel 2007). The reason for this is, in addition to resources being limited, that systems tend to pulse, following a cycling model comprising exploitation, conservation, crisis, and reorganisation (Abel 2007). A hegemonic cycle thus includes a pulse, where the world-system expands and contracts on basis of resource limits. However, it is important to note here, that expansion need not only be spatial. The global system of world trade cannot get bigger



in a geographical sense, since it already covers the globe. Due to time-space compression, distance and time constraints become increasingly irrelevant. Therefore, expansion is rather materialised as intensification of interaction networks, *i.e.*, in terms resource flows getting faster, denser and more intensive (Chase-Dunn *et al* 2007). Initially such expansion is understandable, especially in the light of Odum's (1999) fourth law of thermodynamics – self-organisation for maximum empower, (see pages 95-96), according to which it is only logical to capture untapped resources, thereby enabling expansion of the socio-cultural system. Just as logical however, is that this expansion requires maintenance sustained by increasing throughput of finite resources and energy, and hence, when limits are reached, slowdown is inevitable. On a more positive note, Odum and Odum (2001) though argue that this slowdown need not necessarily be catastrophic or even negative for development, but even prosperous. For this to take place, however, changes are needed in the patterns of production, consumption and distribution of resources. Therefore, again, it is crucial to re-think the role of the market, institutions, values, and of course, the way in which such processes and patterns are assessed.

## General systems theory

Although not explicitly emphasising cores and peripheries, general systems theory offers an alternative for inquiries into the relationships and interactions within and between systems. Similarly to theories of neo-colonialism, general systems theory acknowledges that although political control was withdrawn at the end of colonialism, “the economic colonialism of emergy inequity often continued” (Odum and Odum 2001:146).

According to general systems theory, the world and earth systems alike exist under the same premises, and display similar emergent properties. General systems theory also acknowledges that all systems organise according to hierarchical spatial patterns, or webs of energy transformation, where resources flow towards centres of concentration, *i.e.*, accumulation (Odum and Odum 2001). In addition, by dissipating energy in the process, they also generate entropy according to the second law of thermodynamics.

Geographers such as Johnston and Sidaway (2004) describe general systems theory as the quest for identifying controlling functions and processes common for all systems. This systemic approach responds to among other things the need for more holistic analyses of systems, as opposed to isolated phenomena, and a wish to identify principles that govern systems in general. According to Johnston and Sidaway (2004), the strengths of general systems theory in a geographic context are its emphasis on interdisciplinarity and generalisation possibilities. On the other hand Johnston and Sidaway (2004) also argue that due to their strong empirical traditions, geographers may perhaps have more to contribute than learn from general systems theory.

Whether or not this is true is debatable, but general systems theory indeed withholds a range of application possibilities in geographical research.

Outside of geography, general systems theory has been developed and highly dominated by the work of Howard T. Odum (*c.f.* Odum 1987, 1989, 1995, 1996a, b). Odum (1987) and his followers emphasise a systems view on the world, which means that the world is approached as one single open system (*i.e.*, social-ecological system) within which all processes in nature and society are nested and constantly interacting in a web of energy transactions. In this perspective, nature and society are two equally important sub-systems that are compounded to form the higher level world system.

In contrast to world system theory, general systems theory more explicitly concentrates on flows of energy and materials between systems, as a spatial organisation that increase the overall productivity of the geobiosphere. However, the social perspective is rather weak, which is why it may be beneficial to combine the two perspectives. On the other hand, general systems theory provides a theoretical basis that may aid in operationalising and quantifying the processes conceptualised by world systems theory.

To illustrate efficient spatial organisation of societies, Odum and Odum (2001) use the example of the relationship between cities and rural areas in early agrarian societies, where energy and resources were taken from the rural hinterland and concentrated in towns (*e.g.* agriculture sustaining a city with food for people and hay for their horses). The towns at that time also recycled materials back to the peripheries. However, the service returned, *i.e.*, fed back, by the central consumer part of the system (town) was positive, in that it reinforced the rural agricultural system (*e.g.* through transporting back manure produced by the horses used in the city). This organisational structure is similar to that of systems with high degrees of self-organisation, where the corresponding parts are all beneficial and mutually reinforcing. In today's organisation of cores and peripheries, a key to reducing unfairness and energy efficiency may therefore be to assess what is being returned to the peripheries, that is, to tease out whether relationships are exploitative or mutually reinforcing.

However, as discussed earlier, most core-periphery relations are exploitative, mainly due to unfair trade relations resulting from the present capitalistic system. For example, purchasing cheap labour from the South is a common trend in world trade and the behaviour of multinational corporations. This implies that more labour time is appropriated than is actually paid for, *i.e.*, there is a discrepancy in the amount of energy that is being exchanged. The reason for this is that the emergy equivalent of one dollar originating from a core country is significantly lower than the average emergy equivalent of the labour effort it purchases from poor people in South nations. This argument is based on emergy evaluations of environmental support to nations, and may be used to calculate average buying power. People and money originating from nations where a high share of domestic environ-

mental resources support the national economy generally contribute more energy than is returned to them in exchange, be it in the exchange of goods, services, or in this case, labour. When analysing exchange between two parties, knowing the environmental support of each party thus makes it possible to establish who is the net winner or loser (*c.f.* Rydberg forthcoming).

In rural areas of the South, people can charge less for their labour among other reasons because they are self-sufficient to a higher degree than people in the North. This, Wallerstein (2007) argues, is especially apparent in semi-proletarian households, which he defines as households that are only partly reliant on wage labour for their sustenance, whereas unpaid work performed by other members of the households are equally important to the survival of the household, as a unit comprising several individual members. In addition, by growing subsistence crops for domestic consumption, catching their own fish and cutting their own wood, such households are also supported by unpaid environmental services. When seen in totality, members of semi-proletarian households, especially in the rural South, in this way are able to charge less for their labour, thereby generating surplus value which is transferred to employers. Surplus value is in this way supported by un-paid labour, and local environmental services, which together enables accumulation in other parts of the capitalist system.

Semi-proletarian households, *i.e.*, poor local people in the South, also often have a lower overall per capita consumption, and, weaker negotiation power. Put together, this implies that buying labour from rural people means appropriating not only their labour force, but also the hidden energy contribution of the “free” environmental resources they use, as well as making use of unfair power structures. Whereas world system theory primarily emphasises power and labour aspects of capitalism, general systems theory provides additional insights into such unfair relations, by visualising who are the net-winners and losers in terms of energy transactions. As such, general systems theory offers a complementing basis for achieving sustainable development that is fairer and more energy efficient.

In the context of un-fair global development and relations between the North and South, general systems theory also provides some explanation to why the world system tends to organise in an exploitative, or rather, hierarchical way. The world system, as all systems, tends to develop according to hierarchical patterns, that is, many units at low levels sustain fewer units at higher levels. Odum and Odum (2001) argue that one of the reasons for this unfairness is that there is a natural pattern of distributing wealth between high and low levels in the hierarchy in all systems. Similarly to world system theorists, Odum and Odum (2001) argue that this uneven distribution of real wealth between cores and peripheries is facilitated by global trade dynamics. Market prices underestimate the value of products and services (the reason for this is discussed in chapter 5), which means that raw materials sold from peripheries to cores contribute more to the buyer’s economy. Consequently,

there is a trade imbalance between nations supplying raw materials and those receiving them.

Odum and Odum (2001) however also argue that it is only logical that there are some in-differences in the world system. However, this is not the same as to say that there is any reason for in-differences to be unfair. Whereas some in-difference in terms of resource use may be appropriate, for the overall system to be most efficient, *i.e.*, to generate most empower<sup>10</sup>, wealth distribution should not be too uneven. Therefore, it is not efficient for the system as a whole to have too many rich, or too many poor, or in other words, to promote “policies that cause dysfunctional curves of distribution” (Odum and Odum 2001:130). The problem, however, results when indifference is too extreme, and most importantly, when positive feedback fails to appear. Thus, Odum and Odum (2001) further argue, exaggerated polarisation of wealth distribution is both an ethically and energetically illogical and unwanted organisation of society, and if not dealt with, will generate political un-stability and ultimately result in dramatic societal change.

Several system perspectives (*c.f.* Gotts 2007) share the view that such societal change may be explained by the tendency of all systems to follow cyclical patterns. Within general systems theory, this is called the pulsing paradigm (figure 5).

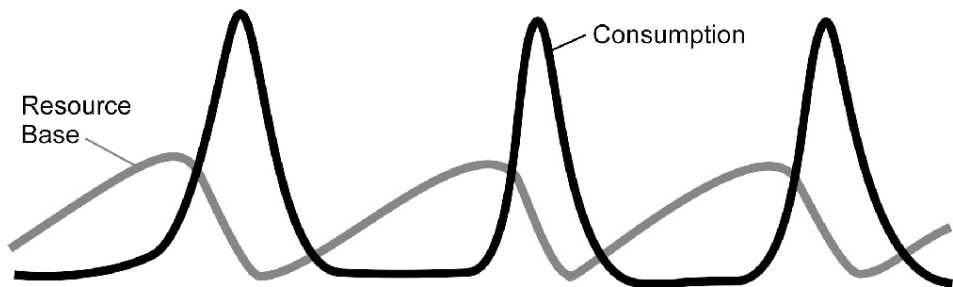


Figure 5. The pulsing paradigm – alternation between consumption and re-growth of resources. Modified from Odum and Odum (2001).

As mentioned earlier, a general misconception among many scientists and policy makers is that society can grow into a sustainable steady state (Ulgiati and Brown 1998b). On the contrary, in the long run, it is only through pulsing that systems have shown to prevail. The ability of living systems to combine overall structural stability with change and fluctuation has in fact in-

<sup>10</sup> Empower may shortly be defined as the tendency of all systems to organise so that all parts work together to further improve available resources and efficiency of the overall system. In this sense, there is a symbiosis between all parts of a system, in that all are mutually stimulating (*c.f.* Odum 1987). The principle of empower is commonly referred to as the fourth law of thermodynamics, and is further explained and discussed as such on page 95.

trigued philosophers and scientists all the way from the early days of biology (Capra 1996). Whereas the reason why all systems pulse is uncertain, studies of many kinds of systems indicate that pulsing is more productive at aggregated levels and scales of time, since it generates more empower than steady states (Odum and Odum 2001). A pulsing system is characterised by alternation between long periods of gradual production and storing of reserves, followed by short but intensive periods of consumption (Odum and Odum 2001). In this sense, pulsing may be seen as oscillation between multiple steady states. For example, human life is characterised by pulsing; in that humans alternate between sleep and intensive activity. The tendency of all systems to pulse means that a principle for generating good policy for human activity is to fit the timing of environmental oscillations. That is, to foster consumption in times of high availability of resources, and more importantly, to restrain consumption in times of decreasing availability of resources. Thus, as argued by Odum and Odum (2001:80), “successful economies are those that can adjust their periods of growth to pulses in their resource basis”. Hence, as pointed out by Odum (1994:212):

If the oscillating pattern is the normal one, then sustainability concerns managing, and adapting to the frequencies of oscillation of natural capital that perform best. Sustainability may not be the level “steady-state” of the classical sigmoid curve but the process of adapting to oscillation”.

In this view, the capitalistic-driven civilisation today is one example of such an oscillation, where contemporary society represents a frenzied pulse. This also suggests that a period of less consumption, *i.e.*, descent and re-growth of resources is to be expected (Odum and Odum 2001). Also Ulgiati and Brown (1998b) concur with the idea that oscillations are the general pattern of all systems. Indeed, all through history, human civilisations have exhibited pulsing patterns, where growth has been followed by collapse (*c.f.* Diamond 2005). Thus, history indicates that oscillations can never be avoided. However, this is not the same as to say that it is impossible to learn from the past and avoid catastrophic decline. Still, it implies that any appropriate definition of sustainable development should also encompass the ability to adapt to oscillating patterns (Ulgiati and Brown 1998b). If the pulsing paradigm is accepted, it thus implies that society will ultimately need to adapt to oscillations in the resource base, which constitutes a major challenge in terms of social and political institutions, and sustainability assessment approaches.

Similarly to world system theorists Odum and Odum (2001), argue that the reason why capitalism has been able to continue for so long, although the resource base on many locations is being emptied, is that global trade has made it possible to acquire resources from other areas (*e.g.* due to neo-colonial processes as discussed earlier). Thereby, GDP’s are able to continue

to growing in the North only as long as there are resources left to exploit abroad. However, as the entire world is finally stripped of its resources, consumption most probably must, level off and start to decline.

On a more positive note, according to Odum and Odum (2001), there are however opportunities for making decent as smooth as possible, and even prosperous for society. For example, in rural areas of the North where farming was abandoned centuries ago, resources have begun to restore as to support rural life again. In this way, neo-colonial processes and transfer of resources from the South to the North, means areas have been left to recuperate. Thus, a part of the solution may be to shift agricultural and material intensive activities back to these areas. This way, resources in the South may be left to re-grow until a new pulse of frenzied consumption and growth may start over.

As argued by Odum and Odum (2001:134), this means that in preparing for the future descent, it will be crucial to protect Earth's production of real wealth, but also to stabilise capitalism and work for increased fairness between and within nations. Accepting the interdependence between natural and human (economic) systems, and revealing the unfairness of international trade is but one step towards achieving this. Ultimately, and perhaps most importantly, reorganising society still means that for some time, humankind must learn how to depend mainly on renewable resources. Therefore, future development need to make more appropriate use of renewable and flow limited resources such as tides, wind and solar energy etc. This way of looking for more sustainable ways for development will be further explored in chapter 7, where a comparison is made between the two cases of aquaculture, emphasising energy use, efficiency and fairness in the light of general system theory and emergy.

## Towards epistemological holism

As rightly noted by Eisenmenger and Giljum (2007:289), to date “no full understanding of socioeconomic processes and their effects on society-nature interactions has been developed”. This statement clearly underscores the difficulties associated with understanding socio-economic and environmental phenomena. There is thus a need for new ways for viewing and visualising the interdependence of society and nature that are more holistic. Capra (1996) however points out that the concept “holistic” may be misleading, since it only implies looking for the functional whole, but by studying the respective parts of systems separately. As opposed to holism, Capra (1996) therefore proposes an ecological approach that would add the perception of systems as embedded and interacting with larger scales of the natural and social environment. There is thus a distinction between holistic and ecological approaches, which may be labelled shallow versus deep ecology. Capra therefore argues that shallow ecology is anthropocentric, since it only

accounts for the use value of nature as perceived by humankind (*i.e.*, instrumental value). As an opposite, deep ecology promotes a view that acknowledges and accounts for the intrinsic value of both humans and nature, and realises that they are intricately interconnected in a global web of life (Capra 1996). As noted by Galois (1977), this notion of an inter-related whole, where the actions of one part only make sense when considered in relation to the whole, was also shared by some geographers, such as Glacken, Yi Fu Tuan and Kropotkin. Whether practiced by geographers or others, according to Capra (1996), the most important aim with deep ecology and systems approaches is to question the very foundations of the industrial and growth-oriented materialistic worldview of modernity, and the way of life that it promotes.

Although there are several benefits derived from ecological systems thinking (Crumley 2007), this world view is however also considered highly controversial by many, and hence has not been exempt from criticism (Hau and Bakshi 2004). Odum (1987) listed examples of this critique, including the main objection that it is enough to understand how parts interact to explain larger scale phenomena, and therefore, synthetic approaches are not necessary. Another point that has been criticised is that looking for laws that govern the way the world works means ascribing it teleological aspirations, something that is often considered un-scientific. Yet, an increasing number of natural and social scientists are today leaning more and more towards the plausibility of such macro-determinacy (*c.f.* Hornborg 2007).

Other issues that have been brought forward is that systems approaches risk becoming too reductionistic, and ultimately leads to modelling smaller and smaller systems, something that is not at all appropriate if we are to understand the complexity of our planet (Crumley 2007). There is also a need for caution when applying biological models to social systems without proper adaptation, since in human society not all individual actions are beneficial to collective survival. Whereas this way of working for the common good is more commonly found in other species than humans, Hornborg (2007) argues it is more of wishful thinking than a social or historical fact to expect it to apply also to humans. This criticism has indeed been addressed and incorporated in World System Theory, for example by questioning whether a world system dominated by consumer states (*i.e.*, the global North) may be capable of keeping in mind what is good for the geobiosphere as a whole, including for poor local people in the South, and organise society accordingly. In contrast to general system theory, world system theory in this sense provides a more ethical and qualitative alternative, by mainly emphasising human history, culture and the biophysical, without reductionism (Crumley 2007).

Furthermore, due to high complexity of the geobiosphere, patterns are subject to random influences, which also results in high levels of uncertainty. Sometimes this opinion is expanded to the argument that there are no natural

laws at all, at least not that can work as constraining on human choice, because the human mind is infinitely brilliant and flexible. Species and humankind are also sometimes considered irreplaceable and therefore of infinite value, which is why they should not be subject to numeric evaluation. This criticism has resulted in strong oppositions towards teaching General Systems Theory, primarily based on scepticism to the idea of looking for, and accepting, the existence of general principles that govern the systems of society and nature (Odum 1987).

Keeping this criticism in mind, world- and general systems theory both open up alternative ways of studying complex systems. If combined, the two perspectives thus offer an opportunity for a more holistic, or rather, ecological, understanding of society-nature interactions, unfair North-South relations, and sustainability – issues that will be of most serious concern if sustainable development is to be achieved in the future. As argued by Eisenmenger and Giljum (2007:291), interactions between society and nature can indeed be “conceived as material or energy flows or as the social colonization of nature, that is, transformations of natural processes for the purpose of making them useful for society”. Hence the title of this thesis; aquaculture can in many ways be understood as colonisation of both nature (the coastal ecosystems) and peoples of the global South (poor local people). Here, transformations are indeed occurring with the purpose of making them useful for society. What is most important however is that this “society” does not include all people. Rather can the process be described as colonisation of the coasts that strengthen the transfer of resources from the peripheries to the core (*i.e.*, global North). As argued by Bunker (1985), the modern society indeed emerges from accelerated and intensified energy use. In this sense, neo-colonialism, as a process of transformation and resource transfer, can be conceived as energy flows between and within (world) systems. However, tracing such flows is a methodological challenge. Furthermore, the ideologies and behaviours lying behind the current world organisation are not directly accessible through concentrating exclusively on energy or emergy, which calls also for some type of sociological or socio-economic analysis. An approach is thus needed, that can handle natural, social, and economic processes simultaneously, and be flexible in terms of iterating between the study of processes at local and global levels, as well as interactions there between. This thesis represents a trial of such an approach, which is therefore focused upon in the next chapter.



## 4. Methodology

This thesis approaches aquaculture and sustainability from different disciplinary, yet complementary, perspectives. It departs from the notion that sustainability in general, and aquaculture in particular, can only be understood by incorporating social, economic, institutional and environmental factors. Therefore, a combination of theories, methodologies and methods are applied, originating in social and natural sciences. In terms of method, the most important are Participatory Learning and Action (PLA), Participatory Rural Appraisal (PRA) and emergy synthesis. Multidisciplinary approaches always put high demands on how methods are combined, and how data is gathered and ultimately integrated in the analysis. Consequently, it is important to thoroughly and transparently account for the research process, to enable readers to judge the accuracy of data gathering procedures, interpretations, and ultimately, validity of the results and conclusions. This chapter therefore embarks by discussing opportunities and constraints of interdisciplinary research, after which the history and applicability of each methodology/method is discussed separately<sup>11</sup>. The chapter is then concluded by providing an outline of the research process, *i.e.*, how the respective methods were combined and applied, as well as how the study areas were selected.

### Inter- and transdisciplinary research

Since the middle of the nineteenth century a kind of university instruction has developed which is no longer interested in transmitting a unified image of the world, but rather in isolating, and mutilating facets of reality in the supposed interest of science. (Josué De Castro, *The Geography of Hunger*, 1952, cited in Slater 1977:40)

The idea of humans and nature as linked entities has long since been a significant theme in geographic thought (Galois 1977). However, research on this complex and multifaceted relationship is often problematic. Not only is this the result of high complexity and uncertainty of socio-ecological sys-

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<sup>11</sup> Emergy synthesis is a broad field encompassing systems theory, thermodynamics and a wide range of technical and theoretical concepts. Therefore, it is only briefly introduced here, whereas a more thorough presentation is provided separately in chapter 5.

tems. Science is also often constrained by a distinction between natural and social domains (Hornborg 2007). However, failure to conserve natural resources alongside positive socio-economic development resulting from specialised or partial research has generated increased interest in integrated approaches. Thus, interdisciplinary research has gained popularity.

There may be several reasons for crossing disciplinary boundaries, the most common being an interest in a problem rather than a discipline. Interdisciplinary research is hence often a means to an end, where participants from different academic disciplines strive towards applying joint terminologies and theoretical frameworks. Hitherto it has been common that mutual interpenetration of disciplinary epistemologies is left out, which has resulted in integrative problems (McNeill *et al* 2001). Simonsson (2004) explains this as the result of an unfortunate situation where research is primarily carried out in specific and isolated academic disciplines. To counteract this isolation, interdisciplinary research attempts to integrate social and natural science during the research process, rather than compiling disparate results from isolated studies on an *ad hoc* basis. Although well-intentioned, these attempts have sometimes had problems, *e.g.* when integrating empirical findings generated using qualitative and quantitative methods, or when trying to integrate results produced by researchers representing different academic disciplines.

Transdisciplinary research emerged to address this challenge and can be seen as an extension of interdisciplinarity that strives towards more thorough integration. Based on common theoretical understandings for analysing multi-source data, either shared by a group of researchers, or performed by a single individual, transdisciplinary research does offer flexibility, but the ambition to be problem-focused and disciplinary unspecific also makes it difficult to define and defend disciplinary boundaries.

With more specific regards to this study, although the research was carried out mainly from a human geographic perspective, the transdisciplinary approach thus made it possible to bring in perspectives also from fields outside of geography. In terms of transdisciplinarity, this study also includes a higher ambition than mere methodological integration. The results and experiences from the fieldwork are therefore also used for discussing prospects for epistemological integration (chapter 8). The aspiration is thus to test to what extent the theories and methodologies are possible to integrate, and what implications they hold for increased transdisciplinarity in research.

## Emergy synthesis – some introductory notes

Emergy synthesis is an environmental accounting methodology that accounts for and considers inputs from the human realm (*i.e.*, social-economic system) and those coming “free” from nature on equal terms. Put simply, it is the evaluation process of measuring “the previous work done to make something, whether the work was done by natural processes or by humans” (Odum and Odum 2001:6). It hence encompasses environmental and human work, as well as temporal and spatial aspects of production and transformation processes. It is expressed in emergy, a “currency” that conveys value of non-monetary and monetary resources, services and products together (Herendeen 2004).

Emergy synthesis thus provides a more universal approach to assessing production processes, since it allows for comparison of similar products that have been produced by different means, resulting in different impacts related to sustainability, energy efficiency (Rydberg and Haden 2006) and more recently, equity (*c.f.* Rydberg forthcoming). It hence is a methodology that enables empirical studies of how global unfairness and resource flows operate through time and space.

In contrast to economic approaches that emphasise money, emergy measures real wealth, as defined previously on page 29. This difference stems from the notion that money only measures what people are willing to pay for products and services, which is not the same as the real wealth that is acquired or used up in the transaction (Odum and Odum 2001). Another important difference between money and emergy is that money primarily aims forward in time, as a way to enable time to pass between moments of production and consumption, whereas emergy simultaneously conceptualises spatiality, the past, present and future; in that it maintains that all production and consumption requires that resources are taken from somewhere, and depend on biological and geological processes of resource accumulation during millennia. Hence, consumption today is connected to the past, and affects the present as well as the future. Since also humans tend to strive forward, while living in the present and understanding backwards, *i.e.*, in relation to past experiences (*c.f.* Abrahamsson forthcoming), emergy more appropriately catches the temporal (and spatial) dimensions of human activity, as opposed to the limited scope of money.

Emergy thus provides an opposing alternative for analysing and valuing different spatial and temporal aspects of sustainability, production and consumption. Furthermore, it is a theoretical concept rooted in a systems view of the world (as discussed in chapter 3). However, it is also a methodology that depends much on statistical data and calculations performed by other researchers in previous evaluations. As a consequence, there are some issues of validity and risk of bias that are worth commenting on.

In energy synthesis, all processes and inputs that contribute to a particular system are aggregated, as opposed to excluding some and concentrating on a limited selection. However, covering all direct as well as indirect inputs, and tracing them all back to the origin, implies an almost infinite task, especially when considering the world view proposed by systems theorists; that everything is ultimately connected to everything else. This of course is not possible to cover in a single study, let alone by a single researcher. Therefore, energy synthesis depends on data published in previous evaluations, and statistics, which may be of varying quality. If there are errors inherent in secondary sources, consequently these will also be passed on to any following evaluation. Therefore, although the quality and quantity of data needed for energy evaluations increase every year, and there is no specific reason to question the trustworthiness of previous evaluations, from a critical viewpoint there is still some risk of bringing earlier bias into new evaluations.

In this study, the same secondary data was used in both energy evaluations, which reduced the detrimental implications of potential bias, at least regarding validity of the overall results. That is, since the explicit aim was to reveal differences between two cases, as opposed to generating new singular and case specific results and energy values, regardless of the secondary data being biased or not, it is of minor importance in terms of relative differences between the two cases. In a way, the comparative approach thus to a certain extent may be said to have neutralised the effects of bias. Bearing this in mind, in this thesis, energy synthesis was therefore considered a valid approach, and was hence used for analysing differences in terms of energy efficiency in aquaculture, and for identifying energy flows, resource transfers and linkages between the study areas and the global North, with the explicit purpose of comparing rather than generating new data for the individual cases.

Since energy synthesis is quite an extensive and time-consuming evaluation process, it needed some delimitation in this study. Therefore, extended fieldwork for the energy syntheses was only carried out on two selected farms. This of course demands some caution when generalising the results. However, this work was carried out in parallel to the other work (*i.e.*, interviews, PRA exercises as described in next section) on all the farms covered. Furthermore, the two farms were specifically selected as representative of typical aquaculture practices in the respective study areas. Albeit limited in scope, this approach thus enabled more detailed study of the respective culture practices, and hence provided indications of more general trends in the two areas, which was important to fulfil some of the main aims of this thesis; *i.e.*, to assess the relative sustainability of two cases of aquaculture, and discuss aquaculture sustainability in general.

## Participatory learning and action

Participatory learning and action (PLA) is an action based approach to learning and research. It emerged as a response to the transfer of information and technology in a single direction, *i.e.*, as conventional one way communication from teacher to pupil. Experiences from *e.g.* rural extension work have shown that this way of transferring information and technology is not always appropriate, since it implies seeing learning as a linear process, as is described by Ison and Russel (2000):

Research ⇒ Knowledge ⇒ Transfer ⇒ Adoption ⇒ Diffusion

This view can be traced back to colonial times, and became even more deeply rooted following WWII, when it was increasingly believed that professionals and scientists should have exclusive rights to the generation and extension of new knowledge and technology. Today, the view of technology transfer as the solution to problems of “under-development” is still very much apparent. However, technology transfer has not been sufficiently successful in improving real conditions for poor people, and poverty amongst farmers of the global South remains a crucial constraint to development. Thus, it may be debated whether technology transfer is appropriate for solving environment and development problems<sup>12</sup>.

As an opposite, local knowledge may provide an alternative, or at least a complement to development policies based on scientific knowledge, and technology transfer. However, local knowledge, which is often based on hundreds of years of accumulated knowledge and trial and error processes by local people, is sometimes seen as obsolete. This was especially so during colonial times, when it was often ignored since it is based on learning by doing rather than scientific inquiry. Belittled as backward or un-scientific, local knowledge thus became more and more neglected. In the late 19<sup>th</sup>, early 20<sup>th</sup> centuries however, some radical educationalists in British and US schools reacted to this division and introduced learning techniques based on action (O’Hara 2004). It was in this context that PLA and other action based methodologies emerged. Following PLA, it is crucial to see research as a:

- (a) collaborative process between researchers and people in the situation,
- (b) process of social inquiry,
- (c) focus on social practice, and
- (d) deliberate process of reflective learning.

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<sup>12</sup> It is too often forgotten that if technology transfer would indeed spawn development, new centres of growth (*i.e.*, cores) would be created that in turn would need new under-developed areas, or peripheries to exploit (Hornborg 2001).

The latter element (d) captures the essence of PLA, hence commonly referred to as learning through action (and reflection). In a more practical sense, Checkland and Holwell (1998) describe the research process in action based research as a cyclic process. First, the researcher defines a problem or issue to study, preferably referred to as research question, or theme rather than hypothesis. Then, the methods that are presumed most appropriate are chosen. By taking on the role as both researcher and participant the researcher then enters the real-world situation through action together with the participants within the situation under study. This way of researcher-informant interaction means that the researcher participates in *e.g.* daily activities together with the informants, under conditions as similar as possible to those of the informants<sup>13</sup>. During this phase, it is crucial to consider and reflect upon the dual role of the researcher and also his or her involvement and role in relation to that of other participants. Finally, the researcher has to negotiate a point of exit from the real-world situation, after which it is time to tease out findings from the interaction. Especially the last but one step of choosing an exit point can be problematic, since the real-world situation under study will continue to evolve. Therefore, a compromise has always to be made regarding when an acceptable level of experience and understanding has been reached that enables trustworthy findings and conclusions.

Although all research approaches demand adaptation to the specific context when taken into practice, here action based learning is described in its ideal form, and is thus shown as such in figure 6.

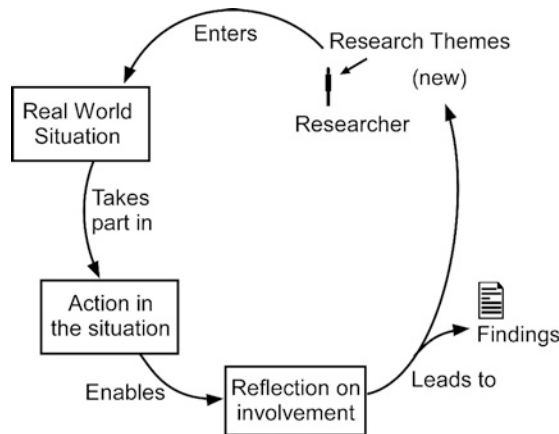


Figure 6. The idealised cycle of action based learning/research (modified from Checkland and Holwell 1998).

<sup>13</sup> As a foreign researcher in an unfamiliar culture or country, where the use of interpreters may even be necessary, it may be hard to achieve such interaction under similar conditions. Still, when applying PLA, the researcher must at least strive towards limiting bias and other problems related to different cultural and social backgrounds of the researcher and informants. Consequently however, participation may therefore take place in a variety of ways and different depths. This is further elaborated upon in the section “Defining participation” (page 76).

Whereas some action based approaches explicitly aim to bring about real-life change during and through the research process, PLA however takes on a less controversial approach, *i.e.*, by striving primarily towards facilitating learning, applying and generating theory through action, and not necessarily to bring about change during the research process. Thus, the facilitator (*i.e.*, researcher) is clearly more passive in PLA, which hence also makes the approach less normative (Raelin 1997). Still, PLA has an underlying ambition to change society, although more by increasing people's understandings of real-life situations, and thereby facilitating decision making at a later stage.

During the fieldwork conducted for this thesis, an adapted version of the learning cycle presented above (figure 6), sometimes referred to as “the magic spiral – action learning guide” was used. The spiral is presented in figure 7. The most important difference between the two models is that the spiral suggests an iterative research process. That is, when a cycle has been completed, the research process continues by incorporating new knowledge into the project ideas, thus facilitating improvement when the cycle is repeated. In this sense, PLA research, when using the magic spiral, becomes an ever evolving and improving multi-cyclic process of learning, hence the term “spiral”.

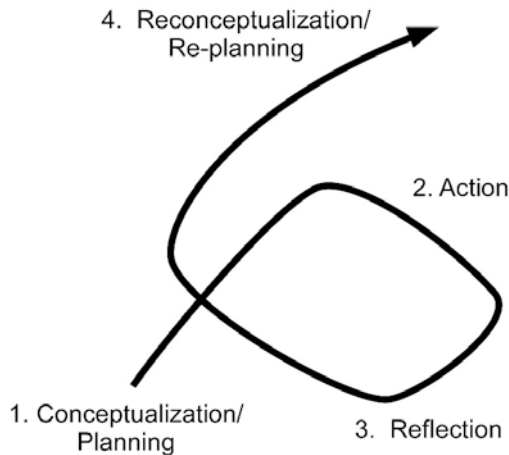


Figure 7. The magic spiral – action learning guide (adapted from O'Hara 2004).

