Part 3

Applications of Multi-Objective Integrated Representation (MOIR)

This part is made by 2 chapters and has the goal to show the feasibility and flexibility of the procedure and analytical tools proposed in Part 2. Case studies are used to verify the usefulness of such an approach in providing new insights in the issues considered (by helping the sharing of meaning among stakeholders). In particular the two case studies proposed refer to different typologies of problems defined at different scales:

Chapter 6 : (Case study 1) Multi-Objective Integrated Representation of freshwater fish aquaculture: comparing low-tech and high-tech farming typologies (P.R. China and Italy)

It presents an analysis of the performance of system of production of aquaculture. In particular the approach of Multi-Scale Integrated Analysis is applied to characterize systems of production operating in two completely different socio-economic and ecological contexts: (i) low-tech rural areas of China; (ii) high-tech rural areas of Italy. The approach makes it possible to compare these two systems, but at the same time to define benchmark values, constraints and opportunities of these two systems in relation to their relative socio-economic contexts.

Chapter 7: (Case study 2) Multi-Objective Integrated Representation of the farming system in Thuong Lo commune, Vietnamese uplands

It presents the application of MOIR to an ex-post analysis of the implementation of a FAO project in a village in the Vietnamese uplands. The MOIR analytical tool is used to describe the effect of the implemented policy in terms of rural development: (a) in parallel on distinct descriptive domains (economic, social and ecological); and (b) in relation to different hierarchical levels (household, village, and the “whole commune” comprising 3 villages). In this analysis MOIR provides an integrated package of socio-economic and environmental indicators across scales. The adoption of MOIR provides new insights about the nature of the problems experienced with the implementation of the program.

Chapter 6

Case study 1

Multi-Objective Integrated Representation of freshwater fish aquaculture: comparing low-tech and high-tech farming typologies (P.R. China and Italy)

Summary

This chapter presents an analysis of the performance of system of production of aquaculture. In particular the approach of Multi-Objective Integrated Representation is applied to characterize systems of production operating in two completely different socio-economic and ecological contexts: (i) low-tech rural areas of China; (ii) high-tech rural areas of Italy. The approach makes it possible to compare these two systems, but at the same time to define benchmark values, constraints and opportunities of these two systems in relation to their relative contexts.

The integrated analysis deals with: (i) the pattern of biodiversity use (ecological side of the production process); (ii) the technical coefficients (technological side of the process) that characterize freshwater aquaculture in P.R. China and in Italy; (iii) the role that freshwater aquaculture plays in these societies (socio-economic context). The comparison between aquaculture in China and Italy covers the following aspects: (1) history and general statistics of aquaculture, (2) cultivated species and trophic structure of managed freshwater ecosystems, (3) technological characteristics of the production process, including inputs/outputs, yields, labor productivity, and fossil energy use, (4) role of freshwater aquaculture within the relative socioeconomic context.

6.1 Introduction: Aquaculture, a general overview and future trends

Aquaculture refers to the farming of aquatic organisms (fish, molluscs, crustaceans and aquatic plants). "*Farming*" indicates human intervention in the rearing process to enhance production (as stocking, feeding, etc.). In this section I introduce general figures on aquaculture, its contribution to human nutrition and relation with the environment, then I will list a number of issues of major concern for the sector.

Currently more than 99% of food consumed by humankind is coming from terrestrial ecosystems, while only 1% come from aquatic ecosystems (Pimentel *et al.*, 1996; Pimentel and Pimentel, 1996). Of this about 30% comes from cultured aquatic products, about 70% of which from inland aquaculture (FAO, 1999b; 2000). Aquaculture contributes to about a quarter of the global food fish supply, with inland (freshwater) fish aquaculture representing about 70% of the total fish production (New, 1997; FAO, 1999b; 2000).

According to this rationale, fish aquaculture can be broadly classified into three types (Barnabé, 1990; Milstein, 1992; Pullin, 1993):

(1) ***Extensive aquaculture***. In this system fishes are lightly stocked, use of external feed or fertilizer inputs is maintained to a minimum. This technique does not require a boosting of the water throughput. As a consequence it is characterized by relatively low yields and low production costs;

(2) ***Semi-intensive aquaculture***. In this system natural production is stimulated through limited amounts of fertilizer input and/or organic manure. Also limited amounts of feed may be supplied to integrate available natural food. Yield increases per unit of water body with production costs;

(3) ***Intensive aquaculture***. In this system fishes are densely stocked, generally in artificial tanks. Intensive aquaculture is largely reliant on feed input and based on a rate of water throughput that is kept artificially high. As a consequence, intensive aquaculture has high yields and high production costs. Boosting the system productive performances much above the ranges feasible according to processes occurring in natural aquatic ecosystems implies that the regulation of flows of matter and energy is put under human control. To make things worse, keeping organisms of the same species at high density required also the control of disease outbreak. This is where a massive use of drugs and chemicals enters into play. The side effects of the boosting of natural densities of flows in the managed productive systems are relevant both concerning the increased demand of productive inputs (energy, feed etc.) and the increased disposal of by-products into the environment linked to the output (e.g. chemical and food residual in the outgoing water, CO_2 emission, etc.).

The choice among these productive strategies depend mostly on the constraints and options posed and offered, by the environmental (quality and abundance of natural resources) and socio-economic context (economic factors plus institutional, cultural and historical factors).

Aquaculture, as other forms of biomass production is a multi-functional activity. Main objectives affecting technical choices in this field are (Lin, 1982; Barnabé, 1990; Li, 1992; Pullin *et al*., 1993; Li and Mathias, 1994; Qian, 1994; Bailey, 1997; FAO, 2000): achievement of food security at an affordable cost, generation of profit and employment, enhancement of ecological functions, minimization of risk for the farming systems.

At present most of the important marine fish stocks are fully exploited, and in many cases overexploited (Ludwig *et al*., 1993; Safina, 1995; Cook *et al*., 1997; FAO, 2000; Naylor *et al*., 2000). This is occurring at the very moment in which the demand of seafood is likely to increase as a result of both demographic pressure and rising income in developing countries, especially in Asia. Because of these trends increasing environmental and social problems, especially in developing countries, have to be expected for aquaculture.

This gives rise to a number of issues such as:

i) Food for the poor vs. luxury products for export

In many developing countries, fish is the only affordable source of animal proteins (Bailey, 1997; Tacon, 1997). But the key role of fish for the poor is often missed in economic reports, as it does not add up to the national GNP, so it not always represents a "value" for decision makers. Under the burden of external debt pay-back and the need to generate hard currency to fuel development, many governments are oriented towards converting aquaculture to the production of luxury commodities for export rather than a tool to meet the nutritional needs of local populations (Pullin, 1993; Reinertsen and Haaland, 1995; Bailey, 1997; New, 1997; Tacon, 1997; Boyd, 1999). In many developing countries small-scale fisheries for household self supply are invisible to the market and therefore non-existent in the international accounts (Tacon, 1997). Average global figures of consumption per capita are not useful to pinpoint at the crucial role plaid by fish in the diet of some populations. More in general the contribution of inland fishery resources to food security is underestimated (for some countries as much as two to three times the figure of production reported in official statistics, Tacon, 1997; Boyd, 1999). The dispersed and informal nature of the small scale fisheries (e.g. practiced for subsistence, individually, by children, in non-perennial water bodies, and seasonally in alternation with agriculture) makes it difficult to assess the overall figure.

Although the total production of finfish and shellfish from capture fisheries amounted to 92 million mt in 1995, only 61 million mt (live weight) or 66.3% was available for direct human consumption as "food fish". The remainder (31 million mt) was reduced into fishmeal and fish oil for use in animal feeding or for industrial purposes (Tacon, 1997). Using data by Pike and Barlow (2000), on fish feed formulation I found that by 2010 about 73% of fish meal and 85% of fish oil consumed at the world level will be used to feed economic valuable species, such as salmonids, shrimps etc., will represent just 21% of the total fish biomass from aquaculture produced in the world. The remaining of fish meal and oil will be included as supplements for low values species, carp and tilapia, reared in developing countries, mainly to feed local population (**Table 6.1**). The issue here is that in order to get the necessary amount of fishmeal for a competitive price, feed industries in developing countries are spurring the catching of "cheap" fish stock in marine areas of developing countries (recently the European Union increased 60% the amount of fish its trawlers are allowed to catch off West Africa - Pearce, 2001a) . This, in turn, from one side leads to the decreasing the fish supply for those populations and, on the other, determines an increase of the price for what used to be a cheap food of high nutritional value (Pearce, 2001a; 2001b).