In the first step (conceptualisation/planning), research objectives are defined by conceptualising the problem under study. This includes reviewing secondary information and conducting recognisance visits (including *e.g.* pilot interviews). Resulting data is then used for improving research questions and choosing appropriate methods. The first step is then finalised by designing the study in terms of improving, preparing and planning for more extensive fieldwork to come. The research design is then taken into practice (action). This step consists of carrying out the interviews etc. When this step has been

concluded, the acquired information is summarised and used for reflecting on what was good or bad, forgotten or could be improved for the following step (reflection). The results are then ultimately used for further improving the project design (re-conceptualisation/re-planning), after which the cycle is once again repeated.

## PLA versus conventional epistemologies and methodologies

Checkland and Holwell (1998) argue that the hypothetical deductive approach often practiced within positivist sciences is the type of knowledge acquisition most often ascribed the strongest truth claim. Sometimes argued as being the only true science, positivist research is often seen as the best source for innovation (Röling and Wagemakers 1998). This view encompasses the notion that reliable and objective knowledge results only from positivist science that strives towards creating probabilistic generalisations (Harré 1981), *i.e.*, laws that are discovered through repetitive experimentation and can be used for predictions. Hence, it has been commonly accepted that it is only through transfer of such positivist founded knowledge and technology that development can be achieved, and therefore, problems are solvable only by experts (Röling and Wagemakers 1998).

Due to the high levels of replicability of positivist research, debating the resulting strong truth claims is somewhat arbitrary. However, this replicability is only possible since conventional positivist science most often study phenomena that homogeneous through time (Checkland and Holwell 1998). Although this may apply to some positivist science disciplines (*e.g.* physics and chemistry), other disciplines are often faced with more uncertainty. Indeed, an increasing number of scholars from both natural and social sciences are realising that in reality few phenomena are truly homogenous through time, but rather cyclical. Thus, when studying temporally heterogeneous or pulsing systems, the need for unconventional approaches has become increasingly more apparent.

Another important critique that highlights the need for extending beyond positivist science approaches is the importance of context. That is, a phenomenon cannot be completely understood if not contextualised, *i.e.*, related to for example geographical and political settings, people, values and the different perspectives represented by a range stakeholders (people) and discourses. In other words, capturing different perspectives on reality, and relating the phenomena under study to these, becomes crucial. Hence today we have entered into a period of more uncertainty and complexity in research, where, as a result, a number of knowledge claims and un-conventional epistemologies have emerged (Röling and Wagemakers 1998). Among these alternatives, PLA is only one that, like other qualitative, social science methodologies, aims at capturing social realities, seen as continuously evolving systems. This makes it a much needed complement to positivist science.



It is however also important to acknowledge that when it comes to replicability, PLA has not much to put up against the hypothetical-deductive approach. Therefore, proponents of PLA need to realise and address the limited truth claims resulting from such research, as it affects validity and generalisability. Checkland and Holwell (1998) therefore point out that PLA practitioners must make the research process as transparent and recoverable as possible. By this is meant that the epistemologies and methodologies must be thoroughly stated and discussed. In other words, when applying PLA it is explicitly more crucial to define what counts as acquired knowledge, and to demonstrate how research is carried out, as it is the only way to enable trustworthy truth claims. Unfortunately however, in the literature of PLA declaring epistemology, methodology and the research process, and making the research process recoverable, has hitherto been poorly exercised.

### Making PLA participatory – rural appraisal influences

The participatory aspects of PLA have been highly influenced by Participatory rural appraisal (PRA). Also PRA emerged as a response to the failures to transfer technology based on one way communication, which especially in post-colonial times had also resulted in exporting western views of natural resource management policies and economics (*e.g.* growth with no limits) to the South. In this view, centralisation and state control over natural resources were seen as the appropriate approach to management. Natural resource management became a way of protecting nature from people, rather than incorporating them with it. This people-nature divide later resulted in a desire to increase involvement of beneficiaries in development and research activities (King *et al* 2001), and to break down the conceptual barriers between society and environment. PRA emerged as a response to this desire, offering an alternative to conventional approaches to natural resource management. Its primary aim is to capture and communicate multiple perspectives and agendas with the help of participation (O’Hara 2004). Proponents of PRA argue “that the production of knowledge and the generation of potential solutions should be carried out by those whose livelihood strategies formed the subject for research” (Cornwall *et al* 1994:108).

In a practical sense, PRA can be described as a tool for changing roles, behaviours, relationships and facilitating learning, where the outsider (*i.e.*, researcher) do not dominate and lecture, but rather facilitates information exchange with and between local people, based on their perceptions and needs (Chambers 1997). Whereas conventional research approaches have aimed to extract knowledge from those that are supposed to know most, *i.e.*, key informants, in PRA, no perspective is seen as less important than another. Because by doing so, the key informants’ versions of reality are prioritised, whereas the perspectives of *e.g.* women, children and less empowered individuals are seldom solicited and hence not acknowledged as important.

PRA therefore stresses that in any analysis, researchers must enable inclusion of all perspectives, since they represent different rather than less knowledge of the issue under study (Cornwall *et al* 1994).

Although the question of validity can be discussed and always has to be addressed in all research, it is clear that much can be achieved by taking on the perspective of local people to better understand real life situations. However, this also brings some practical problems that need to be addressed here. By participating, researchers become part of the problem under study, as opposed to external solution providers. This creates a subjective relationship between the participating researcher and local people, and thus makes it most important to thoroughly state the purpose of research so that false expectations can be avoided. This is especially important in the initial phase of a research project, and brings on the necessity for careful consideration and caution regarding semantics. Many words within the field of environment and development are value laden, and their usage may hinder the learning process. For example, the word “study” has shown less value laden than the word “project”, as well as asking for peoples “views” rather than “needs”. Hence, considering semantics is a simple measure to develop a suitable relationship between the researcher and villagers. It is however also crucial to establish a relaxed relationship at an early stage, because it has importance for the degree of which informants will tend to be honest and open, instead of providing answers that they expect the researcher wants to hear. This risk can also be decreased by applying method triangulation, *i.e.*, by examining the same issue using different tools. It hence becomes crucial to master a wide set of PRA tools, and to plan for the unexpected. PRA can thus be seen as a toolbox, out of which a method is picked *in situ*, rather than arriving with a pre-decided tool that is to be used regardless of the local context at the time of arrival. Of course this demands much from the researcher’s PRA skills, which can only be improved through lots of practice and reflection, *i.e.*, through learning by doing (O’Hara 2004).

## PRA tools applied in this study

PRA offers a wide range of research techniques. However, here only those that were used in this study are presented.

**Transects** were used in the initial phase of the field studies, in each study area respectively. A transect can be described shortly as a systematic walk through the different microenvironments in a particular area, while simultaneously mapping the activities in it and the boundaries between them. By forcing the researcher to follow a straight line through the study area, transects are particularly useful to avoid road side bias that is otherwise common during short recognisance visits (McCracken *et al* 1988).

**Venn-diagrams** were used to de-verbalise sensitive information and identify relationships and interactions between individuals and institutions. By

asking informants to make sketches of such interactions, simplified network maps were produced that could be used for further discussions and analysis, *i.e.*, during talks with informants and field assistants. During the fieldwork for this thesis, Venn-diagramming was also used in an experimental way to better address the issue under study, especially when trying to understand cost distribution and where and on what the informants spent their income. Informants were asked to draw circles on a piece of paper where size represented the amount in relation to other expenses. The informants then marked the farm location on the same piece of paper and placed the circles in relation to this in accordance with the real distance from the farm to the actual place of expenditure. In this way, sketches were produced that indicated where most of their income was spent. The sketches were then used for discussing where and on what most income is spent, and why. Ultimately, this resulted in an estimate of how much of the benefits generated by aquaculture stays within the local area, and how much is dispersed elsewhere. Results from these Venn-diagrams are presented in chapter 7.

**Problem analysis** was used to identify causes and effects of problems. One such exercise that was used in this study is called the problem tree. During these exercises the informants were asked to draw what they experienced as the causes of a problem, illustrated as the roots of a tree, whereas the stem represented the problem and the branches its effects. The sketches produced in this way were later used for discussing inter-linkages between causes and effects of the problem at hand. Problem tree exercises were primarily used initially in this study, but were later abandoned as a technique since it proved to be more appropriate to address these issues during semi-structured interviews (see below).

**Ranking exercises** are particularly useful for understanding which problems local people experience as the most urgent or limiting for development to take place. Ranking also makes visible the complexities of decision making, something that is not possible by using only formal surveys (Cornwall *et al* 1994). Ranking exercises are sometimes carried out separately with different stakeholders, and then brought together for reflection/analysis of findings; thereby influencing the research process as proposed by the Magic spiral mentioned earlier (O'Hara 2004). In this study, ranking exercises were used to identify the most significant problems associated with aquaculture in the two study areas, and to formulate relevant questions for the interviews. In addition, the ranking exercises enabled more standardised ways for comparing problems in the two study areas, as experienced by the informants.

**Semi-structured interviews** can be seen as the basis of PRA, although it is an interview technique widely applied also in other approaches. Semi-structured interviews have much in common with an everyday conversation, thus allowing follow up on the unexpected. In this study, predefined questions and discussion topics were presented to the informants who were then permitted to reflect freely and describe his or her experiences. The role of

the interviewer during semi-structured interviews is only to guide the interviewee onto interesting topics, interrupting as little as possible. When using the magic spiral as referred to earlier, the questions and themes for discussion are possible to change as the interviews proceed, and new and/or differently formulated questions may be developed and posed in succeeding interview sessions. Put together, semi-structured interviews in this way become a dynamic, flexible and iterative learning process, enabling spur of the moment adaptation to different contexts and informants. A selection of semi-structured questions used in this study is presented in appendix 1.

## Defining participation

It has been stated earlier that participation was used in this study. However, there are many ways to participate, among which the degree of participation may vary. Therefore, it is here necessary to further elaborate upon the practical and conceptual meaning of participation, especially in the specific context of this study, where the aim and meaning of participation was twofold. First, it refers to local participation as an explicit aim for involving local people in research. Chambers (2005) mentions two features that are necessary for being able to talk about local participation in terms of who actually participates, *i.e.*, whether those participating are either local government staff, or local inhabitants, or a combination of these two groups of people. It is important to stress here, that this definition is based on the view of local inhabitants as a homogenous group. Since whether the people benefiting from aquaculture are local or not was not the only interest in this study, local participation needed to encompass also individual characteristics of local people (*e.g.* men, women, rich, poor, etc.).

In a second sense, participation refers to the type or degree of participation and interaction between researcher and informants. In this respect, one way of classifying participation is by using a ladder of participation, as proposed by Chambers (2005);

1. Information-sharing: people are informed in order to facilitate collective and individual action.
2. Consultation: people are consulted and interact with an agency or researcher, who can then take account of their feedback.
3. Decision-making: people have a decision-making role, which may be theirs exclusively, or joint with others, on specific issues of a policy or project.
4. Initiating action: people are proactive and able to take the initiative.

This particular ladder proposed by Chambers (2005) was constructed and aimed for application by the World Bank, and hence refers to interaction between an agency and local people. Still, regardless of the outsider is an agency or a researcher, participation increases gradually in a similar way.

To a certain extent step 1 (information-sharing) was used in this study, *e.g.* by presenting and discussing experiences in the Philippines with farmers in Sri Lanka. However, in this study, primarily the second step (consultation) was used, by using interviews and PRA exercises. It may be argued that using only consultation as described above does not qualify as real participation, since information in this way is extracted from informants rather than co-generated by the researcher and informants. Therefore, in this study, another form of participation was used alongside consultation.

By participating in the daily chores at the farms, *e.g.* by preparing feed, cleaning ponds, collecting crabs, cutting grass, bringing food and water etc, a deeper form of interaction with the informants was enabled. In many PRA studies this type of participation is often excluded, *e.g.* due to delimitation necessities and limited time spent in the field. However, in this study it was an important strategy to reach better insight into the daily lives at the farms, and it also aided much in generating relevant interview questions and making informants feel more comfortable in the presence of an outsider/researcher. Still, it is important to point out that the study never explicitly aimed towards using participation for triggering change or decision-making in any practical or political way, which is why it fits better into the consultation category, as opposed to other, more action focussed categories or approaches.

## Geographical information systems

Albeit to a limited extent, this study also used Geographical information systems (GIS). GIS has a number of advantages for analysing and comparing social and environmental data. Environmental scientists have for example used GIS to calculate ecological footprints (*c.f.* Jansson *et al* 1997; Gren 2000). Not only does the information presented in GIS serve as a valuable database (Gren 2000), but it also facilitates comparisons of resource use in countries, regions, islands etc. Other benefits with GIS include the possibility to combine scientific experience with local knowledge (Strömquist *et al* 1999), which is needed to perform more holistic analyses than those traditionally achieved by sectorised academic disciplines (Simonsson 2003). Furthermore, GIS allows researchers to present data in a pedagogical manner to extra-disciplinary researchers, planners, decision makers, resource users etc. (Francis and Lundgren 2000), and hence increases the ability to perform holistic and interdisciplinary research. Working in differing scales also en-

ables the researcher to illustrate and analyse the studied phenomenon from perspectives ranging from the local to the global.

Despite all these positive notes on GIS, there is need for moderate expectation in what GIS may achieve. The ability of GIS is often exaggerated in terms of how well it works as a tool for retrieving accurate data and answering research questions, and still being able to limit the time necessary to spend in the field. For example, a common misconception, at least during the initial stages of GIS applications, was that the combination of scientific knowledge and technical competence possessed by GIS experts more or less automatically would result in more accurate and low cost evaluations. Thus, GIS has sometimes been used and encouraged as a technology in its own right, rather than as one of many tools available (Tripathi and Bhattacharya 2004). However, it is increasingly evident that due to the complexity of environment and development phenomena, top down approaches and technical fixes are not enough. As pointed out by Tripathi and Bhattacharya (2004), scientific knowledge alone has seldom contributed positively to development, and has sometimes even speeded up depletion of social and natural resources. This further highlights the necessity of integrating scientific with local knowledge. These problems are however difficult to solve even by using increased participation by local people in GIS applications (*c.f.* Lindberg *et al* forthcoming).

Bearing this in mind, it is important to stress here, that whereas GIS may in other cases an important research methodology, in this study it was used merely as one of many tools available for analysing spatial data, and hence, other methods were used to give a more nuanced picture. Still, GIS as used in this study proved useful in mapping land use changes, aquaculture expansion and resulting mangrove conversion.

## The current thesis – a multiple case study

The methodologies, methods and tools presented above were all applied simultaneously in the case studies. One of the strengths with case study research is that it allows for dealing with a variety of evidence, arraying documents, interviews and observations etc, all connected to the local context in the study area. However, case study research is also sometimes met by criticism. One of the concerns expressed is the influence of bias. Sometimes, researchers have used misleading evidence or biased views, by purpose or accident, thus influencing the direction of findings and conclusions (Yin 1987). This does not mean that the influence of bias is a bigger problem in case study research; rather has it been less addressed compared to other strategies. Still, it brings on the necessity of putting extra effort in case study research to avoid, or at least address, the issue of biased results.

Another common prejudice concerning case studies is that results are not suitable for generalisation (Yin 1987), especially compared to studies that use repeated experiments as a basis for generalisation. Such strategies however often study systems where parameters are more stable in time and space, thus making generalisation more accurate. This most seldom applies to case study research, and especially not to environment and development phenomena, where the character of the systems under study is open and therefore exposed to external influences, change over time and in space, and also vary from one place to another. Still, one can learn much that is general from single cases, since they indicate what applies also to larger populations (Stake 1995).

With regards to aquaculture, this is perhaps particularly true. Many aquaculture practices originate from research and development efforts by national governments and international research institutes etc, whose recommendations are then extended to farmers at local levels. That is, although there may be variations derived from location specific customs and traditions etc, farming techniques are often developed and disseminated on a global scale, by *e.g.* via regional cooperation, and disseminated through top-down initiated extension efforts such as workshops and courses aimed at local farmers. How such efforts succeed, and how local farmers receive and respond to new technology, and how such external knowledge is merged and combined with local knowledge, is however highly dependent on individual capabilities and conditions at local levels. Case studies are therefore often the best option, especially when dealing with development issues in the South, where specific and secondary data on local farming strategies and socio-economic conditions is commonly sparse. In addition, large scale but shallow surveys often generate dubious results due to technical and logistic problems, whereas results from case studies may be more trustworthy and hence more desirable in such settings (Patton 1990).

### Collection of empirical data – the fieldwork

In practice, the transdisciplinary approach of this study meant that PRA was used for collecting qualitative socio-economic and geographic data, as well as quantitative data needed for the energy evaluations. In addition, Geographical Information Systems (GIS) was used for illustrating land use changes and aquaculture appropriation of mangroves.

The findings accounted for in this thesis are based on repeated field studies, visits to local government offices, and literature reviews. Quantitative data for the energy evaluations was obtained from previous evaluations where available, as well as from informants directly in the field. Additionally, raw data in terms of statistics were retrieved from a range of suppliers of on-line national data, such as FAO, UNDP etc. However, since secondary data needed was sparse, most data had to be collected directly in the field.



*Figure 8.* Semi-structured interview with farmer in Tugas, Makato, the Philippines.  
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Semi-structured interviews (see figure 8), transects, Venn-diagrams, problem analysis and ranking exercises were conducted at a total of 47 farms (28 farms in Sri Lanka and 19 in the Philippines). The farms were selected on basis of their small-scale character. Thus, industrial large-scale enterprises were intentionally avoided. One reason for this choice was that small-scale



farms are more easily accessed, *e.g.* in terms of getting permission from owners and identifying relevant informants. That is, focussing on larger farms would have demanded selecting a few key informants, as opposed to talking to all people involved in the farm work, which is more doable on smaller farms. Another reason why small-scale farms were chosen is that, based on initial literature reviews, it could be assumed that smaller farms are more commonly initiated and driven from the local level, as opposed larger farms, which are often run by large companies, have offices, owners and investors located far away, which put together would bring unwanted constraints upon the study in terms of locating informants. However, the most important reason is that small-scale economic activities are generally a more viable alternative for poor local people, who seldom possess the capital needed for engaging in large-scale economic activities. Therefore, and since aquaculture is often referred to as an important contributor to poverty alleviation, smaller farms were prioritised, based on the assumption that this would generate more results with implications for sustainable and viable livelihoods for poor local people.

The interviews were carried out with assistance of interpreters recruited locally to ensure individuals with good knowledge of the study areas. In Sri Lanka, a local shrimp farmer assisted during interviews, whereas in the Philippines a fisheries extensionist from the local municipality was hired. The assistants were selected on basis of their knowledge of the local communities. However, the reason why two individuals with different professions (farmer versus extensionist) were selected has a more practical explanation. Apart from recruiting assistants on basis of their knowledge of the local communities and aquaculture practices in the study areas, it was necessary to find individuals who could communicate well in the local languages (Tamil and Sinhalese in Sri Lanka, Tagalog and Aklanon in the Philippines), but more importantly, were capable of iterating between these languages and English. In both study areas, individuals with good working ability in English showed very hard to come by, and hence two individuals with different professions had to be chosen, giving preference to their communication, personal and language skills. Whether or not this resulted in any bias is difficult to tell, but given that there were no other locally established and English speaking individuals to choose from, it was the best solution available.

Together with the assistants, interviews and PRA exercises were carried out with farm owners and/or managers, who supplied information of themselves and their workers. This way, interviews at the 47 farms generated information covering a total of 154 individuals<sup>14</sup> (109 in Sri Lanka, 45 in the Philippines). While this way of retrieving information of other individuals than those subject to the interviews enabled wider coverage, it sometimes also resulted in non-responses on certain details. Although non-responses

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<sup>14</sup> More detailed background data of the informants is presented in figures 12, 15 and 19.

were few and thus did not influence overall results, it means that the total sampling population cannot always be referred to throughout the thesis.

More importantly however, and especially since PRA stresses that no perspective should be seen as less important than another, conducting interviews mainly with farm managers resulted in some problems. When commencing fieldwork, the specific conditions in each study area called for some innovation as to how include all perspectives. For example, being a foreigner with a background in academia and Europe had different impacts in the two study areas. In Sri Lanka, it meant that initially, the language barrier proved significantly harder to break down than expected. Before ultimately finding a suitable interpreter, work was tried with many others, who had difficulties understanding instructions, interview questions, and consequently, also follow up questions formulated spontaneously during interviews. Due to these communication constraints, data from some of the initial interviews had to be excluded to avoid the risk of misinterpretation.

Another problem encountered during work with the initial interpreters in Sri Lanka was that local class structures meant interpreters were sometimes reluctant to talk to immigrant Tamil workers. Therefore, to avoid class conflicts and uncomfortable interview situations, formal interviews were conducted with farm managers exclusively. Since the focus of this study was primarily on the specific conditions at farm levels, and not explicitly those in the local communities in general, using key informants proved the most appropriate compromise.

However, to compensate for possible shortcomings derived from this approach, after every interview that felt unfulfilling, permission was solicited to return the day after, to take part in daily work at the farm without interpreter or any explicit aim of conducting interviews. The advice from the interpreters as well as farm managers was often that this would perhaps be uncomfortable for a foreign person, since the farm work is hard and the climate hot. After convincing them that this did not matter, it could still be agreed upon that coming back was not such a bad idea. Hence, with permission from the managers, the interview was concluded by informing the workers that the next day, they would have extra help on the farm, and make sure no special treatment was to be given to the “sudda” (the local term for white foreigner). As a result, it was possible to take part in daily chores at the farms, without neither interpreter nor key informants present. This showed highly rewarding in reaching important insights into the daily life of the workers. Additionally, despite the language barrier, spending a full day in the sun for example helping to remove the mud crust from ponds in fallow (see figure 9) created a certain amount of team spirit that during tea breaks facilitated more relaxed conversations.



*Figure 9.* Pond cleaning/preparation together with Tamil workers. Iranawila, North-Western Sri Lanka. © Daniel A. Bergquist, 2005-03-09.

In such occasions, combining limited Sinhalese skills with broken English meant conversations where actually possible, albeit with a little patience from both parts. Consequently, this enabled a more nuanced picture of work on the farms. Additionally, by revealing the managers (key informants) statements to the workers and allowing them to react to it, the two versions could be put against each other, hence resulting in a sort of triangulation. Thus, despite the obvious obstacles in terms of language and culture, these moments facilitated inclusion of other perspectives than that of key informants. Admittedly however, being able to speak the local language better would have made this detour unnecessary, and surely would have resulted in more trustworthy data retrieval. Working as a foreign researcher in Sri Lanka may sometimes be difficult, and this approach was the most appropriate considering the circumstances.

In Sri Lanka, interviews with women alone were also tried, since they proved responsible for many practical chores on the farms, such as cooking for workers, bringing water, and taking care of household- and farm book keeping etc. However, interviews with women in Sri Lanka were very difficult to realise, since local customs meant unknown men are not supposed to talk to women without a chaperon. Still, an effort was made that however only resulted in the need for concluding the interviews soon after initiation,

since the women were not allowed to speak directly to the interpreter, but only via their husbands. Since this meant a risk getting only the husbands' version, and not that of the women, the choice was made not to conduct interviews with women in Sri Lanka.

Meanwhile, in the Philippines, the situation was completely different. Firstly, interpreters were more skilled in English than in Sri Lanka. Secondly, key informants (managers) often spoke a little English, and thirdly, not many workers are actually hired, and those that are, proved to speak some English themselves, as well as being good friends with and from a similar class as the managers. Thus, language and culture biases were significantly easier to overcome. Also, the fact that no cast system exists in the Philippines, as does it in Sri Lanka<sup>15</sup>, made interaction across classes and cultures far more easy and comfortable. In the Philippines, it was also possible to interview women without their men present, which gave important insights into the importance of small-scale agriculture as a contributor to farm and household economies. However, since aquaculture is not combined with agriculture in Sri Lanka, it does not affect the validity of the results in this respect. Still, it has to be admitted that being a foreign researcher in Sri Lanka proved far more challenging than in the Philippines, which of course needs to be kept in mind when interpreting the results of this study.

On a more general note, what most importantly characterised the PLA approach in this study is the notion that credible results are best achieved in a process of close collaboration between researcher and informants, permeated by continuous reflection, as suggested by Raelin (1997). This way of carrying out the fieldwork was used simultaneously in two ways, with differing duration and scope.

In a wide sense, the process of realising the study, from fieldwork to finalisation of the thesis, can be seen as the completion of one cycle of the spiral discussed earlier. Thus, the four years during which the study was realised consisted of phases representing the different steps of the spiral (see figure 7). First, the problem under study was conceptualised through literature reviews and initial visits to the study areas. This resulted in formulation of research questions and hypotheses and choice of methods (conceptualisation/planning). Fieldwork was then carried out during four occasions of approximately one month respectively (2 in Sri Lanka, 2 in the Philippines), lasting from January 2005 through February 2006 (action). Furthermore, preliminary results were double checked with informants in Sri Lanka in January 2007. After completing the fieldwork, the following reflection phase

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<sup>15</sup> The existence of a cast structure in contemporary Sri Lanka is a contested issue locally, but experiences from this study indicate that at least in the study area, cast belonging does matter. However, research on the cast system in modern times in Sri Lanka is surprisingly sparse, and hence, little has been written on the subject. Still, studies conducted by *e.g.* Thiruchandran (2006) indicate that caste belonging is still of importance in both Sinhalese and Tamil communities, although she especially focussed on the situation for Tamil women.

comprised exposing the results to criticism by peers, *e.g.* through seminars, conferences and publications in scientific journals, and ultimately, writing up the thesis. The re-conceptualisation phase is here represented by the conclusions accounted for in the last chapter of the thesis.

In another view, the magic spiral was also applied on a daily basis, especially during fieldwork. In relation to the spiral, a day in the field comprised preparing for the farm visits, interviews and PRA exercises (conceptualisation/planning), performing the interviews (action), and discussing and thinking of improvement for the following work day (reflection). This was realised through informal discussions with informants after completion of the interviews, and/or with field assistants, who were asked to suggest improvements and express their opinions of the interview format and questions asked. This showed particularly important for reacting and adapting to previously un-known issues and risk of bias. For example, if there was reason to suspect that the informants avoided to answer some question, or provided misleading information, probable reasons for it could be discussed and reacted upon. For example, the field assistants could explain that the informants had felt uncomfortable with some questions, and in some cases had asked the assistants to hold back on sensitive information. In one case in Sri Lanka, the field assistant was explicitly asked by the informant not to translate or give any detail of his answers. Instead, the assistant was requested to tell a lie. Hence, due to informal talks with the field assistants, such shortcomings and underlying reasons could be considered and adapted to for reformulating interview questions, and when analysing results. A selection of check-boxes and semi-structured questions used in these interviews are provided in appendix 1.

On basis of their relative similarities in terms of geo-biophysical conditions, two areas were chosen for the field studies, one in Sri Lanka and one in the Philippines (see figure 1). The two study areas were also selected because aquaculture is practiced in different ways in the two countries, which was of greater importance for the research questions. The aquaculture industry in the two countries is in different phases of the so called “boom and bust” pattern experienced worldwide, where exponential growth is followed by near or total collapse due to environmental and other problems (see chapter 2).

In Sri Lanka, aquaculture was established later than in the Philippines, which has resulted in a time lag between the two areas in terms of when shrimp aquaculture peaked and ultimately started collapsing due to disease outbreaks and environmental problems. This means that in the Philippines, farmers have had more time to recover and adapt to changing conditions, whereas in Sri Lanka the situation is more characterised by trial and error and uncertainty of what is to come. Thus, by learning from experiences on both locations, emergent trends in aquaculture, as well as farmers’ strategies to cope with changing conditions could be compared.

## 5. The environment, society and energy

Few understand that cheap food, clothing, and housing depend on cheap energy and that potatoes are really made from fossil fuel (Odum 2007:7).

All human and economic activities may be seen as molecular, structural and spatial re-organisation of energy and matter (Bunker 1985). Establishing the value of products and services exclusively by using market principles (*e.g.* supply and demand or willingness to pay) neglects this. In addition, under capitalism, few producers or consumers bear all costs alone. Instead, costs are externalised and shared with the larger community, in particular those costs associated with environmental degradation, transportation and infrastructure, and depletion of finite material resources (Wallerstein 2007). Furthermore, not only material things, but also ideas, knowledge and information are necessary for regulating and organising production, trade and society. All these resources have been formed by using energy and materials in previous transformation processes. Put together, this means that monetary values fail to acknowledge all inputs needed for production, and hence, economic value does not reflect total value. This way, the value of goods and services transformed and traded in society is systematically underestimated. In other words, market prices capture only a fraction of the true value of many commodities, including aquaculture products (Gunawardena and Rowan 2005).

Marxists have tried to study the ways in which value is created and accumulated by emphasising the relationship between labour and capital (Bunker 1985). However, these approaches neglect that all production processes are either directly or indirectly connected to nature (*c.f.* Bunker 1985; Capra 1996). All processes are ultimately dependent also on the cyclical (*i.e.*, pulsing) processes found in all natural systems (Capra 1996), in addition to societal and market processes. Therefore, all processes contributing to the survival and reproduction of both nature and society should also be incorporated into our concepts of value, and be considered when goods and services are valued. Bunker (1985) argues that concentrating on the energy transformation processes behind production would reveal unfair and excessive rates of resource consumption, and acknowledge the total value and support by natural resources and processes, knowledge and information, that are otherwise so often systematically undervalued.

Many efforts have been made to make the interdependence between human-kind and nature more visible, and thereby estimate the total and true costs of natural resource utilisation. These attempts are perhaps especially numerous within ecological economics. One example of approaches with such ambitions is Ecological footprint analysis (EF-analysis). During the past decades, many EF-analyses have been conducted (*e.g.* Larsson *et al* 1994; Rees and Wackernagel 1994; Folke *et al* 1997; Deutsch 2002). EF-analysis makes it possible to identify the natural resources needed for an activity and to translate the exploitation in geographical terms, *i.e.*, how many hectares of land are needed to produce a certain commodity, and compare those costs with benefits from conservation. Results from EF-analyses and other attempts to define the value of ecosystem goods and services (*c.f.* Moberg and Rönnbäck 2002) have motivated natural resource conservation and restoration, and addressed equity issues in global development, which has been an important step towards more sustainable development.

However, EF-analysis as well as other approaches to assess environmental costs of natural resource use (*e.g.* energy and exergy analyses) inhere important weaknesses. Resources demanded to produce commodities are not limited only to natural features such as land and water. Human resources, such as labour and knowledge etc, as well as other forms of energy and materials (*e.g.* minerals, chemicals, fossil fuels etc.) are also needed to extract the value of natural resources. This has also been acknowledged within the physical sciences (Berg *et al* 1996), but has not yet been sufficiently included in EF-analysis (Klintman 2000).

One reason for this critique is that EF mainly focuses on the support by local ecosystems, and less on the importance of imported resources. The problem is not that imported resources are not considered at all, but that they are not considered enough. When assessing the contribution and environmental costs of imported resources, it is crucial to consider what previous work by nature and humankind generated them in the first place. Similarly, the value of human labour and information, and more importantly, indirect support to these resources, are paid relatively less attention in EF. Failure to acknowledge and account for these processes is thus what makes the scope of EF-analysis limited. More importantly however, it also results in a risk of underestimating the totality of direct and indirect environmental and human support to production. For example, when calculating the ecological footprint of aquaculture, the support by fossil fuels may in this way be underestimated, mainly since EF does not emphasise the indirect natural support that created the fossil fuels in the first place (*i.e.*, accumulated environmental processes during millennia). Put together, this means that the time dimensions of production are not included to a satisfactory extent in EF analysis.

Much of the shortcomings of EF-analysis mentioned above may be derived from its stance in a receiver based definition of value. Such value systems are constructed by humans, based on subjective perceptions of nature

and hence reflect only the perceived value for humans (Simonsson 2004). Another example of receiver based approaches is willingness to pay, an approach most often used within economic sciences, where the value of nature's contribution is calculated on basis on how much humans are prepared to pay for it (Brown *et al* 2000). This way of conceptualising value (based only on exchange value) totally conceals society's dependence on nature, as well as unfairness of global exchange (Hornborg 2001).

Assessment approaches that are based on receiver based definitions of value all have in common that they do not appropriately account for the "free" services and products that the human economic system receives from the environment (Brown and Ulgiati 2004b). In emergy terms, this means that *e.g.* agricultural products may contain more real wealth (*i.e.*, emergy) than is paid for in monetary transactions (Odum and Odum 2001). These aspects of natural resource utilisation and trade have not been sufficiently included in EF-analysis and similar approaches.

## Emergy – synthesising environment and society

Emergy synthesis is an environmental accounting methodology that emerged with the ambition not only to estimate environmental costs of natural resource utilisation, but to also illustrate nature's overall contribution to the human economic system. It aims at showing relationships and limitations of parts and processes of systems, by visualising and analysing flows of energy, materials, money and information in a diagrammatic way (Odum 2007). By using emergy synthesis, inputs from the human realm (*i.e.*, social-economic system) and those coming "free" from nature are considered on a common basis. Contrary to for example EF, energy and exergy analyses, emergy synthesis is based on a donor perspective (Federici *et al* 2003), which means that environmental contribution to a system's dynamics is accounted for regardless of the value perceived by human users, *e.g.* in terms of money, exergy etc. It is expressed in emergy, a currency that determines value of non-monetary and monetary resources, services and products together (Herendeen 2004), perhaps not perfectly, but at least with ambitions to treat human and environmental contribution on equal terms (Brown and Ulgiati 2004b). Emergy synthesis also connects and visualises processes and interactions on various geographic scales, thereby providing possibilities for more integrative, holistic analyses ranging from small scale agricultural production to public policy and environmental management (Brown *et al* 2001). By some, it is hence considered more ambitious than other approaches (Herendeen 2004).

Emergy synthesis is based on the assumption that in order to achieve holistic analyses of a given problem, it is necessary to understand both the internal mechanisms within a studied system, as well as the larger surrounding



system(s) that control and influence the smaller system (Odum 1996a). This holistic approach to the complexity of the world means that problems cannot be analysed in a literal sense, *i.e.*, to take something apart and study it piece by piece and thereby learning about it. Since analysis implies taking parts away from their larger context, proponents of emergy synthesis argue that instead of taking things apart, they need to be synthesised by aggregating all processes and inputs to a system, as opposed to excluding some to simplify the analysis. Hence, emergy evaluation is sometimes referred to as emergy synthesis, as “the act of combining elements to coherent wholes” (Brown *et al* 2001).

In this thesis, emergy theory and methodology is referred to in different ways; as (a) emergy synthesis, (b) emergy accounting, and (c) emergy evaluation. Therefore, it is perhaps appropriate to clarify the distinction between these ways of referring to what may seem as basically the same process. As mentioned above, the phrase “emergy synthesis” is sometimes used, by which is meant the theoretical and methodological basis of emergy and general systems theory, as a holistic approach for synthesising interlinked society-environment phenomena. Meanwhile, “emergy accounting” refers to the more hands on calculation of emergy flows, including drawing emergy diagrams, organising and calculating data in emergy tables. “Emergy evaluation” on the other hand, refers to the theoretical and methodological aspects of emergy in a wider and more applied sense, encompassing the process of collecting, compiling, synthesising and calculating emergy related data, and relating the results to principles suggested by general systems theory. Hence, emergy evaluation is the process of holistically evaluating a systems’ organisation, functions, effects and relations to environment and society at multiple scales. It is in this latter sense that emergy is applied in this thesis, whereas “emergy synthesis” is used when discussing emergy more generally, and “emergy accounting” when specifically referring to quantitative calculations.

The theoretical and conceptual basis of emergy stems from general systems theory (see chapter 3) and thermodynamics. Thermodynamics has been an important mainstay for developing the emergy accounting methodology, whereas the conceptual/theoretical foundation on which emergy is based has been highly influenced by general systems theory. Therefore, when carrying out an emergy evaluation, the systems view is generally accepted (Brown *et al* 2001), meaning that all processes in the world are ultimately interconnected. While keeping this in mind, when studying a particular process or activity, some delimitation is still necessary. Thus, for facilitating understanding and management of smaller parts of the universe (*i.e.*, sub-systems), it is appropriate to visualise an imaginary box around the part of interest (Odum and Odum 2001). This is done by setting the window of attention, which means dividing the world into three parts; the system under study, its sub-systems, and the next larger system (Campbell 2000). However, it is important to stress here, that according to universal principles, all things are

connected, and hence, the window of attention is more of a mental construct than a real barrier between systems. As noted by Abel (2007), in theory it is of course possible to draw a line around just about anything. In practice however, it is more appropriate to make use of natural patterns of confinement, such as continents, islands, watersheds, ponds etc. Important to stress here is also that although system boundaries are defined in this way, it is crucial to always look to larger scale systems as well and relate them to the system under study (Odum 1989). This derives from the notion that the largest system, or scale of life on the Earth is the geobiosphere (Abel 2007), and hence all other systems are but sub-systems nested therein.

Depending on the characteristics of the system under study, the window of attention can be of differing sizes, ranging from small ecosystems to nations, world-systems, and ultimately the geobiosphere and universe. If it is considered appropriate, for example a region can be defined as the window of attention (*c.f.* Brown and Ulgati 2001). In this case it means that all processes, flows and storages within the system boundary (*e.g.* region) are considered internal, whereas inputs and outputs that either leave the region or come from the world outside are considered external. Internal flows, processes and storages are hence commonly also referred to as local.

In order to understand energy evaluation and its application possibilities it is necessary to explore a number of concepts on which it is based. In the following section, some brief definitions and explanations of the most bearing concepts of thermodynamics and energy synthesis are therefore provided.

## Energy

Energy is most often defined as the ability to do work, based on the basic physical principle that any kind of work needs some sort of energy input (Brown *et al* 2001). Energy is quantified in calories or Joules and is often measured in units of heat. However, heat energy is only a good measure if the purpose is to calculate a form of energy's ability to raise the temperature of water. In reality, energy is used in processes far more complex than that and are thus seldom manifested in energy forms that can be understood by turning them into thermodynamic heat transfers. If energies of the geobiosphere are measured only as heat, as a result, all work processes are converted into heat engines. Since the infinite diversity of processes of the geobiosphere is much more than heat engines, this is not an appropriate approach to quantify the work potential of energies. Instead, energy should be converted into units that consider this complexity and thus span the greater realm of nature and society at work (Brown *et al* 2001).

## Exergy

Different forms of energy are relatively more or less available and suitable to perform work. In this sense, all energy forms have different attributes attached to them in terms of usefulness. The availability and usefulness of energy is referred to as exergy, *i.e.*, the amount of energy convertible into mechanical work. It is a thermodynamic concept relating to the process of bringing a system into equilibrium with the surrounding environment at the same temperature and pressure. In an ecosystem context, exergy may thus be defined as the amount of energy that can be extracted from an ecosystem (Jørgensen *et al* 2004).

## Energy hierarchy

In common language, a hierarchy refers to the interdependent relationship between higher and lower level units. That is, many units at one level contribute to fewer units at a higher level, which feedback controls downwards in the hierarchy (Brown *et al* 2004).

Apparently all systems of the universe organise according to hierarchical principles (Odum 1987), and as a result so is the geobiosphere. When viewed as a complete world system, the geobiosphere consists of an ordered series of energy transformations that together form an energy hierarchy (*c.f.* Brown and Ulgiati 2004a).

The concept of energy hierarchy is based on the conception of different energy forms as unequal in their contribution to processes of the geobiosphere as a result from having different quality, *i.e.*, exergy contents. For example, several joules of sunlight are required to produce one joule of organic matter (*e.g.* plankton), several joules of plankton to make a joule of fish, several joules of fish to produce a joule of fish meal, several joules of fish meal to produce a joule of shrimp, and many joules of shrimp to feed humans, and so forth. What all forms of energy have in common is that they all require input of other forms of energy to be produced, and thus have a position in the energy hierarchy.

## Emergy

As defined by Brown *et al* (2001:1), emergy is “the memory of energy used in the past to make something”. When nature and society work together it results in energy transformations, *i.e.*, one type of energy is used to produce another. A simple example of an energy transformation is the grass that, when grazed, enables a cow to grow. In this view, inputs to a production are the result of preceding transformation processes, or chain of processes (Ulgiati and Brown 1998b). When viewed in totality, these transformation processes are interconnected in webs of energy flows.

The purpose of emergy is to express the total amount of available energy (exergy) in different forms that were required in previous transformation processes, either directly or indirectly, to make another form of energy, product or service (Rydberg and Haden 2006). Since energy is needed in all production processes, there is emergy in everything, ranging from the organic matter of any biological organism to information stored in the genes governing their generation (*c.f.* Jørgensen *et al* 2004). Emergy can thus be defined as the quantity of energy previously used, *i.e.*, energy memory, hence the spelling emergy with an “m”.

To calculate the emergy of any process or commodity, it is necessary to trace back through all the processes that take place and identify all resources and types of energy that were used to produce it (Brown *et al* 2001). To facilitate the emergy accounting procedure, emergy is expressed as one form of energy, for the most part solar energy. It is therefore most often quantified and expressed in solar emergy joules, abbreviated as solar emjoules or SeJ. The result is a measurement of how much solar emergy is needed to provide a certain good or service (*i.e.*, the sum of all inputs and forms of energy). For instance, as in the example of the cow above, the solar emergy of that cow would then be determined by tracing the inputs needed for the cow to thrive (*i.e.*, soils, minerals, rain, wind, genetic information in grass seeds etc.), all the way back to the sun, thereby calculating how many joules of solar energy that were needed to produce the grass that the cow feeds on, and hence is ultimately “embodied” in the cow (Brown and Ulgiati 2004a).

## Transformity

The ratio of how much emergy is required in an energy transformation process, and the energy content in final products or services is called transformity. It is determined by dividing the total emergy used in a transformation process by the total energy yielded (Brown *et al* 2001). When transformity is used in energy evaluations, it is most often expressed as solar transformity. That is, the ratio of how many solar emjoules were needed in the transformation process divided by the total energy yielded. Solar transformity is therefore expressed in solar emjoules per Joule of output flow, or in mathematical terms, as SeJ/J (Brown and Ulgiati 2004a). For example, if 4000 solar emjoules are used to produce a joule of wood, then the transformity of that wood is 4000 solar emjoules per joule (Brown and Ulgiati 2004b). In this sense, transformity measures energy quality. For example, fuels with high transformities are those that can burn at higher temperatures. However, as pointed out by Odum and Odum (2001), this more importantly means that it is wasteful to use high transformity fuels when a lower temperature is needed, since more emergy has been spent to produce them. This applies to all processes, and hence it is considered good policy not to use high transformity sources of energy for process where lower quality (trans-

formity) energy will suffice, that is, when the same process can be performed with less. For example, using electricity (a high transformity energy source) to drive a car is more wasteful than directly using the fuel (*e.g.* coal) that otherwise has to be used to create the electricity in the first place. The reason for this is that, according to the second law of thermodynamics, in every transformation process, energy (or rather exergy) is lost due to dissipation, and therefore it is more energy efficient to keep the number of transformations to a minimum.

According to changing environmental conditions and availability of resources, *i.e.*, where a system operates in terms its position in the cycle suggested by the pulsing paradigm (see figure 5), the optimum transformity will change in correlation with availability of resources. The appropriate, *i.e.*, “sustainable” transformity, or rather, the one with the best fit to present conditions will thus oscillate over time (Ulgiati and Brown 1998b). Thus, transformity is not only a measure of quality in terms of the process’ or product’s position in the energy hierarchy, but indicates whether or not a system is operating at the optimum transformity, that is, fits present environmental conditions and availability of resources (Ulgiati and Brown 1998b). As such, transformity is both a measure of energy quality and how much energy is used to produce a certain good or service, and when put in comparison to other similar goods or services thus helps to determine energy efficiency (Brown and Ulgiati 2004a).

## Self-organisation

The concept of self-organisation has been discussed earlier and is a central concept in emergy synthesis. Studies of how ecosystems are compounded have suggested that energy flows within them generate hierarchies that follow organisational patterns (*c.f.* Hall 1995). When the trial and error process of evolution has been going on for a long period of time, a state is reached where energy use is most efficient. This state is sometimes referred to as a peak, or climax. This takes place because ecosystems self-organise through selective reinforcement of what works, *i.e.*, by feeding back products and services in the system to increase productivity and efficiency.

This way of reinforcing and thereby increasing production is labelled autocatalytic system design, autopoiesis or self-organisation (Odum 1987), and means using a small amount of energy high up in the energy hierarchy (*i.e.*, high quality energy) to amplify production at lower hierarchical levels (*i.e.*, low quality energy). In this way, systems organise and develop to maximise performance for the system as a whole (Ulgiati and Brown 1998b), thus ultimately resulting in optimised emergy use and maximised output.

A self-organising system is perhaps best described by using a simplified example of an enclosed environment, *e.g.* an aquarium containing plants and herbivorous fishes which is influenced by sunlight. Here, sunlight is an external energy source (input), whereas the plants and fishes represent internal producers and consumers. Thus far, the example illustrates a three level energy hierarchy. What is characteristic for self-organising systems is however that a reinforcement process takes place by feeding back resources in the system. In this case, the reinforcement process is represented *e.g.* by the fish that when dying sink to the bottom, thereby providing the plants with nutrition to further increase production. Although this example is very much simplified, it illustrates the ambition to self-organise that is found within any ecological system. When such simple systems are combined as units that together form a larger scale system (*e.g.* world system), complexity emerges. This complexity is necessary for making energy use efficient and enables ecosystems to find designs that are best at sustaining the system functions. When depicting self-organising systems in diagrams (*c.f.* figures 21-24), flows are illustrated as moving from left to right, and feedback as moving from right to left.

In natural ecosystems, the underlying principle of self-organisation always remains, regardless of system scale and thus always affects how interactions are organised. The concept of self-organisation hence provides important insights into how ecosystems function and implies that it is crucial to mimic natural ecosystems organisation to enable energy efficient designs. This has shown important, especially in ecological engineering that aims to design and improve *e.g.* agricultural production systems by joining human design and environmental self-design in a mutually symbiotic way (Odum 1996b). Odum therefore also suggested that an energy source must provide a net contribution to the larger system in which it is embedded, *i.e.*, “it must provide more energy than it costs to extract and process it” (Brown and Uligati 2004b:203). Odum labelled this net energy and thus argued that the true value of energy contribution to society is the net energy that is left after the cost of getting and concentrating that energy has been subtracted.

An example of this is the tendency of polyculture systems to work more sustainable in energy efficiency terms, especially when compared to industrial monoculture production systems. In aquaculture this takes place when shrimp and fish are produced together. By keeping shrimp and fish in the same ponds, the water is aerated by the fish through circulation and is kept clean from eutrophic nutrients that would otherwise limit shrimp growth rates. Simultaneously, the fish grows by consuming nutrients that would otherwise be lost due to depreciation. When viewed from an energy efficiency perspective, these systems are hence often more appropriate. However, according to the technical director at one of the aquaculture farms in Thoduwawa, Sri Lanka (Perera 2004), in practice such production systems are economically inefficient, since high energy efficiency is difficult to

translate into economic terms. Still, it remains that by mimicking self organising natural ecosystems in this way, resources are fed back through the system, thereby increasing energy efficiency. This way of managing and fostering self-organisation is the essence of ecological engineering (Odum 1989).

Self-organisation thus always strives for maximising emergy use. Odum referred to this as the maximum empower principle (Hall 2004), a concept that can be used to explain why most natural systems are similar in terms of organisation. By evolving into self-organised hierarchical systems, all products and services of the ecosystems work to further improve available resources and efficiency according to the maximum empower principle. Odum (1987:28) provides an example of such maximisation of emergy use;

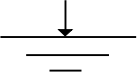
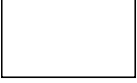
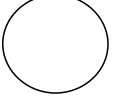
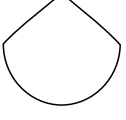

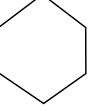
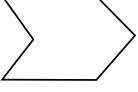
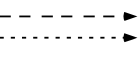

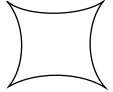
Energy of sunlight drives the photosynthetic part of plants which contribute products to the consumers in parthway [sic!] from left to right, which feed their byproducts back as necessary nutrients to stimulate the plants. There is a symbiosis between one end of the food chain and the other. Each is mutually stimulating.

The maximum empower principle is a more rigorous version of the older maximum power principle stated by Alfred Lotka in 1922 (Hall 1995). Lotka proposed that the maximum power principle was to be considered as the fourth law of thermodynamics, since it guided self-organisation of all open systems (Odum 1995). In emergy synthesis, this fourth law is still considered highly valid, although it has been reformulated as self-organisation for maximum empower (Odum 1999), a principle that nowadays provides the theoretical foundations for assessing levels of adaptation in ecosystems when carrying out of emergy evaluations (Cai *et al* 2004).

The principle of self-organisation for maximum empower implies that systems set performance goals of their own accord. Smaller units (*i.e.*, subsystems) of larger and more complex systems are all ascribed goals that are defined on basis of what works for the system as a whole. For this reason, Odum (1987) argued that by making models of higher level processes, performances at lower levels may be predicted. To grasp the complexity of self-organisation, it is hence not enough to study only processes within the window of attention. This is one reason why larger scale systems have always to be considered and included in emergy accounting (Odum 1989).

## The emergy evaluation procedure

In emergy evaluation, a series of operative steps are performed (Brown and Ulgiati 2004a). First, all system processes and flows are identified and drawn in a diagram of the system under study (see Box 1 for an explanation of symbols used for this purpose).

	<p><i>Heat Sink.</i> In all processes where energy is being used, some of the energy content is always dispersed and diffused out into the environment and is thereby made unavailable according to the second law of thermodynamics. In energy terminology this process is referred to as dissipation and in diagrams it is represented by using a symbol for heat sink. No material, available energy, or usable information ever goes through heat sinks, only degraded energy that is no longer capable of further work.</p>
	<p><i>System Frame.</i> The window of attention always needs to be defined in Emergy Synthesis. When diagramming, the system under study is therefore delimited by defining boundaries around it. The selected boundaries of the system are represented by a rectangular box. This is necessary for determining which inputs and outputs are to be considered as external versus internal.</p>
	<p><i>Source.</i> Any input that crosses the boundary (<i>i.e.</i>, system frame) is a source, regardless of the contribution being positive or negative to the system. Examples of sources are solar insolation, fuels, materials, genes, services and information. They are arranged outside and around the system frame from left to right depending on their solar transformity, e.g. from sunlight on the left to human services and information on the right.</p>
	<p><i>Storage Tank.</i> When energy, materials, money, information or other assets are stored in a system, it is illustrated by using this symbol. The criterion for a storage tank is that a transformation process does not take place, <i>i.e.</i>, in- and out flows to and from the tank must be the same type of flow and are therefore measured in the same units. Sometimes a tank is overlapped by a symbol of which it is part. For example, wood is a material storage that is a part of a producer, namely the trees forming a forest.</p>
	<p><i>Producer.</i> This symbol represents input receivers that use energy or materials to generate new products and are placed to the left in diagrams. It includes biological producers such as plants and trees, as well as human induced production, e.g. industries. The producer symbols often includes other functions such as storages and internal processes taking place within them and are therefore sometimes filled with the respective symbols of such interactions and processes.</p>
	<p><i>Consumer.</i> The symbol for consumer is used for units that receive (consume) inputs in terms of energy, products or services due to external and/or internal inputs and feedback mechanisms. The symbol refers to many similar but different units, e.g. animal or human populations, but also different sectors of society such as urban consumers. Therefore it is sometimes necessary to diagram the details of what constitutes the consumer inside the symbol, e.g. in terms of autocatalytic interactions and storages.</p>
	<p><i>Interaction.</i> When two or more flows are required for a process they are connected by using an interaction symbol. The flows to the interaction are connected to the symbol from left to right depending on their solar transformity. Interactions result in outputs from a production process and therefore move from left to right since production is a transformation that increases quality.</p>
	<p><i>Pathway Line.</i> Any flow (<i>e.g.</i> energy, materials, information etc.) is represented by a single line. If it is considered necessary to emphasise exactly what is flowing, the appearance of the line is varied. For example, a dotted line represents material flows, and a dashed one represents money. The direction of the flow is represented by arrowheads.</p>
	<p><i>Exchange transaction.</i> When one flow is exchanged for another, the symbol for transaction is used. An example of a transaction is selling the yield on the market and thereby receiving payment. Transactions are often dependent on the world market, which is illustrated by adding the symbol for an outside source that regulates the transaction.</p>
	<p><i>Switch.</i> Represents a process that turns on and off. It is often triggered when a threshold is reached. Switching processes exist in natural as well as human systems. Examples are earthquakes, floods, reproductive actions and tidal force etc.</p>

*Box 1.* Energy systems language used in this thesis for emergy systems diagramming (as modified from Odum 1996a).



The system diagram is then used to construct energy evaluation tables of all inputs, *e.g.* energy, materials, labour, services and information. The final step then involves calculating and interpreting the quantitative results. When all inputs and processes have been evaluated, the results can be used for calculating energy indices (Ulgianti and Brown 1998b) that relate the system under study to surrounding systems and higher levels of society and nature in which it is embedded (Brown and Ulgianti 2001). For the energy evaluation to be accurate, transformities for all inputs need to be known. In other words, a separate energy evaluation needs to be carried out for each input. To reduce the number of necessary energy calculations in new evaluations, results from previous energy evaluations are therefore used to the extent available (Brown and Ulgianti 1999).

### Systems diagramming – energy systems language and symbols

All open systems depend on flows of energy and resources (Capra 1996). These flows are apparent within and between systems of a variety of scales, ranging from singular organisms to the universe. As discussed in chapter 3, a systems view is called for if we are to understand the connections between humankind and nature (Odum and Odum 2001). Still, most problems and solutions are being discussed with concepts that do not permit the mind to understand such connections. Therefore, such understanding requires a new language.

By using symbols representing possible system components and interactions, on an early stage, Odum (1995:311) introduced “a general systems energy circuit language”, which enables illustration of system components, thermodynamic processes and their position in energy hierarchies. In energy evaluation, this language is used for drawing hierarchical system diagrams, and is hence a useful method for organising and illustrating energy flows and interactions, while simultaneously considering theories that govern their organisation (Brown 2003). However, since the world is infinitely complex, enabling the human mind to understand connections demands some simplification. Therefore, in systems diagramming, complexity is aggregated into the most important processes and parts of the system under study (Odum and Odum 2001). These main processes and parts are expressed by a range of symbols. Here, only those symbols that are used in this thesis are explained, to facilitate a basic understanding of system diagramming, and for enabling interpretation of the results. These are illustrated and explained in box 1.

The diagramming step in energy accounting is initiated by listing all inputs and outputs in detail, followed by putting it all on paper (Odum 1996a). This creates a complex initial diagram, or sketch of all processes within and outside the studied system (*i.e.*, window of attention). In the diagram, energy transformation processes are illustrated as flowing from left to right, and feedback (autocatalytic) processes from right to left. When all processes

have been listed, they are categorised according to their function (producer, consumer etc.) and position in the energy hierarchy.

To simplify presentation, all processes that have similar properties can be aggregated and put together, thereby reducing the number of symbols and making the diagram less muddled. For example, water, wind and tidal force can be summarised and expressed in a generic symbol representing renewable energies. The result is a simplified diagram that illustrates the system and its most significant processes in a conceivable way.

## Calculation and interpretation – energy ratios and indices

Emergy evaluation offers several ratios and indices for calculating and comparing different aspects of sustainability. In emergy accounting these are often modified to fit the specific context and system characteristics in each case. It would therefore be somewhat superfluous to provide universal definitions and explanations of them all in this thesis. Still, two examples are given here to illustrate some generic characteristics of what emergy evaluation can be used for. The indices used for interpretation of the results of this thesis are defined and discussed where calculated.

One example of an emergy index is emergy per unit money, which is defined as the amount of emergy supporting the generation of one unit of a currency. It can be used to convert money payments into emergy units. To facilitate comparisons between values from different emergy evaluations, the currency most commonly used is US dollar. Therefore, emergy per unit money is often expressed as emergy to dollar ratio, abbreviated as emdollar. Since money is never paid to the environment, but rather to people, emdollar is a measure of the amount of emergy that people buy with their money. The amount of emergy that money can buy depends on two things; (1) the amount of emergy supporting the economy, and (2), the amount of money in circulation. The average emergy to money ratio is therefore calculated by dividing the total emergy use of a national economy by its gross economic product. It is expressed as solar emjoules/\$ (Brown and Ulgiati 2004b).

Another example of an emergy index that can be used to assess sustainability is environmental loading ratio (ELR). It is based on the assumption that most human economic activities involve interaction of renewable emergy provided by the environment and non-renewable emergy that are extracted and added by man. In this sense, the environment is “loaded” (Brown and Ulgiati 2001). ELR can thus be defined as a way to express the amount of non-renewable and imported emergy that are used in a new development, put in relation to the use of renewable resources (Brown 2003). Ulgiati and Brown (1998b) define ELR as the ratio of purchased and non-renewable local emergy to the free environmental emergy. A natural and mature system that has been allowed to self-organise, thereby maximising

the efficiency and depending solely on local renewable resources would have an ELR = 0 (Ulgiati and Brown (1998b).

ELR can be used to compare to what extent different systems, regions or nations are loaded, *i.e.*, sustained by external and non-renewable resources. It can also be used for comparing proposed economic development and relate the expected impacts to the regional average. That is, the potential increase in environmental stress that can follow as a result from development may be calculated and compared to the average for the region within which it is to take place. New developments typically have high ELR's as a result from the high amounts of non-renewable inputs and outside resources that are initially converged into a relatively small area (Brown and Ulgiati 2001).

## 6. Conditions in the two study areas

In chapter 2, world trends and aspects affecting sustainability in aquaculture were discussed. This chapter further narrows the focus down to the more specific conditions in Sri Lanka and the Philippines, emphasising differences in geographic settings, aquaculture practices, societal contexts and challenges for the future<sup>16</sup>.

### Aquaculture in Sri Lanka

Aquaculture is comparably recent in Sri Lanka, dating back to the early 1980s. Initially, (as well as when this study was carried out), the dominating culture practice was semi-intensive monoculture of the black tiger prawn (*Penaeus monodon* Fabricius). The perceived opportunities for foreign exchange earnings and high profits have since been the main driving force for further expansion of the industry (Gunawardena and Rowan 2005). Hitherto, the total costs (*i.e.*, externalities) and impacts derived from aquaculture, such as degradation of mangroves and natural fish stocks have been repeatedly overlooked (Gunawardena and Rowan 2005). Based on this inaccurate view, the Sri Lankan government has developed a strong belief in the economic potential of the industry. There are currently plans for further development, although under controlled forms, *i.e.*, by introducing legal restrictions, Best Management Practices (BMP's) and other guidelines. Whereas the total culture area in the North Western Province is to be reduced by at least 20%, the Coast Conservation Department (CCD) has proposed further expansion and new developments in other locations, especially in the Southern and Eastern Provinces (CCD 2003).

Most farms in the study area are run as small-scale operations, in general comprising 2-3 hectares or less. The small-scale farms receive low levels of technical input and depend mainly on technical support from government and/or private company consultants. Poor accessibility of accurate information, and the fact that new technology often by-passes farmers has sometimes resulted in inappropriate farming techniques, spreading of diseases and production losses (Travaglia *et al* 1999).

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<sup>16</sup> Parts of this chapter are also published in Bergquist (2007).

In the year 2001, the production of cultured shrimp in Sri Lanka reached a total of 5120 tons (Sri Lanka Fisheries Year Book 2001). However, since 1996 frequent outbreaks of the white spot virus have seriously come to threaten Sri Lankan aquaculture. At the time of this study, the industry was experiencing similar problems as those previously encountered in other countries, such as spreading of diseases, inadequate planning and regulatory processes, sometimes resulting in illegal land encroachment. Other problems and impacts related to aquaculture in the country include increased pathogen population, sand bar formation at river mouths due to reduced floods and sedimentation in brackish water bodies (Jayasinghe and Orlina 2004). During the past two decades, the rapid and at times uncontrolled development of shrimp farming has therefore had a negative impact on surrounding ecosystems. A total of 4500 hectares of coastal land in Sri Lanka has been converted into ponds and other shrimp culture related facilities (Jayasinghe and Corea un-dated). According to a study conducted by Dayaratne *et al* (1997) a “considerable amount” of mangrove forest has also been cut down.

Shrimp farming in the country has also resulted in negative impacts on the water quality in surrounding coastal and estuarine ecosystems, as well as percolation of brackish water into ground water aquifers. Some coastal towns, including Chilaw, the nearest major town in the study area, have been forced to bring in freshwater by tanker due to this contamination (Aeron-Thomas un-dated).

In some cases, aquaculture has also brought socio-economic problems, such as conflicts over land use, water use and quality, policies and security issues (Jayasinghe 1995). Some authors (*e.g.* RDC 2002) derive these conflicts from failure to involve local people in planning and decision making processes. Furthermore, most shrimp farmers that run medium to large sized farms originate from outside of the local area, and have little connection or dialogue with local communities. Due to connections to political elites, many investors have also managed to establish farms without the necessary permits. Hence, the mechanisms established by the State to regulate the shrimp culture industry have been repeatedly undermined by local politicians (Aeron-Thomas un-dated).

According to Dayaratne *et al* (1997), the preference by outside entrepreneurs to employ outsiders and migrant workers is another common cause to conflicts in the area. For example, as indicated in the Initial Environmental Examination of one farm in the region, 15 job opportunities out of a total of 30 accrued to outsiders, although only 3 positions demanded highly skilled workers (AICS 1994). Still, many livelihood opportunities are created by the shrimp farming industry. Jobs are many for those directly employed for work on the farms but also indirectly in sectors that supply fry, feed, chemicals, machinery and those involved in processing, packing, transport, insurance and personal transport. However, the positive net effect of shrimp farm-

ing on the communities is low in terms of livelihoods per hectare compared to for example rice farming (Aeron-Thomas un-dated).

When shrimp monoculture was introduced in Sri Lanka, most large-scale farms were foreign-owned (Aeron-Thomas un-dated) and applied intensive culture practises, whereas the small-scale local farmers begun using extensive practices, *i.e.*, with low stocking densities and water exchange facilitated through tidal currents (Hettiarachchi 1996). With time, most small-scale farmers up-graded to semi-intensive production. In the late 1980's, also large-scale and intensive farms turned semi-intensive, mainly due to increasing problems with disease outbreaks (Dayaratne *et al* 1997). Legislation compelling all shrimp farms to apply exclusively semi-intensive practices with culture densities ranging from 15-20 shrimps per m<sup>2</sup> has further added to this trend. As a result, most farms today are run as semi-intensive and monoculture operations (figure 10). Observations during field studies further acknowledge that this is common practice in the country.



*Figure 10.* Semi-intensive shrimp monoculture in Iranawila, North-Western Sri Lanka. Photo: Daniel A. Bergquist, 2005-03-08.

To come to terms with the risk of environmental degradation, disease outbreaks and production losses, the Sri Lankan government has initiated a programme for best management practices (BMP's). BMP's that were being implemented at the time of research include crab fencing, bird lines, post

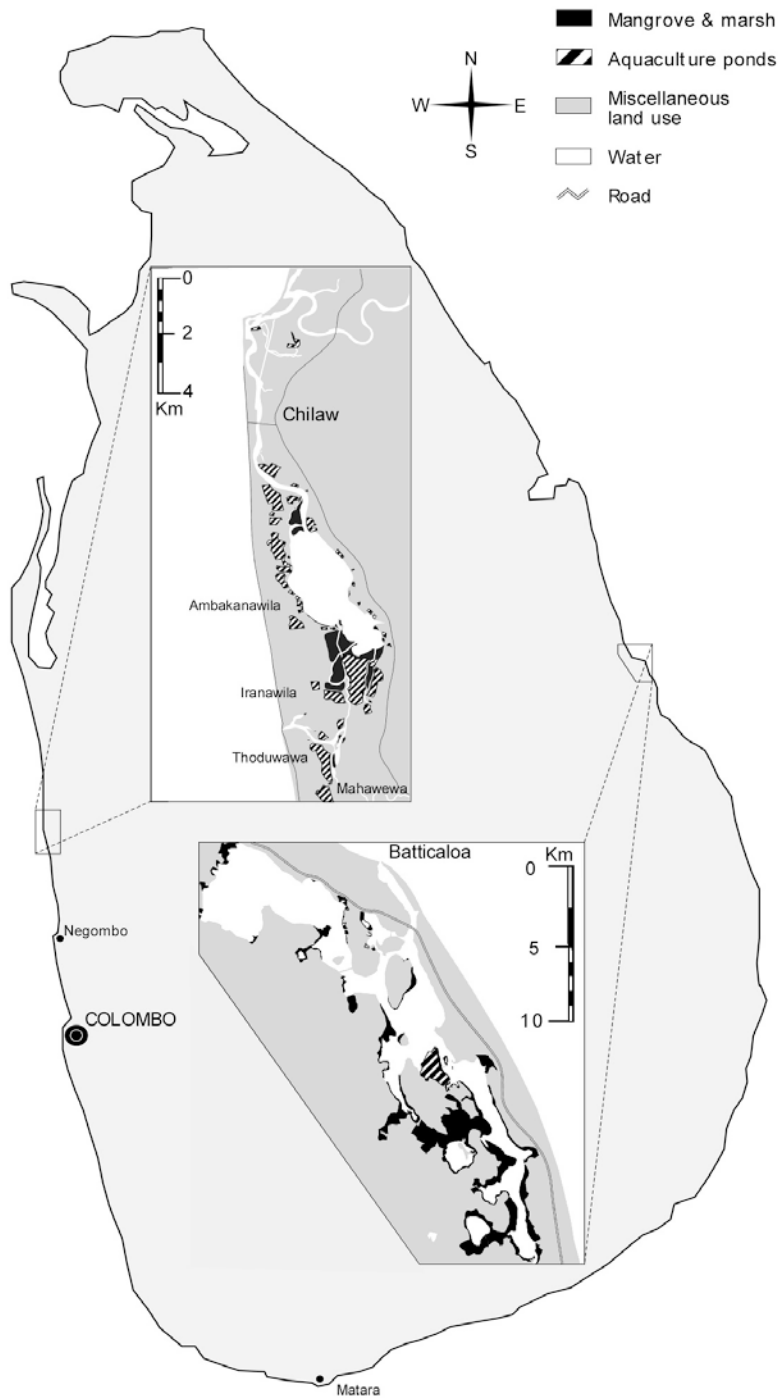
larval screening, water conditioning and treatment, improved aeration, water quality monitoring, use of probiotics etc. However, according to a survey conducted by Jayasinghe and Orlina (2004), adherence to the BMP's has been very poor. Alongside the BMP's, the North-Western Province has been divided into fallow zones, which means that ponds in every other zone will be used for production while the zones between them are left inactive (NAQDA 2004). This way, each farm will be able to complete 1, 3 cycles per year, while the risk for spreading diseases between the zones is supposedly reduced.

As noted above, shrimp farming is relatively recent but well established in Sri Lanka, and currently there are plans of further expansion by introducing sustainable aquaculture in new locations (CCD 2003). Although the intention of introducing sustainable aquaculture is commendable, it is not entirely unproblematic, since there is no certainty of what sustainable aquaculture would be in this case. If the path currently taken by Sri Lankan authorities (*i.e.*, promoting semi-intensive shrimp monoculture and BMP's) fails to increase contribution to local development and improvement of environmental conditions, it may be necessary to explore alternative culture practices or livelihoods that benefit poor local people more, and less at the expense of the environment.

Keeping this in mind, feasibility studies conducted in 1988 (Hettiarachchi 1996) have identified several potential sites for aquaculture development on the entire coastline of Sri Lanka. However, in the North-Western province, the industry has already reached, and most probably passed its full potential. Therefore, further expansion is mainly planned in other areas, *e.g.* in the Southern and Eastern provinces (*c.f.* Gunaratne 2007). Meanwhile, in the North-Western province, production facilities now cover almost all suitable coastal lands and connected water bodies (RDC 2002). Due to the rapid expansion the industry has experienced setbacks, primary due to disease outbreaks, but recently also because of increased awareness of negative environmental as well as socio-economic effects from shrimp farming. Much of the contemporary debate has thus come to focus on the [un]sustainability of shrimp farming (Travaglia *et al* 1999).

## The study area in Sri Lanka

In Sri Lanka, the main area chosen for the case study was the coastal communities of Ambakandawila and Iranawila, south of the town of Chilaw in the North Western Province. Additional fieldwork, though to a lesser extent, was also carried out in the Eastern Province, namely in and around the town of Batticaloa. The respective study areas are indicated in figure 11.



*Figure 11.* The field study areas in Sri Lanka. The main study area is located in the North Western province, whereas additional fieldwork was carried out near Batticaloa in the Eastern Province.



The main study area in North Western Province is permeated by natural lagoons and estuaries. An artificial canal (Dutch Canal) was also built during the Dutch period (1658-1795) to connect the region's major lagoons, including Negombo lagoon, Chilaw lagoon, Muthupanthiya and Mundel Lakes. The canal runs parallel to the coast and, alongside natural estuaries, supplies farms in the area with brackish water (RDC 2002).

The climate of the region is distinctly tropical, equatorial. Located in the intermediate area between a dry zone to the North and a wet zone to the south (Foell *et al* un-dated), daily average temperatures range from 30.4-33.6°C throughout the year. The area is influenced by the Southwest monsoon during May to September and the Northeast monsoon in October to December. There are two rainy seasons that occur almost simultaneously as the two monsoons, resulting in a monthly average of 120mm rainfall in the region (Dayaratne *et al* 1997).

Seasonal migrant fishermen visit the area during the fishing season, during which several fishing crafts are landed on the beach, which is lined by shrimp hatcheries and scattered houses, home gardens and coconut plantations. The nearby lagoon (see the map in figure 17) is bordered by an almost uninterrupted line of shrimp farms (Foell *et al* un-dated).

## Population

The local population comprises three major groups of people; permanent residents, seasonal migrants and refugees (Dayaratne *et al* 1997). The seasonal migrants usually come from nearby Thoduwawa, Mahawewa and Negombo, but also from areas further south such as Matara and beyond.

The mainly Muslim people constituting the refugees part of the population have been arriving in the area from the Mannar District roughly since 1985 due to ethnic persecution by the LTTE (Euroconsult 1994). Tamils come to the area from the hill country<sup>17</sup> in search of job opportunities. Put together, this means that the population is ethnically diverse, consisting of Sinhalese, Tamils and Muslims. Subsequently, a majority (95.8 %) of the population are Buddhists, Hindus, Muslims or Catholics, the rest pertaining to other religious minorities (Foell *et al* un-dated). The common language in the region is Sinhalese. A high proportion of the population has completed primary school. Where aquaculture and marine fishing activities are concentrated the population growth rate is high (RDC 2002).

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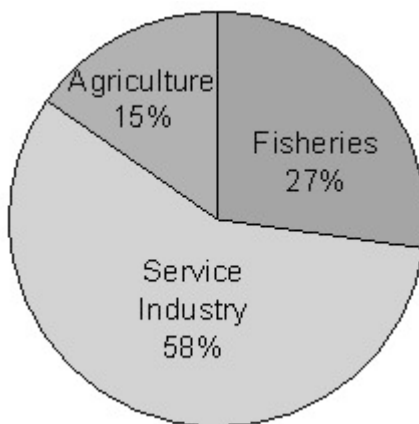
<sup>17</sup> The hill country is a local term for the central highlands of Sri Lanka. Historically, the hill country has been the most important tea-district, and during colonial times, many Tamils were brought there from India to supply the tea plantations with cheap labour. Some of these people nowadays migrate to other areas in Sri Lanka in search of job opportunities, for example on shrimp farms along the coasts.

## Poverty

In rural Sri Lanka, the level of poverty is often dependent on [unfair] access to land and water. However, it is important to mention that, according to Abhayaratna (2001), state sponsored welfare measures and other poverty mitigation schemes have kept people from starvation. Still, in the lower strata of rural societies in Sri Lanka, poverty has increased during the past two decades. In the study area, the largest poverty related problems are low income levels, especially for fishermen and shrimp farmers that have suffered economic losses due to disease outbreaks (RDC 2002).

## Characteristics of informants

Wealth of the people involved in aquaculture in the study area depends much on whether they are employees or owners. Also occupation before engaging in aquaculture is of importance, especially for first time farmers whose opportunities are highly dependent on available investment capital. A majority of the people (both owners and workers) involved in aquaculture in the study area come from professions within the service industry, such as transportation, banking, and engineering etc. Figure 12 shows the most common previous occupational sectors amongst the interviewed farmers in Sri Lanka.



*Figure 12.* Previous occupational sectors of people involved in aquaculture in the study areas in Sri Lanka.

In terms of educational background, a majority of the people at the visited farms in Sri Lanka (52%) had only completed elementary or intermediate schooling, whereas 35% had finished high school, and 13% attended some higher education at university level. The reason a majority are poorly educated can be explained by the fact that relatively more of the people interviewed are low-skilled workers and not owners or employed managers.

## Aquaculture in the Philippines

In contrast to Sri Lanka, coastal aquaculture has existed for at least some centuries in South East Asia and ultimately spread also to the Philippines, where it was initially dominated by extensive fish culture in earthen ponds (Edwards and Demaine 1997). In 1947 the industry started expanding tremendously, when the Bureau of Fisheries and Aquatic Resources was established and development schemes were implemented to facilitate pond construction and further expansion (Primavera 1995). These development initiatives were based on the notion of coastal wetlands and mangroves as valueless wastelands, which has been a common belief among planners, developers and politicians worldwide (Gunawardena and Rowan 2005). Based on this false conviction, everybody was thought to benefit from conversion into aquaculture ponds. As pointed out by Primavera (1995), this view was the main reason why fish pond development efforts were also supported by international development and credit agencies. Initially, aquaculture in the Philippines was almost completely dominated by the culture of milkfish (*Chanos chanos* Forskål), either through monoculture or in polyculture systems together with the black tiger prawn (*Penaeus monodon* Fabricius), and occasionally mud crab (*Scylla serrata* Forskål). However, in the 1980's, shrimp monoculture became more popular, mainly due to increased availability of hatchery fry and artificial feed, only to experience a near total collapse of the industry due to continuous disease outbreaks a few years later in 1989 (Primavera 1997).

In the Philippines, polyculture has traditionally been practiced more by accident than design, *i.e.*, other than targeted species enter the ponds via tidal currents, hence resulting in accidental polyculture (Bardach *et al* 1972). However, farmers in the study area accord more value to polyculture today, since it reduces risks of spreading diseases and suffering from price fluctuations (*i.e.*, through crop diversification). Today, many farms have therefore returned to extensive polyculture practises similar to those before shrimp culture boomed. Extensive polyculture, often in combination with small-scale agriculture is thus once again common (see figure 13).

Results from the fieldwork indicate that apart from growing trees, fruits, vegetables, and keeping cattle, some farmers also plant mangroves around their farms to protect homes and ponds from damage. Although it is questionable to what extent these efforts succeed in reducing mangrove loss, Walters (2000) acknowledges that replanting mangroves is common practice on many locations throughout the Philippines. However, results from the fieldwork indicate that most farmers prefer to plant nipa (*Nypa fruticans* Wumb) instead of mangrove species. The reason for this preference is that nipa contributes to stabilisation of pond walls as well as additional income, since the leaves are frequently used for artisanal housing and hence easily sold at local markets. However, regardless of what is planted, combining

extensive polyculture with cattle breeding and agriculture means spreading risks and improving efficiency, and hence makes it a relatively more reliable and long-lasting livelihood. In fact, in a historical perspective, extensive polyculture is comparably more sustainable and long term than more intensive practices. Studies conducted on other locations in the Philippines showed that virtually all of the extensive ponds that were developed between 1930 and 1980 are still in operation (Walters 2000). This is also the case in the study area, where many of the farms that were established in the 1920-50's are still in operation.



*Figure 13.* Extensive fish/shrimp/crab polyculture, including small scale agriculture and tree planting of mostly nipa palm. Photo: Daniel A. Bergquist, Tugas, Makato, Philippines, 2006-01-17.

## The study area in the Philippines

In the Philippines, fieldwork was carried out on the island of Panay in Western Visayas, on the coastal stretch west of the town of Kalibo, in the municipalities of Numancia and Makato (figure 14). The climate is distinctly tropical, fluctuating between wet and dry seasons.

In the year 2000, Makato had a total population of 22,777 individuals (Municipality of Makato 2007) whereas Numancia in the same year was populated by 24,614 people (Municipality of Numancia 2007). In both mu-

municipalities, roughly 90% are Roman Catholic with the rest pertaining mainly to Christian minorities.

The most important economic activities in both municipalities are agriculture (especially rice, copra, fruits and vegetables) and aquaculture of finfish, shrimp and other crustaceans. Of the total 7.3 kilometres of coastline in the study area, a large share has been converted into aquaculture ponds, covering a total area of 287 hectares of mostly previous mangroves in the municipality of Numancia alone (Municipality of Numancia 2007).

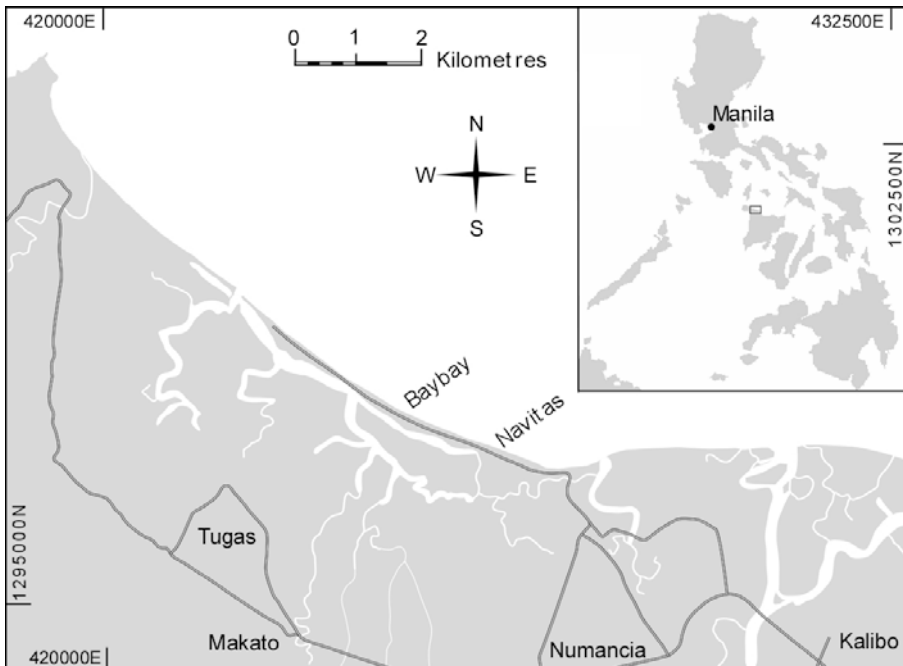


Figure 14. The field study area in the Philippines.

### Socio-economic characteristics of the local population

In the Visayas, where the study area is located, a study of socio-economic conditions of fish farmers (Librero *et al* 1985) showed that their average income in 1978-79 was 30 times higher than households depending exclusively on fishing. Librero *et al* therefore concluded that fish farming generates more income in comparison to other activities such as fishing and agriculture. For example, fish farmers' incomes were about seven times higher than those of rice farmers. Also in comparison to the national average of household incomes in the Philippines, fish farmers in the Visayas received incomes that were more than five times higher than average.

Based on a sample size of 40 individuals, results from the same study showed that the average age of fish farmers in the Western Visayas in 1979 was relatively high (55 years). Out of these, the average years of experience of fish farming was 19. Eight individuals were non-educated, whereas average years of schooling of the total sample individuals were 9 years. These numbers are similar to the results from fieldwork carried out for this thesis. As a comparison, the average age of fish farmers in the Philippine study area was 50 years.

Half of the number of people involved in aquaculture in the study area comes from professions within the service industry, such as *e.g.* transportation, official work, and engineering etc. Figure 15 shows the most common previous occupational sectors amongst the interviewed farmers in the Philippines.

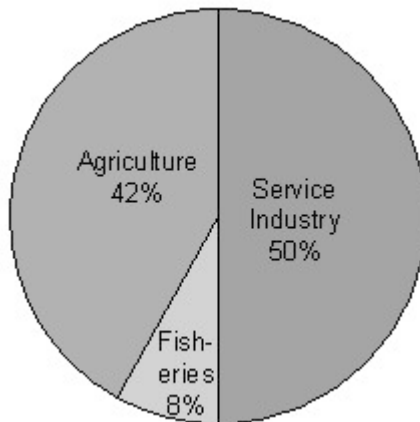


Figure 15. Previous occupational sectors of people involved in aquaculture in the study areas in the Philippines.

A majority of the people at the visited farms in the Philippines (67%) had attended some higher education at university level, whereas 16.5% had finished high school. The remaining 16.5 % had completed only lower education such as elementary or intermediate schooling. The reason why a majority of the informants were relatively high educated is possibly that most informants were owners as opposed to workers. This however, may in return be explained by the fact that most farms do not employ many workers, since the extensive polyculture practices applied are characterised by low labour intensity. When comparing the results to those from Sri Lanka, it is therefore important to bear in mind that differences in terms of education levels do not necessarily reflect higher levels of education in the Philippines. Rather may the difference be a result from differing owner to worker ratios (more on this in chapter 7).

## 7. A comparison of aquaculture in Sri Lanka and the Philippines

To facilitate comparison, in this chapter the analysis is based on the factors and issues discussed in previous chapters. Apart from highlighting differences, the aim with such a comparison is also to enable a more empirically grounded understanding of what constitutes aquaculture sustainability and variability. Findings presented in this chapter are then used for illuminating and discussing neo-colonial processes of aquaculture, and systemic views on sustainability and fairness in chapter 8.

The respective culture practices in Sri Lanka and the Philippines have resulted in different environmental and socio-economic effects. In terms of contribution to local economic development, perhaps the biggest differences derive from institutional and socio-economic factors. For example, most of the Philippine farmers have extensive experience and local knowledge of aquaculture and over time have mastered a range of culture practices and species. In Sri Lanka, aquaculture is relatively recent, and farmers depend mainly on scientific knowledge transferred via extensionists and consultants. Often, new technology bypasses the farmers as a result of poor attendance at extension workshops, and since not all farms are visited on a recurrent basis. There are many reasons for this failure of information extension, such as the farmers and/or workers not having time to attend meetings, or the knowledge of when and where the workshops take place. Furthermore, high-tech production systems are seldom designed to take advantage of local knowledge and adapt to local conditions, experiences and traditions, which generally makes it difficult to achieve sustainable resource management (Thomas 2003).

However, failure to transfer scientific knowledge and technology cannot alone explain why culture practices vary between the two countries. In the Philippines, the long history of aquaculture has affected also farmers' strategies, perhaps most importantly in terms of culture practices, marketing strategies and species selection. For example, the Philippine farmers mainly produce fish, shrimps and crabs aimed for local and national markets. This is in contrast to Sri Lankan farmers who concentrate on export-oriented shrimp monoculture. One reason for this difference is that in Sri Lanka local demand for cultured fish is poor, while in the Philippines local and national demand is high as a result of long-standing cultural preferences for finfish.

## Land-take and mangrove conversion

Incorporation of the peripheries into global markets may result in negative impacts on local social and political processes due to changes in power relations, as well as in land use and biodiversity of affected regions (Moran 2007). In this context, as argued in chapter 2, one of the most important aspects affecting aquaculture sustainability is to what extent mangroves are negatively affected.

Rönnbäck *et al* (2003) have estimated the necessary mangrove ecosystem support area for intensive shrimp aquaculture to 11 times the pond cover, here expressed as a ratio of 11:1. In the same study, it was estimated that the support area required for extensive aquaculture to be sustainable may be less than the pond area. However, the authors only considered the support area needed to supply one input, namely hatchery produced shrimp fry. For mangroves to support aquaculture with all necessary inputs, including *e.g.* natural fry, filtration, waste recycling etc, as well as other economic activities and natural processes, the necessary mangrove to aquaculture ratio would hence far exceed these numbers.

The mangrove support area needed for aquaculture to be sustainable thus varies between different culture practices and intensities. In this section, mangrove to aquaculture ratios are calculated for the study areas in Sri Lanka and the Philippines. The maps were compiled using the software applications MF works and Canvas GIS. Landsat TM and ETM+ satellite images from the years 1987 and 2000 (Sri Lanka), and Landsat ETM+ from 2001 (Philippines) formed the basis for constructing the maps, as well as the spatial analysis and calculation of mangrove to aquaculture ratios.

In Sri Lanka as well as the Philippines, the rapid and at times uncontrolled development of aquaculture has indeed had a negative impact on mangroves. For example, some 4500 hectares of coastal land in Sri Lanka has been converted into ponds and other shrimp culture related facilities (Jayasinghe and Corea un-dated), mainly through clearing of mangrove forest (Dayaratne *et al* 1997). In the study area in North-Western Sri Lanka in 1987, when aquaculture was still in its cradle, expansion had already led to a ratio of 8 hectares of mangrove to every hectare of aquaculture ponds (figure 16). This means that even before the industry boomed, mangrove conversion had already surpassed what may be seen as sustainable.

In the year 2000, continued expansion had led to a ratio of 0.6 hectares of mangroves for every hectare of aquaculture ponds, based on a spatial analysis of the map presented in figure 17. Considering that most farms in this area are semi-intensive shrimp monocultures, far more extensive mangroves would be needed if the industry was to be sustainable. Not surprisingly, aquaculture as well as other economic activities in the area, have suffered greatly from problems normally derived from excessive mangrove clearance, such as decreasing natural fish stocks, pollution and siltation etc.



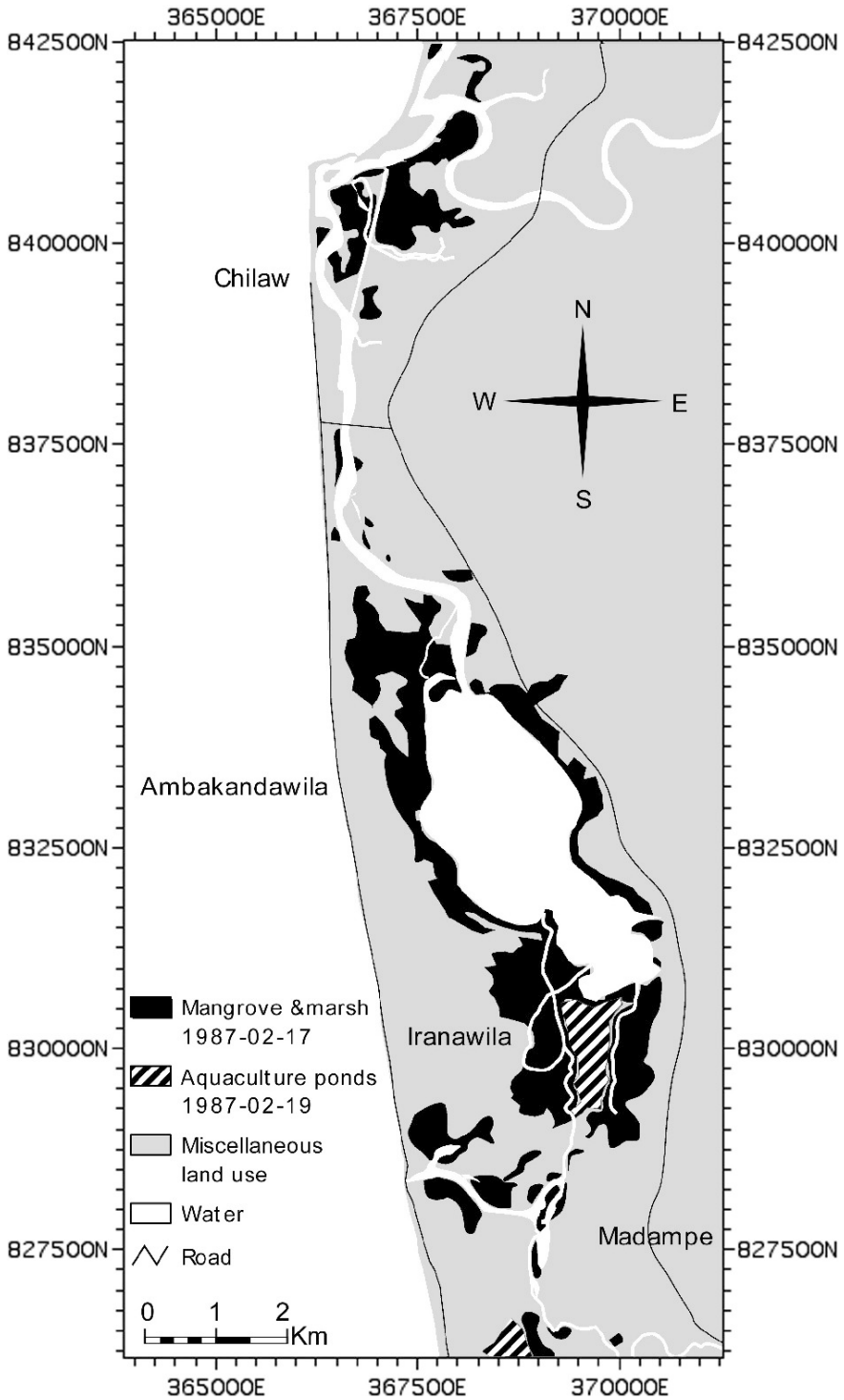


Figure 16. Aquaculture land-take versus mangrove land cover (year 1987) in the study area in North Western Sri Lanka. Mangrove-aquaculture ratio: 8:1.

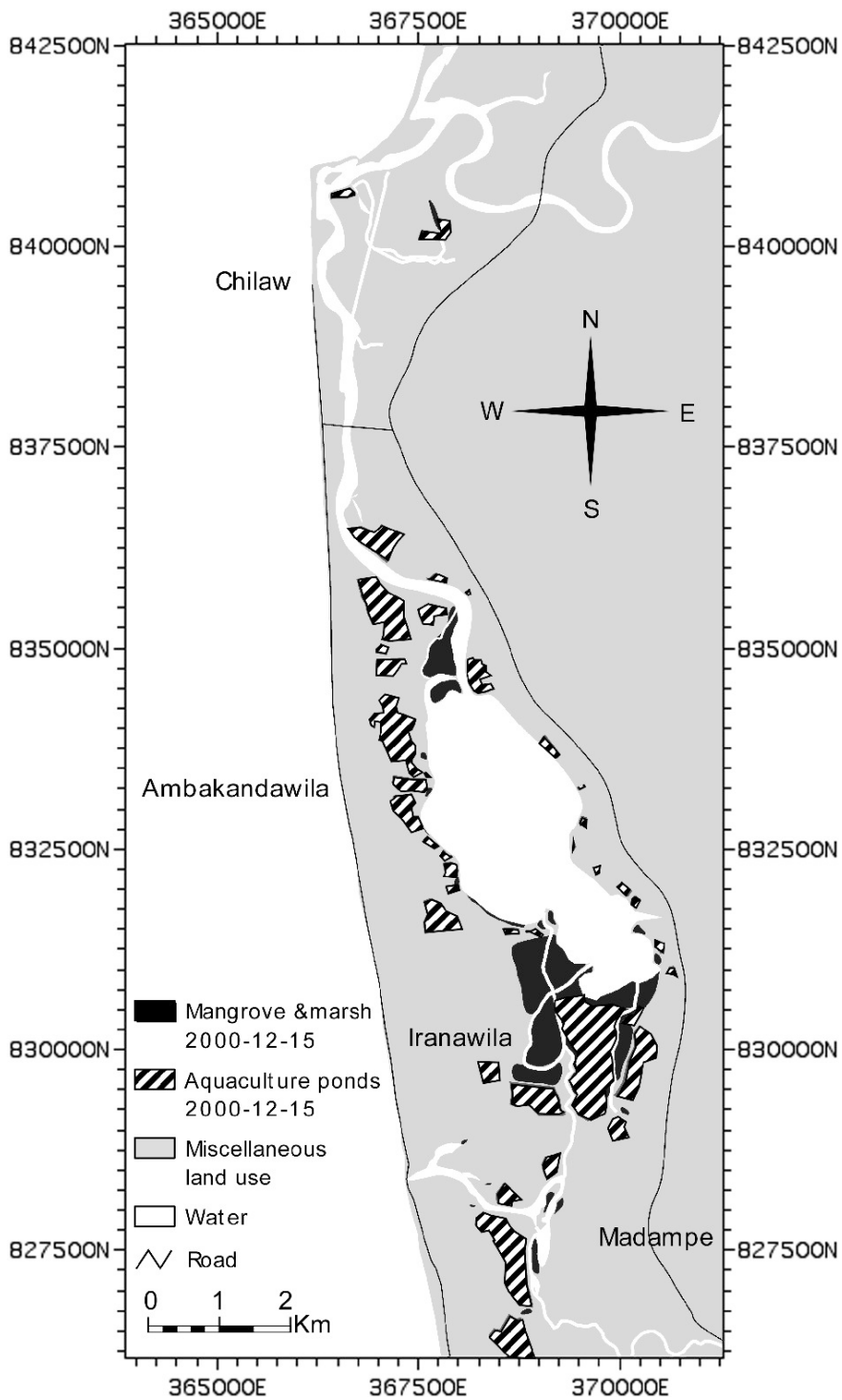


Figure 17. Aquaculture land-take versus mangrove land cover (year 2000) in the study area in North Western Sri Lanka. Mangrove-aquaculture ratio: 0.6:1.

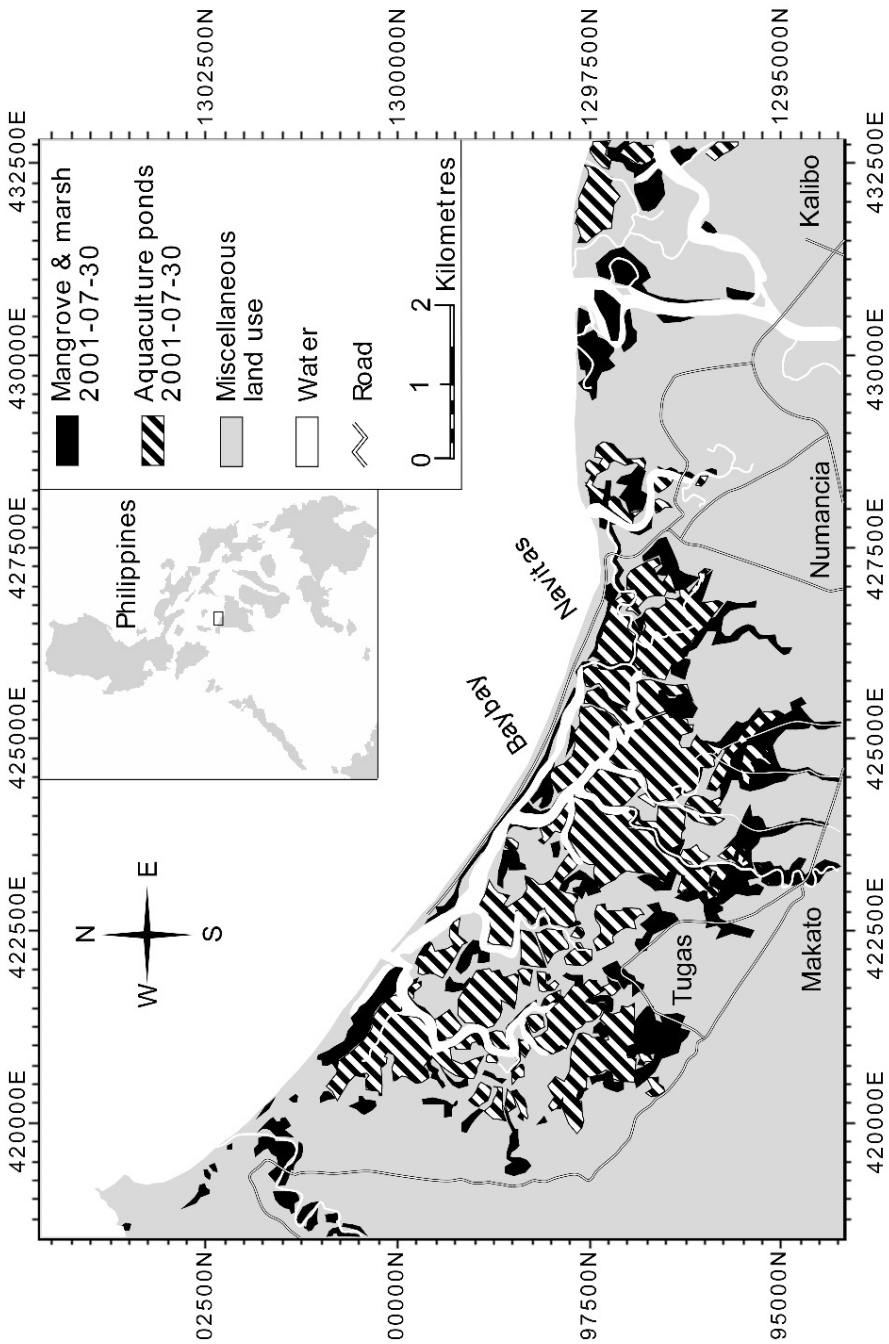


Figure 18. Aquaculture land-take versus mangrove land cover (year 2001) in the study area in the Philippines. Mangrove-aquaculture ratio: 0.5:1.

Similarly to the situation in Sri Lanka, aquaculture encroachment into mangrove areas in the Philippine study area is discouraging. Most farms in the study area in the Philippines were established in 1930s to 50s. Therefore, no satellite images or accurate maps are available from the early days of aquaculture in the area, which means that no differences could be revealed by comparing aquaculture land-take during previous decades. However, mangroves have been cut to make room for ponds in the Philippines as well (Walters 2003). As a comparison to the situation in Sri Lanka, aquaculture expansion in the Philippine study area has resulted in a ratio of 0.5 hectares of mangroves for every hectare of aquaculture ponds, based on spatial analysis of the map presented in figure 18.

As indicated by the maps and ratios, the conditions in the two study areas are quite similar, at least in terms of how much mangrove has been converted. However, this may not necessarily mean that negative impacts are similar. Most farms in the Philippine study area are extensive polycultures, which means they result in relatively more benign effects on mangrove and estuarine ecosystems, *e.g.* in terms of discharging nutrients. As estimated by Rönnbäck *et al* (2003), extensive aquaculture may even demand less mangroves than the actual pond area. This means that in the Philippines, a ratio of 0.5:1 is a relatively closer match to what would be sustainable. However, since no studies have been conducted that consider all necessary inputs, it is reasonable to assume that the mangrove to aquaculture ratio found in the Philippine study area also is far from sustainable. Yet, considering all these aspects, it is possible to conclude that the situation in the Philippines is more sustainable than in Sri Lanka, at least in a relative sense. This is also further confirmed when considering that most farms in the area were established some 60-80 years ago, and are still in operation. However, this is not the same as to say that mangroves would not need to be restored and set aside if aquaculture development in the area is to be more sustainable in the future.

In both study areas, aquaculture expansion has thus reduced mangroves to such an extent that neither situation can be considered sustainable. Therefore, the ratios are here only to be seen as a description of the current situation that further underscores the importance of setting aside extensive mangrove areas when planning for future aquaculture development.

With reference to aquaculture impact on mangroves, an interesting result from the field studies is that some farmers in the Philippines plant mangroves around their farms to protect homes and ponds from damage caused by *e.g.* storms and typhoons. Although it is questionable to what extent these efforts succeed in reducing mangrove loss, Walters (2000, 2003) has shown that replanting mangroves is a common practice in many locations throughout the Philippines. However, the reason for replanting mangrove is not only for protecting ponds, but more importantly also a strategy for establishing tenure claims over mangrove areas that are otherwise viewed as common pool resources (Walters 2003). Results from the fieldwork indicate that al-

though planting mangrove takes place in the study area, most farmers prefer to plant the mangrove palm locally referred to as nipa (*Nypa fruticans* Wumb) rather than true mangrove species. As mentioned earlier, this is much because nipa stabilises pond walls, while also providing an opportunity for additional income if the fronds are sold as *e.g.* building material for artisanal housing. Drawing on experiences from the tsunami event in December 2004, Dahdouh-Guebas *et al* (2005) claim that the nipa palm, although not a true mangrove species, also offers some storm protection. More importantly however, nipa does not offer the same ecosystem goods and services as mangroves in other respects, such as providing several aquatic species with the appropriate nursery grounds.

## A spatial perspective on benefits

So who is actually benefiting from aquaculture in the two study areas? As mentioned in chapter 3, analysing distributive aspects of incomes is crucial for understanding fairness and poverty issues in development. Hence it becomes important to consider who participates in aquaculture, and thereby who benefits from the activity, or in other words, where and with whom benefits end up.

While assessing income distribution demands explicit focus on individual incomes (Anand and Sen 2003), individual data is however often poorly available for incomes of larger populations, especially in rural areas in the South. Fortunately, in this study the relatively small scale made it possible to shift between average values, as well as individual data for illuminating distributive aspects of income. In this study, income distribution was analysed by emphasising who benefits, and connecting this to origin, present home-stead and farm location.

## Local versus external participation

The fact that aquaculture was established relatively late in Sri Lanka, whereas the Philippines has long experience of the activity, may also help explain why the level of local participation and benefit distribution differ in the two regions. In this study, an individual is considered an outsider if he or she originates from more than 10 km away from the farm location. In Sri Lanka as well as the Philippines this definition includes adjoining municipalities as well as the closest bigger regional centres (see the maps in figures 16 and 18). While this definition may seem narrow, a study conducted by Cattermoul and Devendra (2002) revealed that villagers in Ambakandawila and adjoining communities consider also residents in Chilaw as outsiders, even though it is less than 10 kilometres away. Of course other factors than geographical distance may affect local people's perceptions and definitions

of outsiders, such as *e.g.* differing social status, wealth and ambitions to integrate etc. In the case of elites, *e.g.* Hajdu (2006) argues that a rich individual is more likely to be perceived as a good member of the community (and thus less of an outsider) if he or she shares the wealth by contributing to local needs in some way. In the study area in the Philippines, there are some rich and relatively empowered fish farming families that have contributed to community needs, such as *e.g.* building school houses, roads, basketball courts, public parks etc, which most probably has had positive effects on their status in the community.

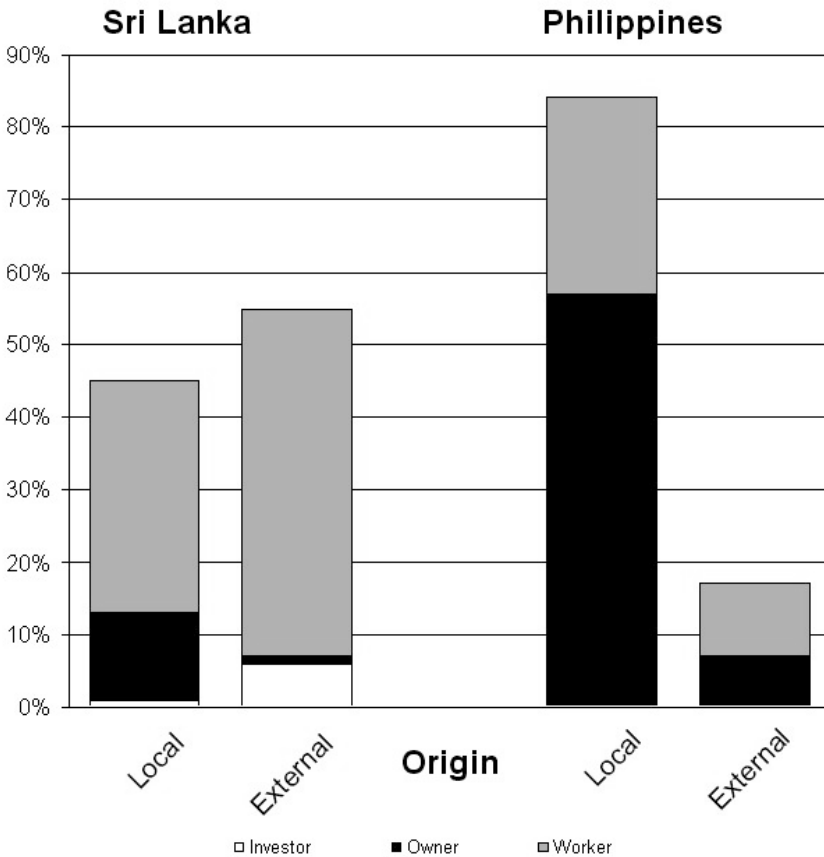
However, due to lack of comparable testimonies of local perceptions of outsiders in the Philippines study area, the 10-kilometre definition is used in both cases to avoid bias based on perceptual differences between the two countries. The definition is thus to be seen as an estimate, and by no means a definitive measure of alienation in general. It is therefore important to stress here, that if the narrower definition of outsiders as used by the villagers in Ambakandawila would have been used in this thesis, the division of local versus external involvement would have resulted in even larger differences.

Either way one defines outsider status there are significant differences in terms of local versus external participation in the two study areas. As figure 19 shows, when applying the 10 km definition, the majority (84%) of people involved in aquaculture at the studied farms in the Philippines originate from and permanently reside in the local area, compared with Sri Lanka where locals account for 45 % of the total people involved.

Investors and/or owners at the studied farms are mainly urban entrepreneurs or members of the local elite, as opposed to poor and less empowered people. Bailey (1988) points out structures and institutions on national and community levels as some of the reasons for this unfairness. These structures and institutions allow local elites to lay their hands on almost any benefit generated from productive technologies. Combined with investments by foreign capital, this means that farm profits seldom reach poor local people, and sometimes even leave the local community since the invested capital comes from outside (Primavera 1997).

In the Philippines, 68% of locals involved in aquaculture were owners compared with 27% in Sri Lanka, where the remaining locals were workers (70%) and investors (3%). This suggests that in the Philippines locals are likely to have greater influence on farm activities since they own the land. Regardless of whether farms are mainly operated by employees, or if the owners themselves take part in work on a daily basis, owners exclusively take all decisions concerning farm management. This means that in Sri Lanka, where a high proportion of people involved in aquaculture are employees, this can result in weaker negotiating power over individual working conditions and decisions concerning farm management. As a contrast, more of the people working at the farms the Philippines are either owners or are paid a percentage of the crop, which implies a stronger relationship to the

land they are working. Regardless of being a worker or owner, people on the farms in the Philippines have a stronger say in farm management. However, it is important to stress here that these differences cannot exclusively be derived from differing power relations, but is also affected by the fact that farms in the Philippines employ less people. Most farms in Sri Lanka are semi-intensive and demand relatively more labour, which affects both the owner to worker ratios, and number of work opportunities per unit area.



*Figure 19.* Origin and type of involvement of people at the studied farms in Sri Lanka and the Philippines. Based on interviews at 13 farms in Sri Lanka and 19 in the Philippines, covering a total of 103 individuals (Sri Lanka 73, Philippines 30). Individuals are here considered external when distance between farm location and place of origin  $\geq 10$  km.

Although fewer workers are recruited locally in Sri Lanka, the total number of work opportunities per farm is higher than in the Philippines. In Sri Lanka, most farms occupy two to four people on a daily basis while in the Philippines one fulltime position per farm is more common. During one

cycle on the farms in the Philippines, an average of 0.15 individuals per hectare are occupied on full time basis, whereas an additional 0.38 extra labourers per hectare are employed during labour intensive phases such as pond preparation and harvest. In Sri Lanka, the predominantly semi-intensive shrimp farms occupy an average of 1.77 people per hectare, and employ 2.83 extra labourers when needed. These results are in contrast to previous studies on other locations, where other researchers (*e.g.* Bailey 1988; Shang *et al* 1998; Rönnbäck 2001a) have argued that semi-intensive to intensive shrimp monoculture is capital rather than labour intensive, and therefore normally employ fewer people per unit area in comparison to extensive culture practices.

In both countries day labourers are hired during labour intensive phases such as stocking and harvesting. These workers are recruited primarily in the local area. Some Sri Lankan farmers who were asked to give their explanations to why most day labourers are recruited locally, while full time positions accrue mainly to outsiders explained that hiring local people is risky, since they are less loyal and more likely to poach. This may be illustrated by quoting one of the farmers in Iranawila, Sri Lanka:

It is troublesome to employ local people because there is a risk that they go home instead of staying at the farm since they have their homes and families nearby. They might also tell friends about the routines at the farm and how big the prawns are. Then, when they work the night shift and are responsible for guarding the prawns, they can pretend to be asleep and let their friends steal the prawns. If there are problems like this, and it results in conflicts and we need to fire them, it is also inconvenient to have them nearby afterwards. Therefore I recruit all workers from at least 20 kilometres away.

According to the Philippine farmers interviewed, this kind of theft is less common. Some farmers argued that in the Philippines there is a long tradition of working together in the villages. Workers are recruited from within the local community and also there are local customs, which involve sharing a part of the harvest with neighbours and passers-by. Also, most full time employees are paid an agreed percentage of the total yield rather than fixed salaries, which provides an incentive for working hard and being honest, since poaching would impact negatively upon workers as well as owners. This correlates well with the discussion earlier on the importance for rich people to integrate and contribute to the local community, which improves the relationship between different socio-economic groups, *i.e.*, local and external, rich and poor, and in this case, between farm owners and employees.

Another important finding is that the category 'investor', defined as people that never or rarely visit the farm, but only help out financially in return for a portion of the profit, was not found in the Philippines. However, there were more or less absent local owners that had handed over most of the re-



sponsibility to employed managers while they were away doing other work in town. In Sri Lanka on the other hand, 18% of the farms depended on investors. The investors were mostly rich people from bigger cities such as Negombo and Colombo, and in one case from abroad.

### Spatial distribution of expenditures and profits

During the interviews, Venn-diagrams were used to let informants describe where and on what they spent most of their incomes. The kind of Venn-diagrams used in this study has been described in detail in chapter 4. Aggregated average percentages of total expenditures and spatial distribution on all visited farms in Sri Lanka and the Philippines are illustrated in figure 20.

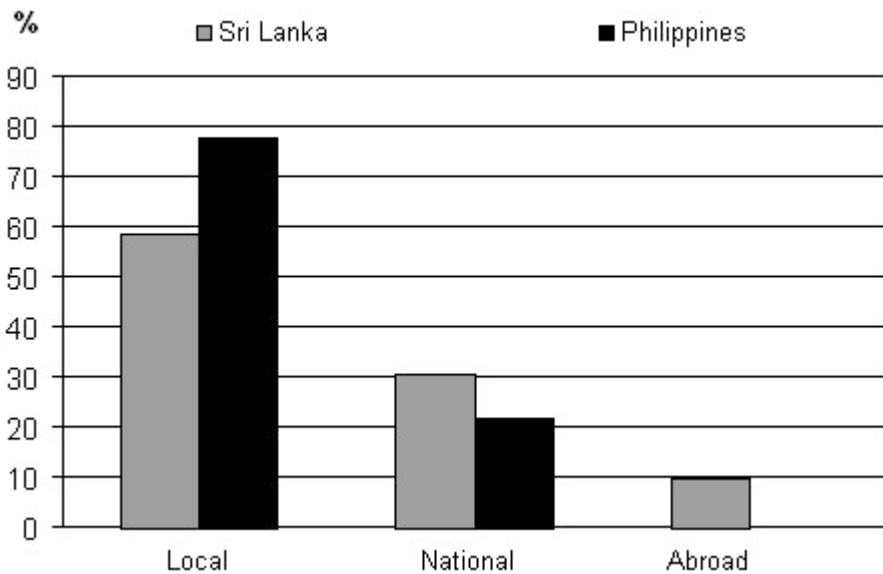


Figure 20. Distribution of farm and household expenditures among farmers in Sri Lanka and the Philippines.

Information from the Venn-diagrams covered place of expenditures, as well as on what most of the earnings were spent. There was no significant correlation between what was purchased and the specific location of such expenditures. However, there were some differences and similarities in terms of what the informants in Sri Lanka and the Philippines prioritised.

In both countries, and in those cases informants were owners, the biggest expenses derived from farm inputs such as machinery, fuels, fry and feed etc, but also labour costs and food for workers. Other common expenses were paying off debts and mortgages, saving money, investing in other businesses and purchasing land. In both countries, a significant part of the infor-

incomes was spent on education for their children. Especially the Sri Lankan farmers, when profits allowed for it, tried to send their children abroad for educational purposes, whereas farmers in the Philippines to a larger extent sent their children to national schools or universities. Also poorer workers stated that family expenses such as education, food and healthcare represented the largest share of expenditures. Especially the Sri Lankan farmers also stated that buying homes for their children was a high priority. If money remained after these expenditures, several of the informants in both countries used it for taking their families on holidays or visiting relatives.

Although origin of people involved in and benefiting from aquaculture, as well as where and on what earnings end up, surely affect sustainability from a fairness perspective, other factors are equally important to consider. For example, although more local people participate and benefit from aquaculture in the Philippines than in Sri Lanka, in both cases relatively few belong to the poorest and least empowered individuals of coastal communities. In this thesis, wealth stratification was not explicitly examined. However, educational background of informants may be used as an indication of class belonging and empowerment. For example, in Sri Lanka, 52% of farm owners and workers had finished only primary or secondary education, whereas 35% had completed high school, and 13% had attended some higher education at university level. In the Philippines, the educational background of informants was 23% primary or secondary education, another 23% that had finished high school. The majority (54%) had attended university or college education. At a glance, these numbers of course seem promising for the situation in the Philippines. Not to forget however, the farms in the Philippines do not employ many workers, but are run mainly by the owners themselves, hence the high share of higher education. In terms of ethnicity, in the study area in North Western Sri Lanka, 47% were Tamils, although the dominating ethnic group in the area is Sinhalese. This is mainly the result of farm owners preferring to recruit poor, less educated and hence cheaper workers from distant communities. Since in the Philippines study area there is no significant ethnic stratification in the local community, percentages for ethnic belonging were not investigated there.

When interpreting previous occupation (figures 12 and 15) and origin (figure 19) of people involved in aquaculture, there are some things that are important to comment on. In Sri Lanka, although relatively many people involved in aquaculture are poor, less educated Tamils, none of them own or manage the farms, and neither reside permanently in the local area, but are employed as seasonal low paid workers, and when off duty, go back to visit their families and permanent homesteads, *e.g.* in the hill country. Thus, whereas contribution is low on local levels, aquaculture may be a more important contributor to poverty alleviation elsewhere. Still, from a local perspective, aquaculture contribution to poverty alleviation will remain prob-

lematic, as long as the people owning the farms and benefiting most is dominated by middleclass entrepreneurs, be they local or external, and since most poor people involved are external. Put together, this means that local environmental resources are being exploited to the benefit of mainly external people, out of which a majority is already relatively well off, some poor, but more importantly, not members of the local community. This is important to consider when referring to aquaculture as a contributor to poverty alleviation. As mentioned in chapter 1, poverty alleviation is often an explicit goal and justification of further aquaculture expansion. However, the results presented here, as well as other studies (*c.f.* Stonich and Bailey 2000; Lewis *et al* 2003) clearly exemplify that there is not necessarily a correlation between aquaculture expansion and real improvement for poor local people.

## Emergy use, efficiency and environmental loading

Odum and Odum (2001) propose that policies for the future facilitate production systems based on the self-organising patterns found in natural ecosystems. In the context of aquaculture, this means that instead of engaging in monoculture for export, it may be more appropriate to diversify production. Furthermore, due to imbalances in world trade, it may also be more appropriate to make more use of local renewable resources, and localise production and consumption. This will be especially crucial in preparing for the descent to a lower energy society that can be expected in the future, as is proposed by the pulsing paradigm (figure 5) and discussed in chapter 3. Unfortunately however, the pattern of contemporary aquaculture development has not moved in such a direction. On the contrary, most aquaculture is not energy efficient, and result in negative environmental effects, as well as social and economic unfairness. As mentioned in chapter 2, intensive aquaculture, similarly to conventional agriculture also often results in problems striking back at crop survival and growth rates, *e.g.* diseases. To come to terms with such problems, farmers are forced to apply artificial remedies. However, such treatments require that the amount of inputs is increased, *e.g.* in terms of antibiotics or pesticides etc, and hence results in additional costs and impacts. Sometimes, these additional costs themselves make production economically un-feasible. Furthermore, and perhaps more importantly, from an emergy perspective the increment in inputs may also result in the amount of energy invested to produce a desired yield surpasses the energy harvested (Altieri 2000). However, in the context of food production, it is important to remember that the primary aim is not to yield as much energy as possible (as is it *e.g.* in bio-fuel production), but to provide humans with a source of nutrition. Therefore, other qualities are important to consider than the energy yielded. For example, when valuing efficiency in food production, other factors may motivate lower efficiencies, *e.g.* if the aim is to provide poor

people with a source of nutrition. However, if the aim of food production is more to give people a culinary experience, making production as efficient as possible becomes increasingly important, especially in times of decreasing availability of natural resources. Especially for aquaculture, this is problematic, since the aim is most often to deliver luxury products, (*i.e.*, sea food), which implies providing a different kind of service to society than giving people something to eat.

For assessing energy efficiency and exploring alternatives for the future, in the following sections farm management and procedures are illuminated from an emergy perspective, emphasising emergy use, efficiency and environmental loading. Data for the emergy evaluations was obtained from previous emergy studies where available. Raw data and statistics were retrieved from suppliers of on-line national data, as indicated by references. However, since farm specific data necessary for this study was sparse, most data was collected in the field, as accounted for in chapter 4.

Since emergy evaluation is a time-consuming and quite extensive endeavour, and it only constitutes one of several methods in this study, some delimitation was necessary. Therefore, the emergy evaluations are based on extended fieldwork on only two selected farms. All results presented here derive from these two farms and thus demand some caution when generalised. However, this work was carried out in parallel to the work on all the farms covered in the study. In addition, the two farms were specifically selected since they could be considered representative for aquaculture in the respective study areas, and hence were especially suitable for providing extended data on farm management and procedures. Despite the obvious limitations in terms of generalisation derived from this approach, results from the emergy evaluations reveal some interesting trends and indicate how farm performance, yield, profitability, emergy use, efficiency, environmental loading and dependence on local and external resources differ between the two study areas. Although limited in scope, the results presented in this section are thus used for fulfilling some of the main aims of this thesis; *i.e.*, to assess the relative sustainability of two cases of aquaculture, discuss aquaculture sustainability in general, and explore whether emergy is an appropriate concept and methodology for this purpose.

## Emergy evaluation of aquaculture in Sri Lanka

Aquaculture in Sri Lanka is highly reliant on importing resources from elsewhere in the country, as well as from abroad. Whereas fry is produced in the farm vicinity in local hatcheries, other goods and services need to be brought into the coastal zone. As shown earlier in this chapter, labour is predominantly imported in terms of unskilled and low-paid workers from inland of Sri Lanka. Investors from national urban centres and abroad sustain the industry with economic capital. Although inflow of external capital is often

perceived as something positive, energy evaluations have shown that external investments often worsen rather than improve the situation in the South (Odum and Odum 2001). Also the hatcheries that support the farms with fry, *i.e.*, shrimp post larvae, are highly reliant on external investments, as well as importing resources needed for fry production (*e.g.* adult shrimp, equipment, labour etc.). Produce from the farms is handled locally by retailers that come to the farms at the time for harvest, whereas consumers are mostly rich urban dwellers, tourists and the global market. Since the aquaculture industry in Sri Lanka mainly produce shrimp, *i.e.*, a luxury good, the produce is rarely consumed by local people.

A systems diagram relating aquaculture production in the coastal zone of Sri Lanka to systems at larger national and global scales is presented in figure 21. The diagram illustrates which resources and processes take place within the coastal zone, as well as those that come from outside. These relationships all affect sustainability at local level.

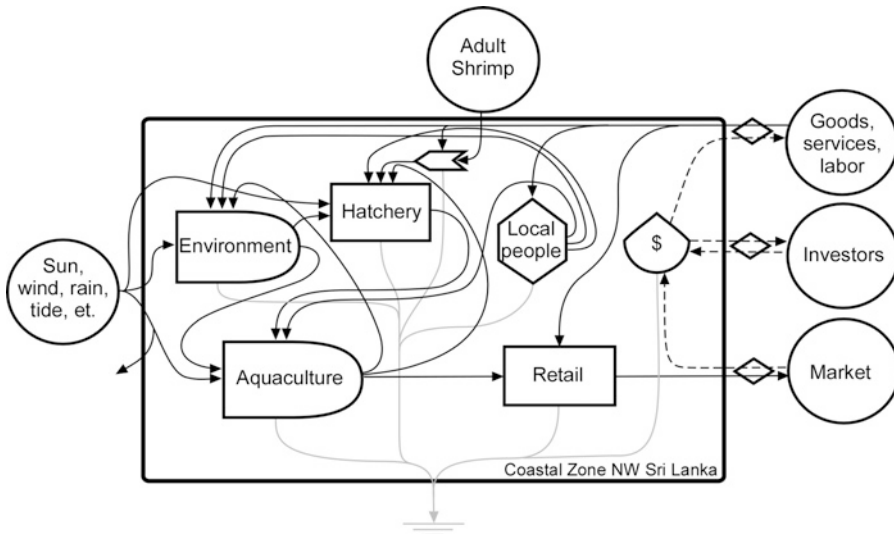


Figure 21. Aquaculture in the coastal zone of Sri Lanka and its connections and relationships to landscape and global levels.

### System characteristics and window of attention

The farm selected for the energy evaluation of aquaculture in Sri Lanka is engaged in semi-intensive monoculture of the black tiger prawn (*Penaeus monodon* Fabricius). It appropriates a total of 3 hectares of previous mangrove land. The window of attention is here set to one hectare, and hence all inputs and the yield is divided by 3, to facilitate comparison with the farm in the Philippines. The total land used (1ha) consists of an estimated 90% rearing ponds and 10% constituted by pond walls.

## System diagram

The first step of the evaluation was to list all inputs and outputs in detail. An initial system diagram was then drawn, illustrating energy transformation processes from left to right according to their position in the energy hierarchy, and feedback (autocatalytic) processes from right to left (as described in chapter 5). All processes with similar properties were thereafter aggregated and put together in the diagram (figure 22).

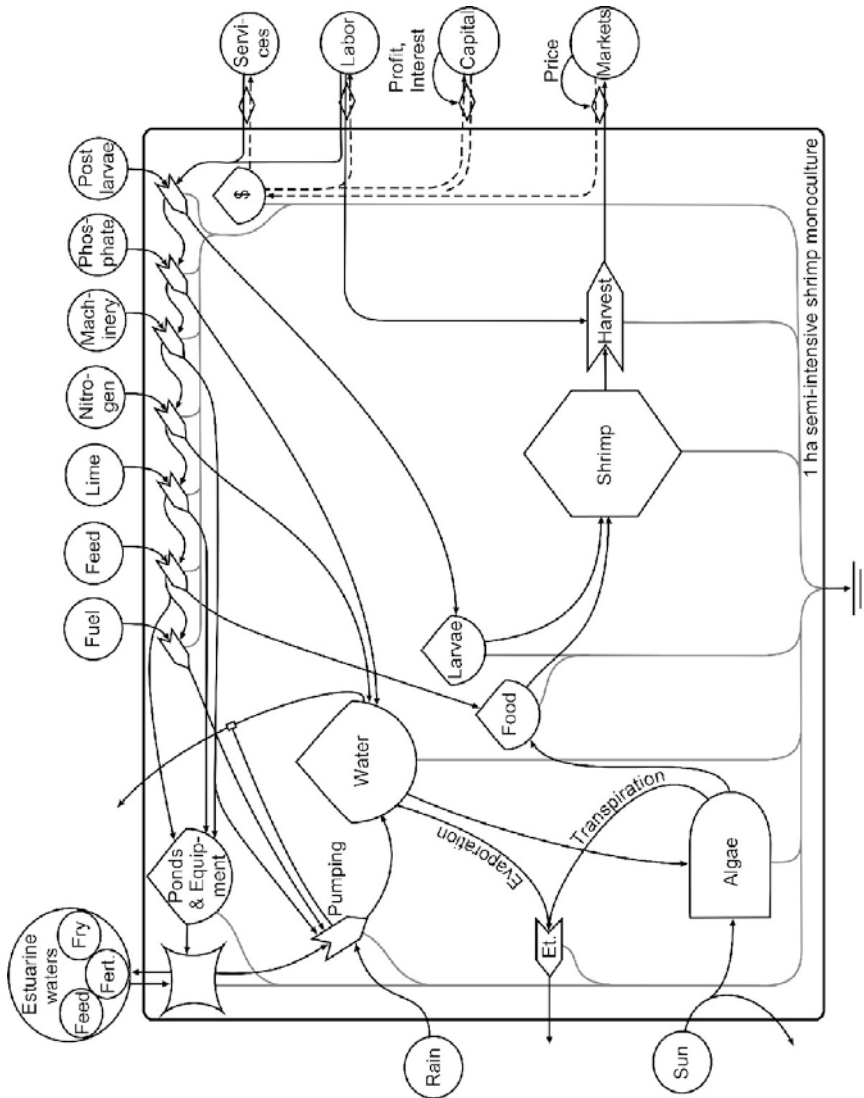


Figure 22. Emergy system diagram of semi-intensive shrimp aquaculture in Sri Lanka. Window of attention is set to 1 hectare during one year. Abbreviations: Et = evapotranspiration. Fert = fertilisers.

As illustrated in figure 22, shrimp monoculture implies low complexity, in contrast to systems with a higher degree of self-organisation. Due to precise control of pond environment, only one species is cultured, thereby reducing interaction with other species, which is otherwise a determinant for hierarchical structures. Whereas this enables high stocking densities of shrimp, it also means by-products are not generated. The low complexity also means that pond environment has to be regulated by using external inputs such as chemicals and feed etc. Aeration is handled through mechanical pumping, which is sustained by large amounts of fuel and equipment. The need for fuel is further increased due to relatively low tidal amplitudes, which means that water exchange also needs to be handled through mechanical pumping.

### Emergy evaluation table

By constructing an emergy evaluation table, the emergy accounting was carried out. The results are here briefly illustrated in table 3 for reference, whereas the full evaluation including all notes is presented in Appendix 2.

Table 3. Emergy evaluation of semi-intensive shrimp monoculture in Sri Lanka, per hectare, per year. The full evaluation including all notes is presented in appendix 2.

Note	Item	Unit	Data (units/yr)	Unit Solar Emergy (SeJ/unit)	Solar Emergy (E13 SeJ/yr)	Em\$ Value (2000 \$/yr)
<b>RENEWABLE RESOURCES</b>						
1	Sun	J	4,71E+13	1	4,71	25,48
2	Rain	J	5,38E+10	3,02E+04	163	881
3	Estuarine waters	J	1,98E+11	2,59E+04	514	2779
	<i>Sum of free inputs (direct sun omitted)</i>				676	3661
<b>PURCHASED INPUTS</b>						
4	Fuel	J	1,16E+11	1,11E+05	1284	6946
5	Feed	J	3,10E+11	2,20E+05	6826	36940
6	Labour	J	3,35E+09	4,40E+06	1477	7991
7	Lime	g	2,00E+06	1,68E+09	336	1818
8	Nitrogen	g N	1,67E+05	7,04E+09	117	635
9	Machinery	g	1,53E+04	1,13E+10	17	93
10	Phosphate	g P	3,33E+03	3,36E+10	11	61
11	Shrimp post larvae	ind	3,00E+05	1,75E+11	5242	28364
12	Services	\$	2,26E+04	1,85E+12	4171	22572
	<i>Sum of purchased inputs</i>				19482	105419
	<i>Total emergy</i>				20158	109080
<b>TRANSFORMITIES, Calculated</b>						
13	Yield, ha/yr	\$	12758	<b>1,58E+13</b>	SeJ/\$	
		J	2,49E+10	<b>8,11E+06</b>	SeJ/J	

Table 3. cont.

**INDICES, calculated**

Note	Name of Index	Expression	Quantity
14	Investment ratio	F/R	29
15	Yield Ratio	Y/F	1,03
16	Emergy exchange ratio	Y/\$ * (SeJ/\$)	6,28E+24
17	% Renewable	R/(R+N)	19
18	Empower Density	SeJ/ha/yr	2,0E+17
19	Environmental loading ratio	(F+N)/R	33,8
20	Emergy sustainability index	EYR/ELR	0,03

## Emergy evaluation of aquaculture in the Philippines

The combination of small-scale agriculture and polyculture of fish, shrimp and crabs means that aquaculture in the Philippines is less reliant on imported resources, and enables harvesting several by-products, *e.g.* trees, fruits and vegetables.

Some of the fry is produced in local hatcheries; some is collected in the wild by local people, and/or brought into the pond with tidal currents. Whereas hatcheries are dependent on importing some goods and services needed for fry production, shrimp (the most resource consuming type of fry) is not purchased from hatcheries but brought in with the tides. Milkfish hatcheries mainly depend on seedlings procured from local ecosystems. Hence, resources are provided mainly from within the local coastal zone. As accounted for earlier in this chapter, labour intensity of extensive polyculture is lower than semi-intensive monoculture as practiced in Sri Lanka. However, workers are mainly recruited at the local level and paid by a percentage of the profit rather than fixed salaries. Similarly to Sri Lanka, the produce is bought locally by retailers that come to the farms at the time for harvest. A major difference though, is that in the Philippines the produce is mainly aimed for local and national markets. In addition, local customs which involve sharing a part of the harvest with neighbours and passers-by mean that the produce to a larger extent is consumed by local people, including workers at the farm. Another important difference is that there are no external investors (*c.f.* Figure 19). Still, though more local people work on the farm and benefit from aquaculture in the Philippines than in Sri Lanka, relatively few belong to the poorest in their communities.

As in the case of aquaculture in Sri Lanka, aquaculture in the coastal zone of Panay, Philippines is related to systems at larger national and global scales in figure 23. The diagram illustrates which resources and processes take place within the coastal zone, as well as those that come from outside.





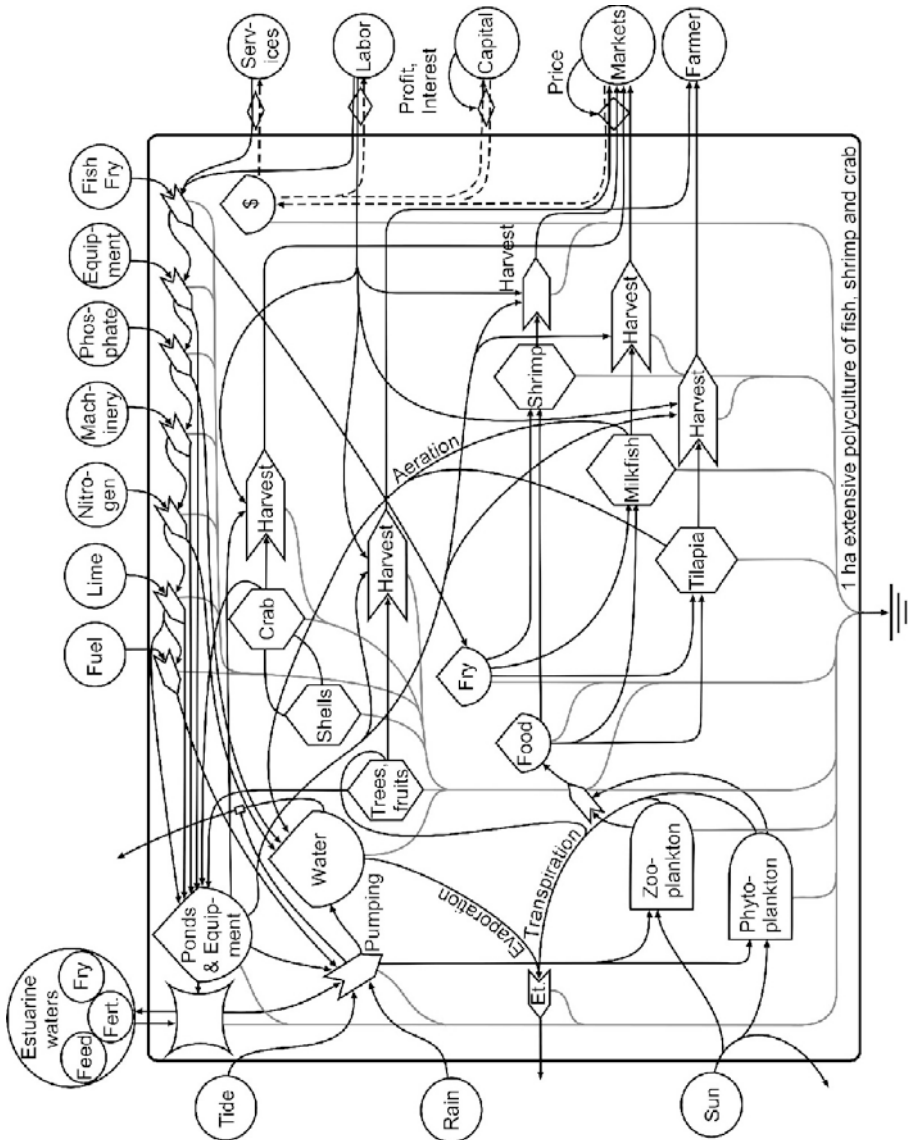


Figure 24. Energy system diagram of extensive milkfish/shrimp/mudcrab polyculture in Panay, the Philippines. Window of attention is set to one hectare during one year. Abbreviations: Et = evapotranspiration. Fert = fertilisers.

Extensive polyculture as practiced in the Philippines is characterised by relatively higher complexity than the semi-intensive monoculture studied in Sri Lanka. This is mainly due to co-production of several species, and combination with small-scale agriculture. When considering single species, stocking density is low, which results in low yields per species, although total yield is relatively high. More importantly however, it also makes the system less

dependent on imported resources, which are instead provided through feedback mechanisms by other species within the system. For example, milkfish and tilapia consume waste produced by shrimps and keep the water clear by feeding on algae, and by swimming stir the water which results in natural aeration. This results in decreased demands on fuels and equipment that would otherwise be needed for exchanging water more often. Furthermore, it reduces the need for aeration by the use of paddle wheels powered by diesel generators. Dependence on fuels is further decreased by filling and exchanging water by using tidal currents. The low stocking density (when considering single species) also means that pond environment to a higher extent is self-regulated and hence demand less resources such as labour, maintenance, chemicals and feed etc. Both the owner and employee consume part of the harvest (mainly tilapia and some fruits), whereas the rest of the produce is sold to local and national markets.

### Emergy evaluation table

The emergy evaluation table for the farm in the Philippines is illustrated in table 4. As with the table for Sri Lanka, here it is only presented briefly for references, whereas the full evaluation including all notes is presented in appendix 3.

*Table 4.* Emergy evaluation table of extensive polyculture in the Philippines, per ha, per year. The full evaluation, including all notes is presented in appendix 3.

Note	Item	Unit	Data (units/yr)	Unit Solar Emergy (SeJ/unit)	Solar Emergy (E13 SeJ/yr)	Em\$ Value (2000 \$/yr)
<b>RENEWABLE RESOURCES</b>						
1	Sun	J	4,60E+13	1	4,60	4,34
2	Evapotranspiration	J	1,67E+07	6,90E+04	0,12	0,11
3	Tide	J	6,62E+10	2,83E+04	187	177
4	Rain	J	8,05E+10	3,02E+04	243	230
5	Estuarine waters	J	2,70E+11	2,59E+04	701	661
	<i>Sum of free inputs (direct sun omitted)</i>				1131	1067
<b>PURCHASED INPUTS</b>						
6	Fuel	J	7,23E+08	1,11E+05	8	8
7	Labour	J	1,52E+09	4,40E+06	669	631
8	Lime	g	2,00E+06	1,68E+09	336	317
9	Nitrogen	g N	1,20E+04	7,04E+09	8	8
10	Machinery	g	1,00E+05	1,13E+10	113	106
11	Phosphate	g P	1,00E+05	3,36E+10	336	317
12	Misc. Equipment	\$	6,92E+00	1,06E+13	7	7
13	Milkfish fry	J	1,67E+10	2,00E+06	3349	3159
14	Services	\$	5,76E+02	1,06E+13	611	576
	<i>Sum of purchased inputs</i>				5437	5130
	<i>Total emergy</i>				6569	6197

Table 4. cont.

**TRANSFORMITIES, Calculated**

15	Yield, specified co-products ( <i>sold to market</i> )				
	Milkfish	\$	3,07E+03	<b>2,14E+13</b>	SeJ/\$
		J	1,11E+10	<b>5,94E+06</b>	SeJ/J
	Shrimp	\$	1,58E+03	<b>4,14E+13</b>	SeJ/\$
		J	6,22E+08	<b>1,06E+08</b>	SeJ/J
	Mud crab	\$	2,88E+02	<b>2,28E+14</b>	SeJ/\$
		J	1,74E+08	<b>3,78E+08</b>	SeJ/J
	Banana	\$	1,92E+01	<b>3,42E+15</b>	SeJ/\$
		J	2,03E+08	<b>3,24E+08</b>	SeJ/J
	Yield, specified co-products ( <i>consumed</i> )				
	Tilapia	J	1,97E+13	<b>3,34E+03</b>	SeJ/J
	Papaya	J	1,67E+07	<b>3,92E+09</b>	SeJ/J
	Cassava	J	3,35E+08	<b>1,96E+08</b>	SeJ/J
	<b>Yield, total</b>	\$	4389	<b>1,32E+13</b>	SeJ/\$
		J	1,97E+13	<b>3,33E+03</b>	SeJ/J

**INDICES, calculated**

Note	Name of Index	Expression	Quantity
16	Investment Ratio	F/R	5
17	Yield Ratio	Y/F	1,21
18	Emergy exchange ratio	Y/\$ * (SeJ/\$)	1,4E+26
19	% Renewable	R/(R+N)	19
20	Empower Density	SeJ/ha/yr	6,57E+16
21	Environmental loading ratio	R/(R+N)	4,8
22	Emergy sustainability index	EYR/ELR	0,25

## Interpretation and comparison

Since the extent of mangrove conversion is similar in the two study areas, differences in terms of culture practices is of more importance as a determinant for environmental impacts, and relative sustainability of the two cases.

Of the visited farms in the Philippines, 90% were engaged in extensive polyculture of fish and shrimp, often combined with intentional stocking of mud crab, with the remaining minority practicing extensive fish monoculture. Although other culture practices (*e.g.* semi-intensive milkfish monoculture) are also common in the Philippines in general, extensive polyculture is the prevailing practice in the study area, and has recently attained increased importance as a means for spreading risks. In Sri Lanka, this practice is uncommon, although some farmers are currently experimenting with alternative practices and/or are planning to do so in the future. This indicates that in Sri Lanka, a period of transition has begun, although at the time of research the dominant practice was still semi-intensive shrimp monoculture (75% of all visited farms), while 25% were experimenting with polyculture and low-density alternatives.

As discussed in chapter 2, several factors are important to consider when assessing the sustainability of aquaculture. Therefore, in this section, conditions in the two study areas are compared based on the factors presented in table 2. However, it is important to stress here, that the valuation is quite subjective in that the two cases are valued only in relation to each other. Still, to highlight differences that affect sustainability, the two cases are compared and valued as objectively as possible. The result of the comparison is presented in table 5.

From an emergy perspective, perhaps the most important differences between the two culture practices are the two parameters dependence on artificial water exchange (5) and aeration (9). In Sri Lanka, a total of 66 000 m<sup>3</sup> of estuarine water is used per hectare during one year, which is equivalent to 514 E+13 SeJ. Meanwhile, in the Philippines, the annual use of estuarine water is 90 000 m<sup>3</sup> per year, or 701 E+13 SeJ. Hence, more water is used per hectare and year in the Philippines, and yet, dependence on diesel fuels is significantly lower. This may in part be explained by the fact that the cultured finfish species contribute to natural aeration through stirring of water. The relatively higher tidal amplitudes in the Philippines also facilitate aeration and enable water exchange aided by tidal currents. In Sri Lanka, due to lower tidal amplitudes water has to be exchanged through mechanical pumping. Also, since few farms in Sri Lanka keep finfish in the ponds, artificial aeration is needed through the use of paddle wheels.

*Table 5.* Comparison of aquaculture in Sri Lanka and the Philippines, indicating relative sustainability of the two cases. The comparison is based on factors affecting environmental impacts, economic viability and fairness in aquaculture as presented earlier in table 2.

<i>Factor/parameter</i>	<i>Sri Lanka</i>	<i>Philippines</i>
1. Water intake and drainage procedures	Poor	Poor
2. Number of farms per unit area	High	High
3. Water storage capacity	Poor	Average
4. Water treatment	Poor	Average
5. Water exchange	High - mechanic	High - tides
6. Fallow	Yes	Yes
7. Silt removal	Yes	Yes
8. Pond area	Small	Large
9. Aeration	Artificial	Natural
10. Crop rotation	No	Yes
11. Feeding practices	Well managed	Well managed
12. Brood stock quality	Poor	Average
13. Mangrove conversion	Yes	Yes
14. Soil type	Acid sulphate	Acid sulphate
15. Tidal amplitude	Low	High
16. Salinity	Suitable	Suitable

Table 5. cont.

17. Temperature	Suitable	Suitable
18. Credit cost and availability	Poor	Poor
19. Market conditions	Poor	Good
20. Land tenure	Private	Private
21. Legislation	Poor	Poor
22. Mitigation	None	None
23. Externalities	High	Low
24. Farmers' management abilities	Consultation	Local knowledge
25. Empowerment	Average	Poor
26. Local and poor people participation	Low	High
27. Resource competition	High	High
28. Poverty	Poor	Poor
29. Cultural preferences	Poor	Beneficial

Together, these factors substantially increase production costs and dependence on external energy sources such as electricity and diesel, although the total amount of water being pumped is actually more in the Philippines. Another way of interpreting this is to say that aquaculture as practiced in the Philippines is a system that is better at making use of local renewable resources (*i.e.*, tides), instead of performing the same work, and even less, by adding external, non-renewable resources (*i.e.*, diesel fuels).

The evaluation also reveals several other differences that have important implications for sustainability. As discussed in chapter 5, environmental accounting by using emergy departs from the notion that all types of production require energy transformation, that is, different kinds of energy are converted into others. By tracing back all resources that are needed to how much solar energy was needed to produce them in the first place, inputs can be expressed in solar emergy. The total amount of solar emergy needed for a certain kind of production thus provides an indication of energy consumption in relation to that yielded. In the case of aquaculture, several types of energy such as *e.g.* estuarine water, fuels, feed, labour etc. are transformed into the harvested produce. When all these inputs are traced back to the solar energy it took to make them, that is, converted into solar emergy equivalents, a comparison of the two cases reveals that one year of aquaculture production in Sri Lanka is sustained by little over 3 times more emergy than in the Philippines. In other words, while the farm in Sri Lanka uses 20.158 E+13 SeJ, in the Philippines the equally big farm uses 6569 E+13 SeJ for the same amount of time. Of course, this also means that different products and quantities may be harvested. In Sri Lanka, using more emergy and concentrating on one single species makes it possible to harvest 6 tonnes or shrimp every year. Meanwhile, in the Philippines only 150 kg of shrimp is harvested per year. However, several other co-products can also be harvested, namely 2 tonnes of milkfish, 50 kg of mud crab, 50 kg of tilapia and an additional 110 kg of fruits and vegetables. Important to keep in mind here is that also other

by-products are being harvested (*e.g.* chicken, nipa etc.) although these were excluded in this study due to lacking data. Furthermore, diversifying production also means spreading risks for crop failures and fluctuating market prices.

When comparing the amount harvested in terms of weight, the farm in the Philippines yields 2360 kg per year, which is roughly a third of the total weight harvested in Sri Lanka. However, this is enabled by using a third of the total energy input as in Sri Lanka, and also makes use of a larger share of local renewable resources, which reduces negative impacts on local and global levels.

### Emergy indices

Based on emergy flows within and between systems, indices can be calculated that evaluate the behaviour of the system under study, address sustainability issues, and hence serve as tools for predicting best alternatives (Ulgiati *et al* 1995). Indices based on emergy provide insights into thermodynamic efficiency as well as the quality and environmental load of the end product, and may thus be used to reveal how production processes interact with and affect their surrounding environment (Ulgiati and Brown 1998b). By calculating a selection of emergy indices, differences between the farms in Sri Lanka and the Philippines in terms of performance, yield, profitability and dependence on local/external and renewable/non-renewable resources could hence be quantified. The indices used in this study were chosen based on the research questions and data available in tables 3 and 4. A summary of the indices is presented in table 6. Each index is then interpreted and explained separately for providing a basis to compare sustainability.

*Table 6.* Comparison of results from emergy evaluations of aquaculture in Sri Lanka and the Philippines.

<b>Transformities and indices</b>	<b>Sri Lanka</b>	<b>The Philippines</b>
Transformities (SeJ/J)		
Shrimp only	8,11E+06	1,06E+08
Including by-products (total)	N/A	3,33E+03
Emergy Investment Ratio	29	5
Emergy Yield Ratio	1,03	1,21
Empower density	2,0E+17	6,57E+16
Environmental Loading Ratio	33,8	4,8
Emergy Sustainability Index (1= sustainable)	0,03	0,23

Aquaculture as practiced in Sri Lanka appropriates more emergy than in the Philippines, which indicates higher energy (fuels and environmental resources etc.) consumption. However, this says nothing about efficiency, *i.e.*, how well the emergy is used and returned in relation to systems at larger scales. For this purpose, transformity is a better measure.

As briefly mentioned in chapter 5, transformity indicates the position of one type of energy in the universal energy hierarchy, in relation to other types of energy (Brown *et al* 2004). It is determined by calculating how much energy is required in an energy transformation process in relation to the energy yielded (Brown *et al* 2001). The transformity of any given product depends on the process lying behind its creation (Ulgiati and Brown 1998a), and thus varies between different production strategies, although the end product might ultimately be the same. As such, transformity is a measure of how much energy is used to produce a certain good or service, and when put in comparison to other similar goods or services helps to determine energy efficiency (Brown and Ulgiati 2004b). Still, transformity needs to be used with caution. For example, when considering shrimp only, the transformity is  $8,11E+06$  SeJ/J in Sri Lanka, and  $1,06 E+08$  SeJ/J in the Philippines (see tables 3 and 4), which gives the impression that production is more efficient in semi-intensive monoculture. That is, less emergy is used per unit shrimp harvested. However, in the Philippines, the total amount of emergy is not used only for producing shrimp, since fish, crabs, trees and fruits are also generated from the same emergy input. Furthermore, the emergy used in the Philippines to a larger extent come from renewable resources, which indicates it puts less pressure on the global resource base. Thus, comparing the transformity of shrimp only is misleading, since it is not sensitive to differences in systems complexity, which in the Philippines results in additional by-products. Accounting for both shrimp and by-products significantly reduces the transformity of the total end product (*i.e.*, fish, shrimp, crabs, trees and fruits). A comparison of transformities for the total produce thus reveals that in reality the transformity in Sri Lanka is higher than in the Philippines. This indicates that for every joule of total produce more emergy is needed in semi-intensive aquaculture, and hence, it is a less efficient system.

The Emergy Investment Ratio (EIR) expresses the share of emergy that is fed back from outside of the system (invested) in contrast to that provided by local resources (Brown and Ulgiati 1997). In Sri Lanka, the investment ratio is almost 5 times higher than in the Philippines, which means it is 5 times more dependent on imported resources than local. Depending on what kinds of resources are imported, this has different implications for sustainability. For interpreting EIR it is therefore necessary to consider other indices as well.

The Emergy Yield Ratio (EYR) is calculated by dividing the emergy yielded by the emergy imported, *i.e.*, fed back from outside (Brown and Ulgiati 1997). EYR is thus a measure of the systems ability to use local resources (Ulgiati and Brown 1998b). In the Philippines, the EYR is slightly higher than in Sri Lanka, which means that it is a system better adapted to making use of local resources.

Empower density is the sum of emergy concentrated into one hectare during one year. In that sense, it illustrates how much emergy that converges at



the farm location. The higher empower density, the higher is the expected impact for environment and society, regardless of the impacts being positive or negative. The relatively higher empower density in Sri Lanka thus indicates that impacts are higher than in the Philippines, but other ratios need to be considered to determine how these impacts affect society and environment in detail. However, as discussed earlier in this thesis, aquaculture most often implies negative effects, and hence the higher empower density in Sri Lanka indicates that the effects will turn out more severe there. Still, since higher empower density may result in higher yields also, from the farmers' perspective it may be a good thing, since they are mainly concerned with securing their livelihoods rather than considering effects on larger scales. However, Odum (1977) early pointed out that although some things may seem good from a small-scale perspective, they may in fact be illogical and even negative when considered on larger scales of the geobiosphere. This difference resulting from whether impacts are valued at local or global levels, acknowledges Chambers' (1997) view that no perspective is less important than another. It also implies that the valuation process is complex and that multi-faceted approaches are needed in environmental management.

The Environmental Loading Ratio (ELR) is a better indicator of the pressure put on local ecosystems (Brown and Ulgiati 1997). The fact that the ELR is about 7 times higher in Sri Lanka than in the Philippines implies that the pressure is 7 times higher on the environment. Still, in both cases the environmental load is significant, since both ELR's far exceed 0, which would be the ratio if they where to depend solely on local renewable resources (Ulgiati and Brown 1998b).

The Emery Sustainability Index (ESI) is calculated by dividing EYR with ELR (Ulgiati and Brown 1998b). As such, it is sensitive to the share of locally renewable, locally non-renewable and imported resources (*i.e.*, emergy) and thus relates the emergy yielded to the load put on natural ecosystems. That is, a high ESI indicates high yield per unit environmental stress (Ulgiati and Brown (1998b). In this sense, it is a ratio that globally indicates if a process contributes something useful, and whether or not this is achieved with a low environmental pressure (Ulgiati and Brown 1998b). For the sake of simplicity, emergy values and shares of local and imported renewable and non-renewable resources used in the respective study areas are compared in table 7.

*Table 7.* Shares of local versus imported renewable and non-renewable emergy inputs in the respective study areas.

	<b>Sri Lanka</b>	<b>Philippines</b>
Locally renewable (E+13 SeJ)	676	1130
Locally non-renewable (E+13 SeJ)	3390	497
Imported from outside (E+13 SeJ)	19 500	5437
Total emergy used (E+13 SeJ)	20 158	6569

The values in table 7 are all rounded up and squared to 13 to facilitate comparison. For exact values and calculations, please refer to appendices 2 and 3. Based on these numbers, the ESI's for the studied culture practice in Sri Lanka is 0.03, and 0.23 in the Philippines (as presented in table 6). ESI's  $\leq 1$  indicate consumer products or processes, whereas ESI's equal to, or larger than 1 implies a product or process that provides a net contribution to society, considering economic as well as ecological aspects (Ulgiati and Brown 1998b).

Aquaculture as applied in the Philippines has comparably higher ESI than in Sri Lanka, which implies it is a relatively more sustainable alternative. However, neither one comes even close to being a net provider to society, if considering the cost in environmental terms. Still, the higher ESI in the Philippines indicates that it is a system with relatively better fit to present environmental conditions, *i.e.*, in terms of economic and ecological compatibility. Put in comparison to aquaculture as practised in Sri Lanka, it is hence an alternative that delivers more utility to society while using less emergy and putting less pressure on the environment, both locally and globally. Since making production processes more sustainable means reducing the pressure on ecosystems, much emergy should thus be yielded while the load is low. By increasing complexity, and fostering self-organisation and feedback mechanisms, emergy is used more efficiently. This is the reason why agro-ecosystems based on eco-technology have higher ESI than technology based alternatives (Brown and Ulgiati 1997), and hence, so does the culture practice studied in the Philippines. As argued by Ulgiati and Brown (1998b), a process, such as in this case aquaculture, can thus be modified to yield more societal use per unit environmental stress, for example through introducing new eco-technologies. One way to achieve this may be to learn from past experiences and local knowledge in the Philippines. However, if this is to be achieved, systems need to be developed that increase the ability to use local renewable resources, and decrease environmental pressure and dependence on non-renewable external inputs (Ulgiati and Brown 1998b). A trend towards higher ESI's would thus indicate a step closer towards more environmentally sound patterns of production. Unfortunately however, as pointed out by Ulgiati and Brown (1998b:33), "a decreasing trend is more likely to be observed in present economies".

In table 8, results from the emergy evaluations are qualitatively interpreted and translated into ordinary language. However, as with table 5, it is important to stress that this valuation is subjective, and thus demands caution if used for generalisation. Still, the valuation indicates differences in terms of the relative sustainability of the two cases studied in this thesis.

Table 8. Comparison of selected results from the emergy evaluations of aquaculture in Sri Lanka and the Philippines, translated into ordinary language

	Sri Lanka	The Philippines
Transformity (SeJ/J)	High	High
Emergy Investment Ratio	High	High
Emergy Yield Ratio	Similar	Similar
Empower density	Relatively high	Relatively low
Environmental Loading Ratio	Very high	Low
Emergy Sustainability Index	Low	Higher, but too low

### Emergy signatures

Emergy signature is another and perhaps more pedagogical way of illustrating the dependence of a system on resources of different kinds. For determining what impacts this has for sustainability, each resource needs to be considered separately. The emergy signatures of the two cases of aquaculture are presented in figure 25. Inputs are organised from left to right according to their position in the energy hierarchy. A high bar to the right of the chart indicates high dependency on high transformity inputs.

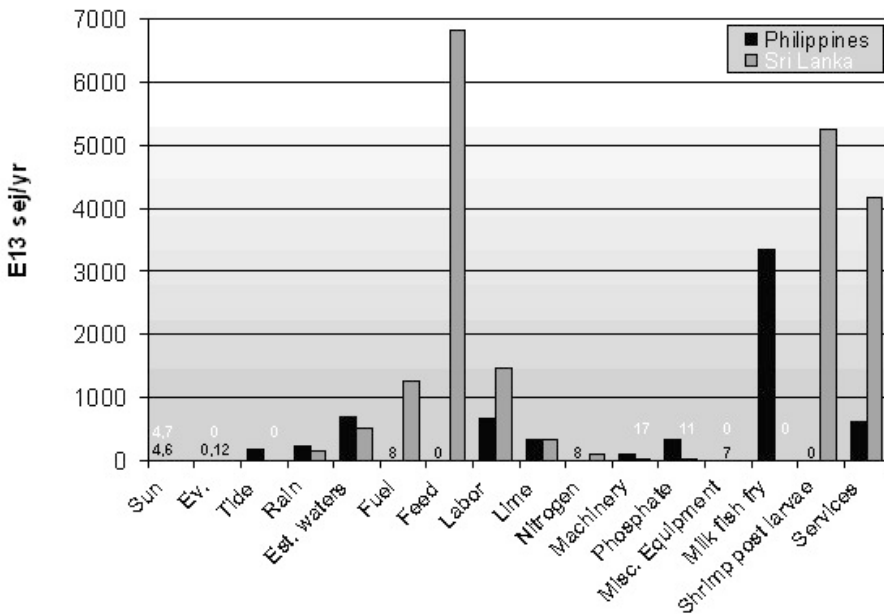


Figure 25. Emergy signatures of semi-intensive shrimp aquaculture in Sri Lanka and extensive polyculture of shrimp, milkfish and mudcrab in the Philippines, per hectare, per annum. Signatures illustrate differences in input dependence, organised from left to right in order of increasing transformity.

Solar insolation (Sun), rainfall (Rain) and estuarine water use (Est. waters) is similar in the two study areas, which result only in slight differences between the bars. Evapotranspiration (Ev.) only contributes to production in the Philippines since it is only there that production is combined with agriculture, where plants depend on evapotranspiration. Also tidal force (Tide) is only used in the Philippines, (for water exchange). This is especially important in terms of decreasing fuel consumption (Fuel), which is higher in Sri Lanka since water exchange and aeration is handled by mechanical pumping. In Sri Lanka, another significant input are artificial feed pellets (Feed), which is not added in the Philippines at all. This has negative effects on sustainability since it is produced from pelagic fish species such as herring, sardines and in some cases even shrimp. These in turn are high quality species and may therefore be better used directly as food for humans. Thus, as pointed out by Odum and Arding (1991), using such food products as feed for producing lesser quantity of luxury food may not make sense at all. In addition, supplying hatcheries with mature female shrimp for producing post larvae may be highly resource consuming due to overexploitation of wild broodstock and high rates of discarded by-catches in off shore fisheries supplying mature female shrimp (Rönnbäck *et al* 2003).

In the Philippines, feed is produced by adding manure (Phosphate), which triggers algal bloom. Therefore, the contribution from phosphates is higher than in Sri Lanka. Another important difference is how much manual labour (Labor) is needed. In Sri Lanka, about the double amount of labour contributes to production. In emergy terms this indicates higher efficiency in the Philippines. Yet, if aquaculture is justified as a means for poverty alleviation, higher labour inputs implies more job opportunities. Thus, decreasing the need for labour may not necessarily be a good thing. However, here it is also crucial to consider who access the job opportunities (*e.g.* poor/rich, locals/outside etc.), as accounted for earlier.

Another important difference between the two cases is that in Sri Lanka relatively more of the fry (Milkfish fry, Shrimp post larvae) come from hatcheries. Since inputs are higher, and due to the high transformity of shrimp post larvae (which is only used in Sri Lanka), it means this input has important implications for sustainability. An emergy evaluation carried out by Odum and Arding (1991) showed that fish fry is less resource demanding than shrimp fry.

As mentioned in chapter 5, emergy synthesis is more holistic than *e.g.* cost benefit analysis (CBA). The complexity of the results presented here reinforces this argument. In emergy synthesis, economic viability is but one of many aspects accounted for. That is, whereas most CBA's emphasise one aspect only (*i.e.*, money), emergy synthesis covers a range of aspects related to sustainability and energy efficiency, in addition to economic viability. In appendices 2 and 3, this is indicated by the diversity of calculations in the notes. As a comparison, one note is enough to convey the results aimed for

in most CBA's. Still, when considering economic viability only, also the CBA's embedded in the emergy evaluations reveal some important differences between the two cases.

Semi-intensive practices indeed generate more profit per unit area when considering economics only. Whereas extensive polyculture in the Philippines generated 4389 US\$/ha/year, semi-intensive shrimp monoculture in Sri Lanka generated a total of 12.758 US\$/ha/year, after all expenses were subtracted. However, due to lacking data and since some produce is consumed on-farm, this study did not cover all yielded by-products in the Philippines (*i.e.*, tilapia, crabs, trees and fruits). Hence, if all by-products were to be covered in the synthesis, and were sold at the market, economic viability would differ less between the two practices. Considering these results, extensive aquaculture may not necessarily be a much less economically viable alternative. In addition, most semi-intensive farms tend to lose parts of, and sometimes the total yield during some cycles due to disease outbreaks. In a long term perspective, this implies that the difference between the two culture practices is even more negligible, at least in terms of economic viability. Furthermore, if externalities from aquaculture would be included in CBA's, polyculture would most probably be even more economically viable by comparison. By performing a more realistic CBA of a proposed shrimp culture development, *e.g.* Gunawardena and Rowan (2005) showed that the overall economic cost for society would be 6-11 times higher than the economic benefits generated by the project alone.

As has also been shown in this thesis, benefits from aquaculture often accrue to a limited number of individuals, while many others are exposed to the risk of losing their livelihoods. Another study in Rekawa, a coastal community in Southern Sri Lanka, showed that 1512 people in the area depended on the mangrove ecosystem being intact (Gunawardena and Rowan 2005). The long-term livelihood of all these people would be threatened if a proposed shrimp farm would be approved, only to provide about 50 full-time positions for a limited 10-year period. However, the Environmental Impact Statement that accompanied the application for the project only showed the internal costs and benefits associated with the project. Meanwhile, potential profits, and more importantly losses, that were to be made by the local community as well as society as a whole were completely left out. Such evaluation approaches may thus be totally miss-leading to decision-makers. Hence, it is crucial to include also valuation of externalities as a complement to economic evaluations, thereby facilitating well-informed and intelligent decision-making. This becomes even more evident when considering that sustainability can only be achieved if development is considered on both global and local levels, and by including a fairness perspective. Thus, as argued by Kates *et al* (2001) research development strategies should concentrate on both ecological and societal processes at differing spatial and temporal scales, ranging from local to global levels and changes over time.

## 8. Towards a transdisciplinary understanding of accumulation

In this chapter, coastal aquaculture is related to the world system, within the framework of energy and systems theories, albeit in the light of theories of dependency and neo-colonialism.

The preceding chapters have exemplified how neo-colonial forces interact with people and nature at local and global levels. Local farmers respond to market principles imposed on them from far away, or in other words by the global North. As discussed in chapter 3, due to unfavourable market mechanisms, aquaculturists and the environment at the local level are potential net-losers in terms of the quantity and quality of exported products and what is returned to them in payments. Many people involved in coastal aquaculture in Sri Lanka and the Philippines belong to what may be referred to as the global South, whereas buyers of aquaculture products, *i.e.*, local and urban elites or foreign consumers in the North represent the global North.

As discussed in chapter 3, the global North imposes unfair terms of trade on peripheries, thereby reinforcing exploitative North-South relations. As stated in dependency theory, peripheries are in this way dependent on the cores. However, especially in the context of this thesis, it may be argued that this dependence is rather reversed. That is, whereas the periphery is dependent on the cores in terms of trade conditions and opportunities, the North is more importantly dependent on the South for supplying environmental resources and cheap labour, through which wealth accumulation in the core is facilitated. This world order sets the conditions for interactions and resource flows from and between different parts of the world, generating socio-economic as well as environmental effects of various kinds and proportions. From a geographical point of view, this interplay between humankind and nature, and scales, may be conceptualised as flows of energy, resources and control back and forth in time and space. This chapter exemplifies this argument, based on the results presented in this thesis.

Although to varying degrees, in both the studied cases in Sri Lanka and the Philippines, environmental and human resources from within the coastal zones, merged with external inputs from other peripheries (*e.g.* oil from the Middle East, fish meal from the Pacific etc.), are transformed with the purpose of bringing aquaculture products to the market. Resources and energy generated at local levels and associated ecosystems, in combination with

imported resources, are thereby transformed into the end product (seafood), and ultimately flow out of the local areas to be consumed mainly by the global North. In exchange, farmers receive payment, but more importantly, become integrated and dependent on global capitalism. Due to flaws in how resources are valued, the contribution by local people and the environment is underestimated, which results in under-compensation, and ultimately, in depreciation of natural as well as human resources in the local coastal communities and associated ecosystems. As world system theorists would express it: entropy is in this way absorbed in the periphery, for order to be accumulated in the core.

In addition to under-compensating local farmers and displacing entropy, the global North also reinforces exploitation by acting as a control (feedback) mechanism, *e.g.* through imposing unfavourable terms of trade, (economic domination), as well as other neo-colonial ways to exercise control such as political and cultural imperialism (as discussed in chapter 3). Also locally dominant classes have an important role in reinforcing this exploitative North-South relation. As implied by the results in chapter 7, local elites sometimes contribute to the exploitation, transfer, and ultimately, depletion of local coastal resources. However, this is not the same as to say that local elites in the South themselves are not subject to exploitation. As argued by Bunker (1985), entire regions may in this way be exploited due to unfair exchange on the global market, since, in addition to suffering from aggravated environmental conditions locally, improvement of social and economic institutions and infrastructure is obstructed in the whole exploited region. This eventually worsens conditions for the local society as a whole, including poor people and elites.

In chapter 3, it was argued that transfers of resources may be revealed by looking closer into origins of inputs and destinations of end products. Thence, it becomes possible to visualise that coastal zones (*i.e.*, people and ecosystems) in the South supply the global North with aquaculture products, and in the process are left absorbing most of the environmental and socio-economic costs. In this view, coastal colonisation becomes more apparent, and entropy displacement less metaphoric.

Aquaculture also exemplifies how social entropy is absorbed. As has been shown in this thesis, aquaculture seldom improves real living conditions for poor local people, and in some cases it has resulted in social conflicts and increasing poverty, which may be seen as one example of social disorder, *i.e.*, social entropy. Furthermore, aquaculture also competes for natural resources that could otherwise be used for local consumption and livelihoods. In this way, resources at local levels are extracted and accumulated in urban areas within the country, as well as in the industrialised countries, *i.e.*, in the global North, resulting in depreciation of local environmental and social conditions.

This way of reasoning exemplifies how the position and role of aquaculture in the world system may be conceptualised. By this view, aquaculture and energy flows in the world system are run by dominant consumers (*i.e.*, the global North). The problem then, is that the global North does not necessarily keep in mind what is good for the geobiosphere as a whole, or for poor local people in the South.

Another problem derived from this world order is that the pulsing paradigm suggests that after some time of frenzied consumption and accumulation, resources are prone to depletion. This may ultimately force transition into a low energy society during which resources are replenished. As pointed out in chapter 3, this pattern of iterating between excessive consumption and re-growth of resource storages has been noted in all natural systems. If this pattern also applies to the world system is of course still but a hypothesis. However, if proven right, it implies additional constraints for aquaculture that are hard to foresee. More important however, it also implies that since processes at local levels are largely determined and dependent on changing global processes. Local farmers will therefore have to develop strategies (culture practices) that fit these changing conditions, and respond to fluctuating demands and resource availability at regional and global scales, *i.e.*, in the larger whole. As pointed out earlier, for sustainability to be reached, local processes that benefit society AND nature at local and larger scales are those that should be prioritised. This way of organising society in terms of what works for the larger whole is generally accepted in general systems theory. However, it is also problematic, since what is considered to work in today's world system is not often based on ecological but rather on economic principles.

As argued earlier, a consequence of inappropriate economic principles, *e.g.* resource valuation and pricing, is that the contribution by environmental and human services to production is underestimated. As a result, the energy value of aquaculture products, as most products available on the world market, is not equal to that of the money paid in exchange for them (*c.f.* Rydberg forthcoming). The reason for this is that nations are backed up by different amounts of energy, and circulate different amounts of money. These differences are possible to quantify by calculating energy to dollar ratios, and when put in comparison, reveal relative buying power of nations. Such comparisons thus offer a new opportunity to evaluate and address fairness in trade of *e.g.* aquaculture products. For this purpose, however, the process of determining emdollar values first need some more clarification.

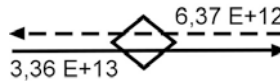
The emdollar value of nations is calculated by dividing the energy support to a nation with the money circulated during *e.g.* one year, hence resulting in an energy to money ratio, which determines the average buying power of that nation. It is usually expressed in solar emjoules per dollar and abbreviated as SeJ/\$. When analysing trade between two nations, knowing the emdollar values makes it possible to establish who is the net winner or



loser. In other words, it becomes possible to quantify who benefits from trade. South nations generally have higher emdollar values than North nations, since in the South relatively little money is circulated in relation to relatively high support from domestic environmental resources. Meanwhile, richer economies base most of their large economies on imported resources, which gives lower emdollar ratios. When countries with high emdollar values (typically South nations) engage in trade with countries with low emdollar values (typically North nations), the result is a net transfer of emergy to the North. As long as value is only measured in monetary terms this unfairness cannot be noticed, and can hence even less be understood or corrected.

To further clarify this reasoning, it is possible to use a hypothetical example of a world market transaction, drawing on the results of this study. Suppose that one kilo of shrimp as produced in Sri Lanka is sold to a Swedish consumer. The total emergy use per hectare and year for semi-intensive shrimp aquaculture in Sri Lanka is 20 158 E13 SeJ (see table 3). Divided by the total yield (6000kg), the emergy value of 1kg shrimp is then 3.36 E+13 SeJ<sup>18</sup>. In 2007, the gate price for 1 kg of shrimp in Sri Lanka was US\$ 5.90 (Fernando 2007). Based on the emdollar ratio for Sweden of 1.08E+12 SeJ/\$ (Hagström and Nilsson 2005), US\$ 5.9 is equivalent to 6.37 E12 SeJ, which hence is the emergy in the money paid in exchange for one kg of shrimp. To calculate the net benefit in terms of emergy appropriated by the Swedish buyer, the following equation may be used:

Net benefit = emergy in product – emergy in money:



Which gives:

$$3.36 \text{ E}+13 \text{ SeJ} - 6.37 \text{ E}12 \text{ SeJ} = 2.72\text{E}+13$$

By subtracting the emergy in the money spent from the emergy in the product, the net benefit in terms of emergy appropriated by the Swedish buyer of Sri Lankan shrimp is thus 2,72E+13 SeJ. This reveals that in the transaction significantly less emergy is paid (fed back) than is appropriated by the buyer.

<sup>18</sup> These calculations are based on a hypothetical transaction between a Sri Lankan producer and Swedish consumer. It is assumed that Sri Lankan shrimp reaches the Swedish market without drawing further resources due to retail, processing, transportation and distribution etc. This is also why the local gate price is used, as opposed to the real market price in Sweden, which would in reality be much higher due to involvement of middlemen and processes not covered in this study. However, the relation in terms of flow imbalances would be similar. Still, it is imperative that these numbers are not used for generalisation, since more thorough emergy evaluations would be necessary for this purpose.

Now, for this transaction to be fairer, by which is meant that the total support by environmental and human subsystems is compensated for, it is possible to calculate how much higher the fair price would be than the market price, by using the equations below. First, the exchange ratio, *i.e.*, how much more energy is in the product than the money, is calculated as follows:

$$\text{Exchange ratio} = \text{energy in product} / \text{energy in money},$$

Which gives:

$$3.36 \text{ E+13 SeJ} / 6.37 \text{ E12 SeJ} = 5.27$$

The exchange ratio above means that in a transaction where the total emergy value is not accounted for, 5.27 times more emergy per unit exchanged product leaves the coastal zone than is returned in trade. For establishing the fair price, by which here is meant a price that acknowledges and compensates for the support by human and environmental subsystems, the gate price is multiplied with the fair price exchange ratio as below:

$$\text{Fair price} = \text{price} \times \text{exchange ratio},$$

Which gives:

$$5.9 \times 5.27 \approx 31$$

According to the calculations above, if all services from nature and humans that went into the product are accounted for, *i.e.*, for the transaction to be fair, the price for one kilo of shrimp as produced in Sri Lanka should thus be US\$31. This implies that when using emergy as a basis for establishing value, the price, at least in this case, would be more than 5 times that based solely on market principles. The example also shows that a Swedish consumer (as a representative of the global North) in this hypothetical transaction drains the South of more than 5 times more emergy than is paid in exchange.

It is important to remember however, that this is just a hypothetical example. In reality, transport, marketing and other process are also needed for bringing the shrimp from farm gate to the market place in Sweden. Therefore, the emergy value of one kilo of shrimp, when ultimately reaching consumers, would be significantly higher than in the above example. To a certain extent, these additional costs are reflected by the higher market price in Sweden, as compared to the gate price in Sri Lanka. Although the gate price is used here, it may be expected that flow-imbalances between the producer and end-consumer would be similar, at least in a relative sense, since payments for these additional costs do not accrue to the local farmers. In other

words, when the shrimp leaves the farm, it enters another sub-system, where other agents exchange benefits and costs associated with transport, marketing and sales etc. The fact that these processes are not covered in this study is also the reason why the gate price is used in the calculations, hence hypothetically supposing that a Swedish consumer is able to purchase Sri Lankan shrimp without involving middlemen. Although this far the example is enough for addressing fairness in trade in a general sense, for generating more exact and generalisable results, all resources and processes also in these sub-systems would thus need to be included in the analysis. This, however, would demand more extensive analysis than a limited study such as this one.

Still, on an aggregate level too, emergy offers an alternative approach for exploring the characteristics of trade between the North and South. Furthermore, if all necessary resources are included it would also reveal that the emergy support to commodities brought from the South to the North is higher than if the produce is consumed locally. In a broader perspective, this implies that using emergy for establishing value shows that goods and services that are consumed near the production site reduces appropriation of emergy, and hence also should be cheaper than imported products. The price for a particular product or service on the world market would hence differ significantly depending on how and where it is produced, and where and by whom it is consumed. The reason for this is that different countries have different emdollars ratios, and therefore, the price for the same commodity would differ between countries, thus reflecting both how much emergy has been used in production and getting it to the market place in each country, as well as the amount of emergy that needs to be returned to the producer country if the transaction is to be fair. However, for this to work, it is crucial that resulting extra compensation is put into fair and sustainable use, *e.g.* to improve conditions for poor people and the environment.

As accounted for in chapter 5, emergy and associated systems language provides a tool for illustrating energy and material flows between regions, as well as controlling (feedback) mechanisms. In other words it becomes possible to visualise the flows and interactions referred to above, and simplify them through aggregation, thereby enabling the human mind to conceptualise small and large parts simultaneously, and hence see the bigger picture more clearly. By drawing on the results in this thesis, and the example above, figure 26 therefore illustrates the coastal zone's position and role in the world system, exemplified by the above hypothetical transaction between a Sri Lankan shrimp farmer and Swedish consumer (as a representative of the global North), depicted in emergy systems language.

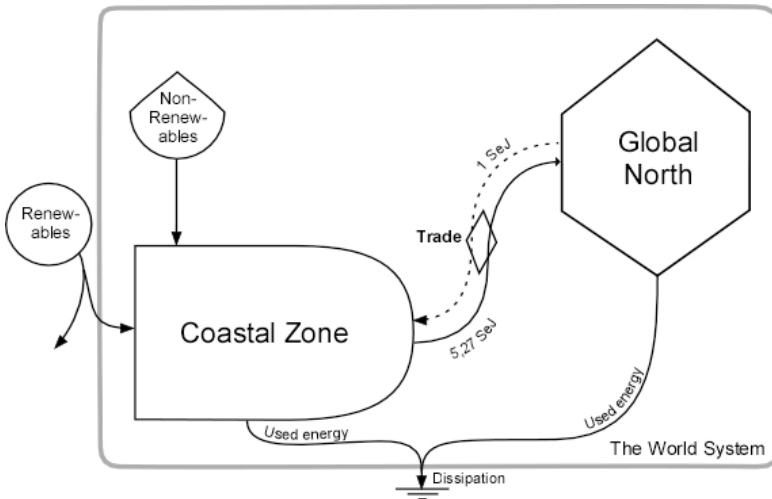


Figure 26. The coastal zone's position and role as shrimp producer in the world system, described in terms of net energy flows and trade between aquaculturists in the Sri Lankan coastal zone and the global North (Swedish consumers).

As figure 26 shows, 5.27 times more energy flows from the coastal zone to the global North, than is returned via monetary transactions. This way of illustrating net energy flows is also possible to apply to North-South relations in general. That is, by replacing the producer symbol in figure 26 (the coastal zone) with an aggregated South, a generalised view of the world system may be constructed, as depicted in figure 27.

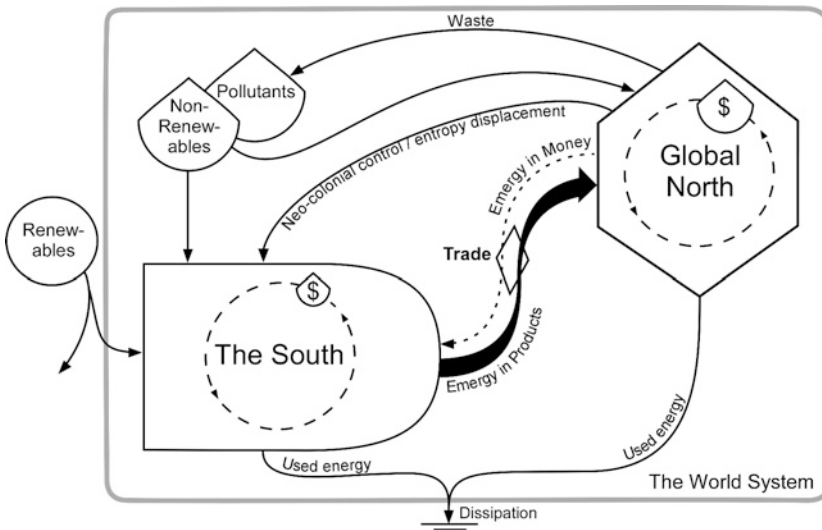


Figure 27. A generalised view of the world system, described in terms of energy flows, unequal transactions and resource transfers between the South and global North, resulting in accumulation of energy in the core.

As illustrated in figure 27, denser flows of energy move from left to right than is fed back via monetary transactions, hence resulting in accumulation in the global North. In addition, this unfair exchange is self-reinforcing due to neo-colonial controls (see chapter 3) resulting from power relations through history. Therefore, as also argued *e.g.* by many Marxists, poverty and distribution of resources and wealth can never be fully understood without explicit emphasis on power relations and fairness (Johnston and Sidaway 2004). In figure 27, control resulting from such power relations is represented by the pathway line moving from right to left. This process of self-reinforcing accumulation in the core has been referred to earlier, although by using different terminology. For example, Bunker (1985:33) claimed that

accelerated energy flow to the world industrial core permits the social complexity which generates political and economic power there and permits the rapid technological changes which transform world market demands.

Hornborg (2001) similarly argue that this reinforcement is a result of advantageous economies exercising power to improve terms of trade for their own benefit. The current organisation of global trade in this way enables the global North to appropriate increasing amounts of resources from the South, resulting in accumulation. Facilitated by neo-colonial processes and local elites in the South, this wealth then further amplifies the global North's ability to accumulate even more resources and exercise control.

The processes described in figures 26 and 27 are similar in many ways, but have one major difference; on a more aggregate scale not only control is fed back, but also waste generated by the global North, as for example when discarded electronics (e-Waste) are exported to peripheries *e.g.* in Africa (*c.f.* Schmidt 2006). Put together, this means that the South draws on local environmental and human resources, together with non-renewable energies from other peripheries, hence facilitating the process of accumulation in the core, only to risk exhausting the local and global resource base, and building up storages of waste (represented by the pollutants symbol in figure 27).

As mentioned earlier, the notion of accumulation in the core is not a new idea. However, this thesis attempts to visualise it in a more pedagogical and illustrative manner than has been achieved *e.g.* in dependency theory. This way of thinking of, and illustrating world system organisation, also makes it possible to emphasise and focus on specific nodes of production and consumption. However, perhaps the most important processes to understand in the context of unfair development may not be in these nodes *per se*, but rather in the nexus, or "in-between", where resource flows, human action and control converge to create value and meaning, and trigger consequence. That is, it is in the moment of transaction that all processes discussed earlier coincide spatially and temporally, as a snapshot of global interconnectedness, represented by a specific moment of exchange (trade). It may thus be

argued that when a product leaves the producer, it represents one type of resource, but since its value and meaning is then negotiated in the moment of trade, it results in a transformation of content (not as much physically as symbolically) before ultimately reaching the consumer (*c.f.* Hauge 2007). This implies that it is in the intangible interface between the physical and symbolic that human-nature interaction is manifested. Understanding this connection may thus withhold the key to increasing our knowledge of humankind's embeddedness in the earth system, but also relations between different nodes of the world system. Olsson (2007) has pointed to the importance of emphasising this relational nexus, as opposed to more tangible nodes, exemplified in this case by producers (the South) and consumers (the global North). In attempting to concretise this notion, Abrahamsson (forthcoming) explores this "in-between", where matter is given meaning, as a multi-directional flow between material objects, via immaterial relations. In doing so, Abrahamsson strives towards identifying the boundary between physical matter and immaterial meaning, where the symbolic and material are simultaneously transformed. However, the illusive character of the interface between the physical and abstract (symbolic) makes it difficult to fix and describe such relations, as opposed to characterising dots. Put together, this means that grasping the connection between physical-abstract, and human-nature, represents a major epistemological and methodological challenge.

Still, as mentioned earlier, re-thinking the way we look upon the world and what we choose to study may be the only way forward. Especially in geography, this may be worthwhile to reflect upon. For example, Abrahamsson (forthcoming) proposes a geography that does not dissolve relations by prioritising fixed categories. In this thesis, it is argued that the systems perspective offers such an approach, in that it focuses on how physical entities interact and are bound together, via a variety of relations and transformation processes, within and between systems. As pointed out by Johnston and Sidaway (2004), the systems view in geography was in fact widespread in the 1950s and 60s, especially within quantitative geography. It was however more or less abandoned following extensive critique during the 1970s, when the shortcomings of statistical methods had pushed the systems perspective within geography to an impasse. The argument was that not all processes and principles dictating the behaviour of systems could be described by using mathematical models. Ultimately, they needed some complement in terms of explanatory models, which are more prominent in qualitative approaches. Resulting from philosophic reason, qualitative explanations however need to be expressed orally or in writing, and are hence not easily translated into mathematical equations. One reason to why systems approaches (at least within geography) failed is thus that they failed to combine quantitative descriptions of reality with qualitative explanations. This critique ultimately resulted in abandonment of the systems approach by a majority of geogra-

phers. Still, as this thesis has shown, much can be learnt from the past. Therefore, it may be suggested that rather than completely rejecting systems thinking, methodological and epistemological progress in other disciplines than geography, in physical as well as social sciences, may be used for improving and re-introducing the systems view in contemporary geography, as well as in other disciplines where the systems view is weak. However, as pointed out earlier, the question is whether academia is ready for such a shift in terms of how the world is looked upon, that is, to once again start viewing humankind and nature as interconnected elements in a larger whole, and the nexus between the physical and abstract as key to fuller understanding of the relation between the world and earth systems.

### Emergy: conceptualising accumulation in the world system?

If rates of energy dissipation are an essential component in the inequitable dynamics of the world system, it must be a central theoretical challenge to integrate perspectives from the social and natural sciences to achieve a more complete understanding of capital accumulation. (Hornborg 2001:29).

The examples illustrated in figures 26 and 27 imply that general and world systems theories may be integrated to better illustrate the organisation and effects of global trade. Capitalism is in many ways a means for accumulation similar to colonialism and neo-colonialism. However, when the concept of accumulation is applied in this context, it is seldom stated precisely what is being accumulated (Hornborg 2001). Therefore, it is proposed here that emergy be used for conceptualising what is actually being accumulated. Thereby, unfair transactions resulting in accumulation in different parts of the world system may be revealed more easily if thought of as emergy accumulation. As illustrated above, flows of resources and the exercise of power (control) within the world-system may be depicted in emergy diagrams. However, whether or not this adds something new is an entirely different question. Neo-colonial processes and unfair transactions in the world system are long-since known. Still, illustrating these relationships in diagrams offers a new way of conceptualising and communicating dependence and interactions between peripheries and the global North in a more explicit manner. That is, to make the global North's dependence on the South more visible. What is new here, therefore, is that the approach offers a perhaps more pedagogical way to communicate what may be already sensed, *i.e.*, that rural areas of the South are being exploited for the benefit of the global North. By doing so, hopefully it becomes easier to discuss transformation processes and unfairness of the world system across academic disciplines, as well as in politics and civil society.

As argued by Hornborg (2001), solving the problems of environment and development will indeed demand profound changes in our way of organising life, but also how we communicate. However, in the contemporary environment and development discourse, solutions are seldom discussed that are radical enough. Thus, there is a need for new approaches to global development that are ecologically realist, and acknowledge the unfair distributive aspects of development, technology and environment (Hornborg 2001).

As suggested in this thesis, merging general and world systems theories may offer such a new and radical approach. However, Hornborg (2001) does not seem to concur with the idea of using emergy as an analytical unit to measure the value of products and resource flows. He argues that emergy is a misleading concept, since it is too abstract, and cannot be embodied in anything. For instance, he uses the example of a farmer producing food crops. By farming the crops, the farmer uses various forms of energy, such as sun, rain, fertilisers, and food for the farmer. But, this energy is inevitably lost in the process, rather than converted, or embodied into the crops. Thus, Hornborg concludes, emergy is a misleading concept, since the emergy is not in the crops or anywhere else but in our minds. In fact, Hornborg is correct in the sense that emergy is an abstract concept and therefore should be used with caution. However, this is not the same as to say that it cannot be used for conceptualising the value of things. By calculating the emergy value of goods and services, regardless of them being provided directly or indirectly by nature or humans, emergy, although not physically “there” still expresses what it took to produce them, and hence can serve as an indicator of value, perhaps not alone, but rather as a complement to other ways of establishing value.

Furthermore, Hornborg (2001) has pointed out that the concept of emergy may contradict the exploitative relation of core-periphery trade, as proposed by world system theory. He argues, that if emergy was to be used for example to value commodities on the world market, it would only legitimate the current situation, since high economic value products sold by the North would also be considered of high value in terms of their emergy contents (processed commodities indeed have high emergy values). But this is precisely the point. Accumulation in the capitalist world system builds upon a discrepancy between the price that is paid for a resource or commodity, and the true value of these (as argued in chapter 3). Otherwise accumulation of capital (or rather, emergy) would not take place. Thus, only because a consideration of emergy value implies commodities produced in the North would be more expensive, it is not the same as to say that goods and services originating from the South would not. Many commodities produced in the South depend on extensive exploitation of local natural resources, and under-compensated labour. The problem is that this support is not acknowledged, and hence even more seldom compensated for. Therefore, trade as practiced in the current capitalist system always implies over-appropriation to the



dominant party (and under-compensation in the peripheries), and hence, the North drains the South of its resources, as is precisely the argument in World System Theory. Emergy synthesis thus offers an alternative approach to establishing value, that would illuminate the unfair and environmental aspects of trade, which is needed if the global capitalist system is to be re-designed for the benefit of all humans, as well as nature. Hence, in this thesis it is argued that accumulation be re-conceptualised as emergy accumulation, thereby putting an ease to the failure of dependency and world system theories to define accumulation. This by no means would contradict their main argument, *i.e.*, that resources are unfairly transferred and distributed in the world system, since this is exactly what would be revealed by using emergy as the analytical unit for illuminating that the peoples and ecosystems of the South supplies the North with more emergy than is being returned to them in trade.

The examples above clearly demonstrate that emergy may be used for revealing and quantifying unfair transactions resulting from world trade under current premises. Thus, emergy not only serves as a useful concept for research on resource transfers in the world system, but may also be used in a more applied sense, such as for making global trade fairer in the future. Furthermore, since emergy acknowledges human and environmental support simultaneously, it also means it may be applied for making product certification systems such as *e.g.* “fair-trade” more holistic. Indeed, some researchers (*e.g.* Rydberg and Salomonsson 2004) have proposed that emergy be used as a concept and unit of analysis, but also for more appropriate pricing of goods and services for sale on the world market. The results of this thesis thus serve as yet another example of why, and more importantly, how, goods and services may be valued in ways that acknowledge and account for the contribution by natural and human systems together.

## 9. Conclusions and discussion

The overall ambition of this thesis has been threefold; (1) to study and compare spatial distribution of environmental effects and socioeconomic benefits from coastal aquaculture under different conditions, (2) to assess the relative sustainability of two cases of aquaculture, and relate them to systems at larger scales, thereby exploring emergy as an alternative concept for more holistic and interdisciplinary sustainability assessment, and (3) to use the results to discuss and highlight implications for more sustainable aquaculture.

Although the two cases differ in terms of their specific socio-economic and environmental effects, they clearly exemplify the complexity of human-nature interactions, as well as connections between the colonised coasts and the world system. This chapter draws on these experiences to conclude and highlight the most important results, as well as discussing implications for more sustainable aquaculture.

The research questions listed in chapter 1 have all been answered to a varying degree. With increasing intensity, (*i.e.*, from extensive to semi-intensive) the results indicate that aquaculture tends to depend more on resources from geographically distant areas. Also economic benefits tend to be scattered further away from the production site when semi-intensive monoculture is applied. However, whether or not this is a general trend in aquaculture when other culture practices are applied in other locations would require further research. Still, in other areas with similar characteristics throughout the region, it may be expected that conditions are similar. Although primarily location specific, the results therefore provide some more generic indications of contemporary trends in aquaculture.

It may be concluded that local people are involved to a greater extent in the Philippines than in Sri Lanka, which indicates that benefits congregate more locally when extensive polyculture practices are applied. The higher complexity of polyculture as practiced in the Philippines, reduces the need for external and non-renewable inputs, and also reduces farmers' vulnerability to price fluctuations. Put together, these aspects make it a relatively more sustainable culture practice

In a wider context, the study has shown that natural resources and people in the coastal zones of the South, combined with additional external inputs from other peripheries, support wealth accumulation in the global North to little benefit for local people and the environment. However, the results also suggest that this may be counteracted by formulating policies for more fair

and sustainable aquaculture, especially by learning from past experiences in different locations, as well as mimicking the self-organisational patterns found in natural ecosystems. Furthermore, formulation of such policies may be supported by transdisciplinary assessment approaches. To aid such transdisciplinary analysis, this study has shown that one possible alternative is to combine general systems theory, emergy synthesis and world system theory. Together, these approaches provide a means for quantifying and illustrating sustainability and fairness in resource flows, and enable more qualitative and explanatory description of how and why these relationships emerge and operate.

Apart from these overall implications for policy and research, the study has led to a range of more specific conclusions, among which the following are most important;

1. Several factors are important to consider for aquaculture to be more sustainable, out of which the most important are mangrove conversion, local people involvement, and the degree and character of external input dependence.
2. Semi-intensive monoculture as practiced in Sri Lanka is too capital and fuel intensive to be sustainable, and results in significant environmental pressure locally and globally, as well as few economic benefits for poor local people. As a comparison, extensive polyculture as practiced in the Philippines is a relatively more sustainable alternative, since more local people are positively affected, whereas environmental pressure at local and global levels is lower. However, in areas where land is scarce, extensive practices are not an alternative, which is indicated by the activity's destructive intrusion on mangroves. Thus, neither culture practice is a viable alternative for environmentally sound approaches to poverty alleviation.
3. In the light of decreasing world market prices for cultured shrimp and diminishing oil reserves, economic benefits of extensive polyculture increasingly resemble those of more intensive practices, while negative environmental impacts remain smaller. If mangrove conversion is counteracted, the viability of extensive polyculture for environmentally sound poverty alleviation hence increases due to low demand for fuel, labour and capital, which will be crucial in adapting aquaculture to a future characterised by resource scarcity.
4. If the aquaculture industry continues towards increasingly resource intensive and export-oriented production, it will not only depreciate natural resources due to net-losses, but the South will also be under-compensated economically due to in-balances in world trade relations.

5. Policies are needed that favour resource efficient polyculture practices, local small-scale and resource poor farmers, instead of the global North.
6. Emergy synthesis, PRA, and systems theories are possible to integrate, and provide an opportunity for transdisciplinary analysis and communication of [un]sustainability in aquaculture, and how production/ consumption systems and the environment are intertwined. Emergy and associated sustainability indices may therefore be worthwhile to incorporate in sustainability assessment approaches, thereby facilitating transition towards more sustainable development.

As indicated by the results and conclusions above, aquaculture as practiced in Sri Lanka clearly represents a less sustainable model, meaning that it to a lesser extent benefits local populations, and also to a larger extent degrades natural resources. However, none of the two practices studied here can be called sustainable, at least not when considering local, global, and long term effects simultaneously.

From a methodological perspective, combining PLA and emergy synthesis proved useful for carrying out transdisciplinary research. Physical as well as socio-economic differences between the two cases could be analysed and visualised in a formalised way that enables results to be used for future reference and comparisons with aquaculture on other locations. Illustrating emergy flows and calculating indices also aided in assessing their relative sustainability, as well as relating the two cases to systems at larger scales. The approach hence provided a basis for discussing the role that aquaculture plays in development and how it is related to other parts of the world system.

The study has also shown that if local knowledge combined with new technology and past experiences are used for creating more intelligent resource use, emergy indices may be used for monitoring and changing patterns of production to become more sustainable.

## Implications for sustainability assessment and planning

As the thesis also points out, assessing and managing sustainability is complex. Therefore, the remaining part of this chapter discusses (1) what factors are most important for making aquaculture sustainable, (2), what sustainability would mean in this context, and (3), why and how emergy may be useful as an alternative scientific language for analysing and communicating such issues, in research as well as planning.

So what factors then favour a more sustainable model of aquaculture? As summarised above, the most important factors are mangrove conversion, local people involvement, and dependence on external inputs, in this case specifically fossil fuels, hatchery fry and artificial feed.

Conversion of mangrove forests has taken place to a similar extent in the two study areas. As mentioned, this severely decreases sustainability in aquaculture. Regardless of which culture practice is promoted in future aquaculture development, mangrove conversion will therefore always have to be monitored and counteracted. Still, the fact that mangrove has been converted into ponds in both areas negatively affects sustainability in both cases, especially when considering cumulative effects resulting from congregation of many farms. Extensive practices indeed demand more land in comparison to semi-intensive and intensive practices. In areas with limited land resources, extensive aquaculture may therefore not be a viable solution. On the other hand, given that further aquaculture development is better regulated, this problem might be counteracted by not allowing farms to congregate excessively, and by setting aside areas for mangrove conservation, as well as promoting restoration of abandoned ponds. This may be worthwhile to keep in mind when planning for further aquaculture expansion and new developments in previously unexploited areas.

The results also imply that the analytical scope of any sustainability assessment needs to be widened, and consider effects on global as well as local levels. For example, when concentrating new resources in one area, be they economic or physical, this will not only have a local impact, since resources need to be extracted from somewhere and not necessarily only from the local area. Hence, local developments will most probably have effects also in those locations. These interactions between developments in one area and with societies and the environment outside the direct vicinity of project sites therefore call for assessment approaches that holistically consider local, global and cumulative effects. With special reference to aquaculture development, another reason for implementing more holistic assessment and management strategies is that legislation is unclear regarding accountability and responsibilities of cumulative effects. Surely, it cannot be a single project proponent's responsibility to manage such effects, although consideration of course is necessary. Considering cumulative effects also makes it possible to be more pro-active in estimating the totality of effects resulting in numerous developments in a region, and to choose better between alternative scenarios. However, uncertainty increases when predicting the results of multiple choices of action. In other words, the more scenarios that are to be considered in planning, the more difficult it becomes to assess their respective impacts on environment and society as a whole.

The results from this study have also shown that if the aquaculture industry in particular and the South in general follow the current path towards increasingly resource intensive and export-oriented production, there is a

risk that not only local natural resources are depreciated due to net-losses, but also that the South is under-compensated in the process. In this context, although more local people participate and benefit from aquaculture in the Philippines than in Sri Lanka, in both cases relatively few belong to the poorest and least empowered individuals of coastal communities. Thus, aquaculture contribution to poverty alleviation will remain problematic as long as the beneficiaries are middleclass or elites, be they local or external. Furthermore, environmental impacts are often underestimated and hence considered negligible or acceptable in relation to the positive socio-economic effects expected from the industry. This is especially unfortunate since sustainable use of natural resources is of paramount importance for a positive rural development. Although research elsewhere (*c.f.* Hajdu 2006) indicates that poor people's dependence on local natural resources is decreasing, livelihoods of many local, and especially poor people, are still highly reliant on biomass economies (Karunanayake 2001).

Since shrimp is expensive and mostly consumed by the global North, also in terms of increasing food security, aquaculture contribution is questionable, at least where only shrimp monoculture is practiced. The problem of skewed distributional patterns is well recognised in the case of agriculture and marine fisheries throughout the South, and as underscored by Bailey (1988), also applies to aquaculture development. In other locations, for example Java, the benefits of aquaculture developments have mainly accrued to local elites, whereas the poor have been largely excluded (Bailey 1988). Observations and discussions with informants in the field study areas, especially in Sri Lanka, acknowledge that also there this failure to involve the local poor community is common. The situation in the Philippines is rather similar, although it is important to stress that during this fieldwork, class and social stratification of informants were not explicitly examined. Therefore, further research is necessary to better understand who benefits from the activity, and hence, to what extent aquaculture creates local livelihoods and contributes to poverty alleviation. Furthermore, policies are needed that favour resource efficient polyculture practices, and local small-scale and resource poor farmers, instead of local or external elites and multinational companies. After all, favouring small-scale and more localised/self-sufficient socio-spatial organisation in harmony with nature is not a new idea (*c.f.* Kropotkin 1996).

Although the results suggest that the culture practices in the Philippines are more integrated with natural ecosystems, and hence pose a less serious threat to the environment, this need not be explicitly so. Environmental, as well as socio-economic impacts, from aquaculture are difficult to determine, and sometimes only appear long after actions have been taken. Therefore, further research is needed on the relationship between different aquaculture practices and sustainability, and how this varies between regions, countries and over time.

As argued by Odum and Odum (2001), if managed more appropriately, aquaculture may yet play an important role in the future. Some low-intensity aquaculture is indeed managed with little more effort by humans than to harvest the crops, while simultaneously putting low pressure on natural ecosystems and depending little on imported resources. With rising prices for external inputs such as fry, feed and fuels, ultimately it may be expected that the declining investment ratio will result in aquaculture becoming less concentrated on luxury products and turn towards more diversified production and species lower down the food chain (Odum and Odum 2001). Then, aquaculture may prove an energetically efficient way to produce food, as well as to absorb nutrients and by-products from agriculture. In this context, again, it will be crucial to consider also who is the main beneficiary, *i.e.*, to include a fairness component in sustainability assessment.

As the results have shown, extensive polyculture as practiced in the Philippines demands fewer inputs in terms of fossil fuels, hatchery fry and artificial feeds. This implies a relatively less sustainable situation in Sri Lanka. It is therefore likely that experiences from the past and current situation in the Philippines withhold implications for making future aquaculture more sustainable and fair in Sri Lanka, as well as worldwide. However, there is great need for caution here. If aquaculture is to become more sustainable in the future the problems illuminated in this thesis need to be avoided. Especially in Sri Lanka, where the government is planning further aquaculture development in Eastern and Southern provinces (*c.f.* CCD 2003; Gunaratne 2007), learning from past experiences will therefore be crucial if development is to be more sustainable and fair in the future.

It will also be crucial to keep in mind what constitutes sustainability. Aquaculture, as well as many other economic activities may seem sustainable on either local or global levels. For example, by importing resources, environmental impacts may be reduced at local levels. However, on a global scale it may not be as viable. Although pressure may in this way be reduced locally *e.g.* by limiting use of natural fry from the estuary, these resources still have to be taken from somewhere. Hence, negative environmental effects are not decreased, but rather, exported. This process is similar to that referred to as entropy displacement (as discussed in chapter 3), and ultimately needs to be avoided if aquaculture is to be sustainable on both local and global levels. In existing legislative frameworks and planning strategies such as environmental impact assessment (EIA) and strategic environmental assessment (SEA), this is too often neglected. On the contrary, EIA and SEA are often exclusively concentrated on what is sustainable at local levels.

An alternative way for revealing entropy displacement, and hence, to improve the accuracy of SEA, may be to incorporate emergy synthesis as a methodology. Furthermore, by using emergy as the unit of analysis, the total costs (*i.e.*, including externalities) of aquaculture production, as well as other economic activities, may be better reflected in market prices. Perhaps then,

price will reflect the true value of aquaculture products, and nature as well as farmers may be acknowledged and compensated accordingly.

Meanwhile, other researchers (*e.g.* Rönnbäck *et al* 2003:351) have chosen other approaches. By arguing that “technical and economic inputs such as construction materials, energy and labour, form only a small part of the many inputs needed for aquaculture” (referred to as purchased inputs in this thesis), they claim that the main inputs are in fact ecosystem goods and services. And hence, the availability of such natural resources is the most important determinant for sustainability and limitations of future aquaculture expansion. The results of this thesis also acknowledge that the availability of such resources is very important, and will most probably limit further aquaculture development. However, the contribution by purchased inputs should not be underestimated. The emergy evaluations of the two cases have shown that whereas dependence on local natural resources is highly critical, a more important determinant is still purchased inputs, as is illustrated *e.g.* in the emergy signatures (figure 25). These results reinforce the argument suggested by general systems theory; that apart from having a local focus, it is necessary to consider also processes and impacts that take place on other locations than the production site itself. As this study has shown, it is indeed only by importing large quantities of *e.g.* fuels, fry, and feed etc, that semi-intensive aquaculture can work. In this sense, semi-intensive aquaculture is subsidised by resources from other systems, which according to many scholars (*e.g.* Carpenter *et al* 2001; Walker *et al* 2004) may potentially compromise functions and opportunities in other systems and time periods. Furthermore, if the pulsing paradigm proposed by Odum and Odum (2001) is accepted, *i.e.*, that descent to a low energy future is approaching, also decreasing resources availability on multiple scales, ranging from the local to the global, will be a crucial determinant for aquaculture development in the future. Odum (*e.g.* 2007), as well as proponents of other system approaches (*c.f.* Hollis 2004) agree that, therefore, it is increasingly plausible that radical shifts are coming in this century. If proven right, the aquaculture industry in Sri Lanka and the Philippines, as well as the entire global community will thus inevitably be forced to adapt to these changing conditions, only to experience even greater challenges than in the past.



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# Appendices

Appendix 1. Check boxes and key questions posed during semi-structured interviews

## *Information about farm*

a) Number of ponds	b) Farm size	c) Yield	d) Cycle duration	e) External investors	f) Year of establishment
g) Previous land use	h) Costs/salaries	i) Stocking density	j) Net benefit	l) No. of full-time employees	m) No. of extra employees

Comments/additional information:

## *Information about informant*

a) Name	b) Surname	c) Sex	d) Age	e) Employment form	f) Years at farm
g) Years in area	h) Education	i) Home-stead location	j) Origin	l) Previous profession	m) Monthly salary

Comments/additional information:

## *Questions*

- Do you own or lease the land?
- What kind of culture practices have you tried? (e.g. monoculture, polyculture etc.)
- Do you grow anything else, except fish/shrimp? (e.g. coconut, banana, etc.)
- On what and where do you spend your money?
- What do you do if you have money left after all expenses are paid?
- Do you work with something else than aquaculture?

Appendix 2. Emergy evaluation table of semi-intensive shrimp monoculture in Sri Lanka, per hectare, per year.

Note	Item	Unit	Data (units/yr)	Unit Emery (SeJ/unit)	Solar Emery (E13 SeJ/yr)	Em\$ Value (2000 \$/yr)
<b>RENEWABLE RESOURCES</b>						
1	Sun	J	4,71E+13	1	4,71	25,48
2	Rain	J	5,38E+10	3,02E+04	163	881
3	Estuarine waters	J	1,98E+11	2,59E+04	514	2779
	<i>Sum of free inputs (direct sun omitted)</i>				676	3661
<b>PURCHASED INPUTS</b>						
4	Fuel	J	1,16E+11	1,11E+05	1284	6946
5	Feed	J	3,10E+11	2,20E+05	6826	36940
6	Labour	J	3,35E+09	4,40E+06	1477	7991
7	Lime	g	2,00E+06	1,68E+09	336	1818
8	Nitrogen	g N	1,67E+05	7,04E+09	117	635
9	Machinery	g	1,53E+04	1,13E+10	17	93
10	Phosphate	g P	3,33E+03	3,36E+10	11	61
11	Shrimp post larvae	ind	3,00E+05	1,75E+11	5242	28364
12	Services	\$	2,26E+04	1,85E+12	4171	22572
	<i>Sum of purchased inputs</i>				19482	105419
	<i>Total emery</i>				20158	109080
<b>TRANSFORMITIES, Calculated</b>						
13	Yield, ha/yr	\$	12758	<b>1,58E+13</b>	SeJ/\$	
		J	2,49E+10	<b>8,11E+06</b>	SeJ/J	
<b>INDICES, calculated</b>						
Note	Name of Index	Expression	Quantity			
14	Investment ratio	F/R	29			
15	Yield Ratio	Y/F	1,03			
16	Emery exchange ratio	Y/\$ * (SeJ/\$)	6,28E+24			
17	% Renewable	R/(R+N)	19			
18	Empower Density	SeJ/ha/yr	2,0E+17			
19	Environmental loading ratio	(F+N)/R	33,8			
20	Emery sustainability index	EYR/ELR	0,03			

**Notes, appendix 2**

**1 Sun, J**

Annual energy = (Avg. Total Annual Insolation J/yr)(Area)(1-albedo)		
Insolation:	6,73E+09 J/m <sup>2</sup> /yr	5,12 kwh/m <sup>2</sup> /day (IDEA un-dated)
Area:	1,00E+04 m <sup>2</sup>	
Albedo:	0,3	(Brown and Bardi 2001)
Annual energy:	4,71E+13 J	
Emergy per unit input =	1 SeJ/J	(Odum 1996a)

**2 Rain, J**

Annual energy = (m/yr)(Area)(1E6g/m <sup>3</sup> )(4.94J/g)		
m/yr:	1,09 m	(NOAA 2006)
Area, m <sup>2</sup> :	10000 m <sup>2</sup>	
Annual energy:	5,38E+10 J	
Emergy per unit input =	1,80E+04 SeJ/J	(Odum 1996a)

**3 Estuarine water, chemical potential**

2 initial fillings + water exchange (Fernando 2005)

Annual energy=(fillings/yr)(depth, m)(area, m<sup>2</sup>)(g/m<sup>3</sup>)(j/g estuarine water)

Fillings:	2	
Depth:	1,35 m	
Area:	9000 m <sup>2</sup>	
g water/m <sup>3</sup> :	1000000 g	
j/g estuarine water:	3 J	(Brown <i>et al</i> 1992)
Annual energy, fillings=	3,56E+09	

Annual energy=(exchange, changes/yr)(depth, m)(area, m<sup>2</sup>)(g/m<sup>3</sup>)(j/g estuarine water)

Exchange:	24	
Depth:	0,3 m	
Area:	9000 m <sup>2</sup>	
g water/m <sup>3</sup> :	1000000 g	
j/g estuarine water:	3 J	(Brown <i>et al</i> 1992)
Annual energy, exchange=	1,94E+11	

Total estuarine water 1,98E+11 J

Emergy per unit input = 1,54E+04 SeJ/J (Odum and Arding 1991)

**4 Fuel, J per ha (includes diesel, gasoline, lubricants)**

Annual energy = (J/gallon)(gallons/yr)

J/gallon:	1,37E+08 J	(Odum and Arding 1991)
Gallons/yr:	8,45E+02 Gallons	(Fernando 2005)
Annual energy:	1,16E+11 J	
Emergy per unit input =	6,60E+04 SeJ/J	(Odum 1996a)



**Notes, appendix 2, cont.**

- 5 **Feed, g per ha**  
(Pellets –from fish-, shrimp-, squid meal and fish oil)  
Annual energy = (g/yr)(5,7kcal/g)(4186J/kcal)  
Annual consumption: 1,30E+07 g (Fernando 2005)  
Annual energy: 3,10E+11 J  
Emergy per unit input = 1,31E+05 SeJ/J (Odum and Arding 1991)
- 6 **Labour, J**  
Extra labour during preparation/harvest and two full time positions/year  
(pers-hours/ha/yr)\*(2500 kcal/day)\*(4186J/Cal)  
pers-hours, ha/yr: 7,69E+03 h (Fernando 2005)  
Annual energy: 3,35E+09 J/yr  
Emergy per unit input = 2,62E+06 SeJ/J (Odum and Arding 1991)
- 7 **Lime, g per ha**  
Annual consumption: 2,00E+06 g (Fernando 2007)  
Emergy per unit input = 1,00E+09 SeJ/g (Odum 1996a)
- 8 **Nitrogen, g N per ha**  
Annual consumption: 1,67E+05 g (Fernando 2005)  
Emergy per unit input = 4,19E+09 SeJ/g (Odum and Arding 1991)
- 9 **Machinery, (assuming 10 year life)**  
2 generators/3ha: 2,00E+03 kg (Fernando 2005)  
12 paddle weels/3ha: 4,00E+02 kg  
g/kg: 1,00E+03 g  
Annual consumption: 1,53E+04 g  
Emergy per unit input = 6,70E+09 SeJ/g (Brown *et al* 1992)
- 10 **Phosphate, g P per ha**  
Annual consumption: 3,33E+03 g (Fernando 2005)  
Emergy per unit input = 2,00E+10 SeJ/g (Odum and Arding 1991)
- 11 **Shrimp post larvae, from hatchery**  
Annual consumption, ind: 3,00E+05 ind (Fernando 2005)  
Emergy per unit input = 1,04E+11 SeJ/ind (Odum and Arding 1991)
- 12 **Services, \$ per ha (fuel, labour, feed, post larvae, consultancy, harvest etc.)**  
Annual consumption 2,30E+06 Rupees (Fernando 2005)  
\$/Rupee: 9,81E-03 \$ (FXconverter 2006)  
\$/yr: 2,26E+04 \$  
Emergy per unit input = 1,10E+12 SeJ/\$ World average (Brown and Ulgiati 1999)

**Notes, appendix 2, cont.**

**13 Yield, assuming 80% survival rate**

Shrimp, kg/yr	6,00E+03	kg	(Fernando 2005)
Annual energy = (g/yr)(kcal/g)(j/kcal)			
g/yr:	6,00E+06	g	
Kcal/g:	9,90E-01	g	(FAO 1989)
J/kcal:	4,19E+03	J	(Odum and Arding 1991)
Annual energy:	2,49E+10	J	
Sales price:	35330	\$	(Fernando 2007)

**Indices, calculated**

R = Free renewable energy of environmental inputs

Items 1 + 2 + 3

F = Feedback; purchased energy of fuels, raw materials and services

Items 5 + 6 + 7 + 8 + 9 + 10 + 11 + 12 + 13

Y = Yield

N = Non-renewable energy of inputs

**14 Investment Ratio**

Expression:	F/R	
F:	1,95E+17	SeJ/ha/yr
R:	6,76E+15	SeJ/ha/yr
Quantity:	29	

**15 Energy Yield Ratio, (EYR)**

Expression:	Y/F	(Brown and Ulgiati 1997)
Y:	2,02E+17	SeJ/ha/yr
F:	1,95E+17	SeJ/ha/yr
Quantity:	1,03	

**16 Energy exchange ratio**

Expression:	Y/\$ * (SeJ/\$)	
Y:	2,02E+17	SeJ/ha/yr
\$:	3,53E+04	
Quantity:	6,28E+24	

**17 % Renewable, (% Renew)** Based on Philippines national average, for comparison

R = Items 1,2,3,7,18,7% of 13 (% renewable services) (Database 2006)

N = Items 5,6,9,10,11,12, 81,3 % of 13 (% non-renewable services) (Database 2006)

Expression:	R/(R+N)	
R:	7,80E+15	SeJ/ha/yr
N:	3,39E+16	SeJ/ha/yr
R+N:	4,17E+16	SeJ/ha/yr
Quantity:	19	% Renew

**Notes, appendix 2, cont.**

18 **Empower Density** - sum of emergy per hectare per year

Expression: SeJ/ha/yr

Quantity: 2,02E+17

19 **Environmental loading ratio, (ELR)**

Expression:  $(F+N)/R$

F: 1,95E+17 SeJ/ha/yr

N: 3,39E+16

R: 6,76E+15 SeJ/ha/yr

Quantity: 34

20 **Emergy sustainability index, (ESI)**

Expression: EYR/ELR

(Brown and Ulgiati 1997)

Quantity: 0,03

Appendix 3. Emergy evaluation table of extensive polyculture in the Philippines, per hectare, per year.

Note	Item	Unit	Data (units/yr)	Unit Solar Emergy (SeJ/unit)	Solar Emergy (E13 SeJ/yr)	Em\$ Value (2000 \$/yr)
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**RENEWABLE RESOURCES**

1	Sun	J	4,60E+13	1	4,60	4,34
2	Evapotranspiration	J	1,67E+07	6,90E+04	0,12	0,11
3	Tide	J	6,62E+10	2,83E+04	187	177
4	Rain	J	8,05E+10	3,02E+04	243	230
5	Estuarine waters	J	2,70E+11	2,59E+04	701	661
<i>Sum of free inputs (direct sun omitted)</i>					1131	1067

**PURCHASED INPUTS**

6	Fuel	J	7,23E+08	1,11E+05	8	8
7	Labour	J	1,52E+09	4,40E+06	669	631
8	Lime	g	2,00E+06	1,68E+09	336	317
9	Nitrogen	g N	1,20E+04	7,04E+09	8	8
10	Machinery	g	1,00E+05	1,13E+10	113	106
11	Phosphate	g P	1,00E+05	3,36E+10	336	317
12	Misc. Equipment	\$	6,92E+00	1,06E+13	7	7
13	Milkfish fry	J	1,67E+10	2,00E+06	3349	3159
14	Services	\$	5,76E+02	1,06E+13	611	576
<i>Sum of purchased inputs</i>					5437	5130
<i>Total emergy</i>					6569	6197

**TRANSFORMITIES, Calculated**

15 Yield, specified co-products

*Sold to market*

Milkfish	\$	3,07E+03	<b>2,14E+13</b>	SeJ/\$
	J	1,11E+10	<b>5,94E+06</b>	SeJ/J
Shrimp	\$	1,58E+03	<b>4,14E+13</b>	SeJ/\$
	J	6,22E+08	<b>1,06E+08</b>	SeJ/J
Mud crab	\$	2,88E+02	<b>2,28E+14</b>	SeJ/\$
	J	1,74E+08	<b>3,78E+08</b>	SeJ/J
Banana	\$	1,92E+01	<b>3,42E+15</b>	SeJ/\$
	J	2,03E+08	<b>3,24E+08</b>	SeJ/J

### Appendix 3, cont.

#### Consumed

Tilapia	J	1,97E+13	<b>3,34E+03</b>	SeJ/J
Papaya	J	1,67E+07	<b>3,92E+09</b>	SeJ/J
Cassava	J	3,35E+08	<b>1,96E+08</b>	SeJ/J

<b>Yield, total</b>	\$	4389	<b>1,32E+13</b>	SeJ/\$
	J	1,97E+13	<b>3,33E+03</b>	SeJ/J

### INDICES, calculated

Note	Name of Index	Expression	Quantity
16	Investment Ratio	F/R	5
17	Yield Ratio	Y/F	1,21
18	Emergy exchange ratio	Y/\$ * (SeJ/\$)	1,4E+26
19	% Renewable	R/(R+N)	19
20	Empower Density	SeJ/ha/yr	6,57E+16
21	Environmental loading ratio	R/(R+N)	4,8
22	Emergy sustainability index	EYR/ELR	0,25

### Notes, appendix 3

#### 1 Sun, J

$$\text{Annual energy} = (\text{Avg. Total Annual Insolation J/yr})(\text{Area})(1-\text{albedo})$$

Insolation: 6,57E+09 J/m<sup>2</sup>/yr      5 kwh/m<sup>2</sup>/d (DOE 2006)  
 Area: 1,00E+04 m<sup>2</sup>  
 Albedo: 0,3 (Brown and Bardi 2001)  
 Annual energy: 4,60E+13 J  
 Emergy per unit input = 1 SeJ/J (Odum 1996a)

#### 2 Evapotranspiration, J

Vegetation on pond walls

$$\text{Annual energy} = (\text{mm/d})(365\text{d/yr})(1000\text{g/mm/m}^2)(4.0\text{J/g})(\text{area})$$

mm/yr: 1,53E+03 mm (IDIS 2006)  
 Area, m<sup>2</sup>: 1000 m<sup>2</sup>  
 g/ha: 4,18E+06 g  
 Annual energy: 1,67E+07 J  
 Emergy per unit input = 4,11E+04 SeJ/J (Odum and Arding 1991)

#### 3 Tides, physical energy in pond water

Tidal range used for water exchange

$$\text{Annual energy} = (\text{amplitude}/2)(\text{pond water, m}^3/\text{yr})(\text{density})(\text{gravity})$$

Average amplitude: 7,50E-01 m (Dumalaog 2006)

**Notes, appendix 3, cont.**

Pond water/yr	9,00E+04	m <sup>3</sup>	
Density, water, :	1,00E+06	g/m <sup>3</sup>	
Gravity:	9,80E-01	m/s <sup>2</sup>	
Annual energy:	6,62E+10	J	
Emergy per unit input =	1,68E+04	SeJ/J	(Odum 1996a)

**4 Rain, J**

Annual energy =	(m/yr)(Area)(1E6g/m <sup>3</sup> )(4.94J/g)		
m/yr:	1,63	m	(IDIS 2006)
Area, m <sup>2</sup> :	10000	m <sup>2</sup>	
Annual energy:	8,05E+10	J	
Emergy per unit input =	1,80E+04	SeJ/J	(Odum 1996a)

**5 Estuarine water, chemical potential**

2 initial fillings + water exchange (Dumalaog 2006)

Annual energy=(fillings/yr)(depth, m)(area, m<sup>2</sup>)(g/m<sup>3</sup>)(j/g estuarine water)

Fillings:	2		
Depth:	0,8	m	
Area:	9000	m <sup>2</sup>	
g water/m <sup>3</sup> :	1000000	g	
j/g estuarine water:	3	J	(Brown <i>et al</i> 1992)
Annual energy, fillings=	4,32E+10		

Annual energy=(exchange/changes/yr)(depth)(area, m<sup>2</sup>)(g/m<sup>3</sup>)(j/g estuarine water)

Exchange:	168		
Depth:	0,05	m	
Area:	9000	m <sup>2</sup>	
g water/m <sup>3</sup> :	1000000	g	
j/g estuarine water:	3	J	(Brown <i>et al</i> 1992)
Annual energy, exchange=	2,27E+11		

Total estuarine water	2,70E+11	J	
Emergy per unit input =	1,54E+04	SeJ/J	(Odum and Arding 1991)

**6 Fuel, J per ha (includes diesel, gasoline, lubricants)**

Annual energy = (J/gallon)(gallons/yr)

J/gallon:	1,37E+08	J	(Odum and Arding 1991)
Gallons/yr:	5,28E+00	Gallons	(Dumalaog 2006)
Annual energy:	7,23E+08	J	
Emergy per unit input =	6,60E+04	SeJ/J	(Odum 1996a)

**Notes, appendix 3, cont.**

7	<b>Labour, J</b>			
	Extra labour during preparation/harvest and two full time positions/year			
	(pers-hours/ha/yr)*(2500 kcal/day)*(4186J/Cal)			
	pers-hours, ha/yr:	7,20E+03	h	(Dumalaog 2006)
	Annual energy:	1,52E+09	J/yr	Consumption subtracted
	Emergy per unit input =	2,62E+06	SeJ/J	(Odum and Arding 1991)
8	<b>Lime, g per ha</b>			
	Annual consumption:	2,00E+06	g	(Dumalaog 2006)
	Emergy per unit input =	1,00E+09	SeJ/g	(Odum 1996a)
9	<b>Nitrogen, g N per ha</b>			
	Annual consumption:	1,20E+04	g	(Dumalaog 2006)
	Emergy per unit input =	4,19E+09	SeJ/g	(Odum and Arding 1991)
10	<b>Machinery, (assuming 10 year life)</b>			
	1 pump:	1,00E+03	kg	(Dumalaog 2006)
	g/kg:	1,00E+03	g	
	Annual consumption:	1,00E+05	g	
	Emergy per unit input =	6,70E+09	SeJ/g	(Brown <i>et al</i> 1992)
11	<b>Phosphate, g P per ha</b>			
	(ammonium phosphate 1620)			
	Annual consumption:	1,00E+05	g	(Dumalaog 2006)
	Emergy per unit input =	2,00E+10	SeJ/g	(Odum and Arding 1991)
12	<b>Misc. equipment, \$ per ha (assuming 10 year life)</b>			
	Shuffles, nets, bamboo etc.			
	Purchase price:	3,60E+03	peso	(Dumalaog 2006)
	\$/peso:	1,92E-02	\$	(FXconverter 2006)
	\$/yr:	6,92E+00	\$	
	Emergy per unit input =	1,06E+13	SeJ/\$	National average (Database 2006)
13	<b>Milkfish fry, from hatchery</b>			
	Annual consumption, ind:	2,00E+04	ind	(Dumalaog 2006)
	Annual consumption, g:	8,00E+05	g	
	Annual consumption, J:	1,67E+10	J	
	Emergy per unit input =	2,00E+06	SeJ/J	Data for tilapia (Brown <i>et al</i> 1992)
14	<b>Services, \$ per ha (pond preparation, fry, consultancy, harvest etc.)</b>			
	Annual consumption	3,00E+04	peso	(Dumalaog 2006)
	\$/peso:	1,92E-02	\$	(FXconverter 2006)

**Notes, appendix 3, cont.**

	\$/yr: 5,76E+02	\$	
Energy per unit input=	1,06E+13	SeJ/\$	National average (Database 2006)

**15 Yield, J/ha (excluding nipa, coconut, lemon, guanavana, guava)**

Milkfish, kg/yr:	2,00E+03	kg	(Dumalaog 2006)
Annual energy = (g/yr)(kcal/g)(j/kcal)			
g/yr:	2,00E+06	g	(Dumalaog 2006)
Kcal/g:	1,32E+00	g	(FAO 1989)
J/kcal:	4,19E+03	J	(Odum and Arding 1991)
Annual energy:	1,11E+10	J	
Sales price, pesos/yr:	1,60E+05	peso	(Dumalaog 2006)
Shrimp, kg/yr	1,50E+02	kg	(Dumalaog 2006)
Annual energy = (g/yr)(kcal/g)(j/kcal)			
g/yr:	1,50E+05	g	
Kcal/g:	9,90E-01	g	(FAO 1989)
J/kcal:	4,19E+03	J	(Odum and Arding 1991)
Annual energy:	6,22E+08	J	
Sales price, pesos/yr:	8,25E+04	peso	(Dumalaog 2006)
Mud crab, kg/yr:	5,00E+01	kg	(Dumalaog 2006)
Annual energy = (g/yr)(kcal/g)(j/kcal)			
g/yr:	5,00E+04	g	(Dumalaog 2006)
Kcal/g:	8,30E-01	g	(NFA 2006)
J/kcal:	4,19E+03	J	(Odum and Arding 1991)
Annual energy:	1,74E+08	J	
Sales price, pesos/yr:	1,50E+04	peso	(Dumalaog 2006)
Banana, kg/yr:	5,00E+01	kg	
Annual energy = (g/yr)(kcal/g)(j/kcal)			
g/yr:	5,00E+04	g	(Dumalaog 2006)
Kcal/g:	9,70E-01	g	(NFA 2006)
J/kcal:	4,19E+03	J	(Odum and Arding 1991)
Annual energy:	2,03E+08	J	
Sales price, pesos/yr:	1,00E+03	peso	(Dumalaog 2006)
Tilapia, kg/yr:	5,00E+01	kg	
Annual energy = (g/yr)(kcal/g)(j/kcal)			
g/yr:	5,00E+09	g	(Dumalaog 2006)
Kcal/g:	9,40E-01	g	FAO 1989
J/kcal:	4,19E+03	J	(Odum and Arding 1991)
Annual energy:	1,97E+13	J	



**Notes, appendix 3, cont.**

Papaya, kg/yr:	1,00E+01	kg	
Annual energy = (g/yr)(kcal/g)(j/kcal)			
g/yr:	1,00E+04	g	(Dumalaog 2006)
Kcal/g:	4,00E-01	g	(NFA 2006)
J/kcal:	4,19E+03	J	(Odum and Arding 1991)
Annual energy:	1,67E+07	J	
Cassava, kg/yr	5,00E+01	kg	
Annual energy = (g/yr)(kcal/g)(j/kcal)			
g/yr:	5,00E+04	g	(Dumalaog 2006)
Kcal/g:	1,60E+00	g	(Nutrition data 2006)
J/kcal:	4,19E+03	J	(Odum and Arding 1991)
Annual energy:	3,35E+08	J	
Total yield, ha/yr:	4,97E+03	\$	
Total yield, ha/yr:	1,97E+13	J	

**Indices, calculated**

R = Free renewable emergy of environmental inputs

Items 1 + 2 + 3 + 4 + 5

F = Feedback; purchased emergy of fuels, raw materials and services

Items 7 + 8 + 9 + 10 + 11 + 12 + 13 + 14 + 15

Y = Yield

N = Non-renewable emergy of inputs

**16 Investment Ratio**

Expression: F/R

F: 5,44E+16 SeJ/ha/yr

R: 1,13E+16 SeJ/ha/yr

Quantity: 5

**17 Emergy Yield Ratio, (EYR)**

Expression: Y/F (Brown and Ulgiati 1997)

Y: 6,57E+16 SeJ/ha/yr

F: 5,44E+16 SeJ/ha/yr

Quantity: 1,21

**18 Emergy exchange ratio**

Expression: Y/\$ \* (SeJ/\$)

Y: 6,57E+16 SeJ/ha/yr

\$: 4,97E+03

Quantity: 1,40E+26

**Notes, appendix 3, cont.**

19 **% Renewable, (%Renew)**

R = Items 1,2,3,4,5,8,18,7% of 15 (% renewable services) (Database 2006)

N = Items 7,9,10,11,12,13,14, 81,3 % of 15 (% non-renewable services) (Database 2006)

Expression:  $R/(R+N)$

R: 1,14E+15 SeJ/ha/yr

N: 4,97E+15 SeJ/ha/yr

R+N: 6,11E+15 SeJ/ha/yr

Quantity: 19 %Renew

20 **Empower Density** - sum of emergy per hectare per year

Expression: SeJ/ha/yr

Quantity: 6,57E+16

21 **Environmental loading ratio, (ELR)**

Expression:  $(F+N)/R$

F: 5,44E+16 SeJ/ha/yr

N: 4,97E+15

R: 1,13E+16 SeJ/ha/yr

Quantity: 5

22 **Emergy sustainability index, (ESI)**

Expression: EYR/ELR (Brown and Ulgiati 1997)

Quantity: 0,23

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