***Table 6.1** Percentage of use of feeds in aquaculture by 2010 (elaboration from estimate by Pike and Barlow, 2000)*

%	Low economic value products (e.g. carp, tilapia)	High economic value products (e.g. salmonids, shrimps)
Production	79	21
Feeds consumption	72	28
fish meal	26	74
fish oil	15	85

ii) Environmental and social conflicts

Land conversion to ponds, for intensive aquaculture of valuable species, in particular shrimps, has plagued entire coastal areas all over the tropics (e.g. Thailand, Vietnam, India, Ecuador, Nicaragua). The extension of the conversion has been of such an entity to dramatically transform the landscape of entire regions and alter the local ecological equilibrium (Dierberg and Kiattisimkul, 1996; Boyd and Clay, 1998; Nguyen Hoan Tri, *et al*., 1998; Adger, 1999; Wong Chor Yee, 1999; Kautsky, *et al*., 2000). Moreover, this alteration implies the destruction of a coastal ecosystem (mangroves), that plays a crucial role in protecting long term ecologic equilibria (Chapman, 1977; Odum, 1983; Odum and Heald, 1975). This policy, intended to generate hard currency for developing tropical countries, eventually generated intensive social and environmental conflicts. In many cases local inhabitants found themselves deprived of their customary subsistence means (Larsson, *et al*., 1994; Stonich, 1995).

Social conflicts are expected to rise along with the collapse of fish stocks, in particular in developing countries where most of the jobs related to fishing and aquaculture are found. Estimates concerning only small-scale fisheries account for about 100 million people employed in the sector, mostly in developing countries. Large scale fishing on the other hand employs 500,000 people, mostly in developed countries (Pimentel *et al*., 1996). Had fishing activity to be drastically reduced because of fish stocks collapse (as already happening in some locations in the planet), it will dramatically affect the subsistence of hundreds of million of people, mainly located in developing countries, where job opportunities and means of subsistence are already scarce.

iii) Increasing pollution from residual waste waters

Intensive aquaculture is characterised by an high use of inputs in form of feeds, drugs (antibiotics, disinfectants etc.,), and energy to manage the plans (Beveridge, *et al*., 1994; Gomiero *et al*., 1997; FAO, 1996a; Folke *et al*., 1998; Naylor *et al*., 1998). Naylor *et al*., (1998) report that "*The Nordic salmon farming industry discharge quantity of nitrogen and phosphorous equivalent to the amounts in untreated sewage from a population of 3.9 and 1.7 million people, respectively*.", (pg. 884). Faecal, food and urinary wastes are diluted in the enormous quantity of water that this activity required. Estimates are 2-3 hundred thousand m^3 per ton of fish, in trout production in Europe (Beveridge, *et al*., 1994; Gomiero *et al*., 1997).

Such output can cause the degradation of water quality and affect biodiversty of the surrounding environments.

iv) Increasing energy consumption and decreasing efficiency of energy use

High-tech, intensive aquaculture activities are characterized by low energy efficiency (Folke and Kautsky, 1989; 1992; Pimentel *et al*., 1996, Pimentel and Pimentel, 1996; Folke *et al*., 1998).

v) Pest and exotic species spreading to cultured stocks and wild populations

Along with the globalisation process, aquaculture has become a leading vector of aquatic invasive species world wide. In the last decades the spreading of unwanted seaweed, fish, invertebrate parasites, has been a quite common event, causing major environmental damages. It is expected that the rapid expansion of this sector will result in the spread of even more pests. Although their possible environmental impact is difficult to be assessed at this stage, based on the previous cases and the delicate equilibrium that characterises ecosystems, researchers argue that it will be far from negligible (Beveridge, *et al*., 1994; Harvell, *et al*., 1999; Kautsky, *et al*., 2000; Naylor, *et al*., 2001).

vi) Risk related to the use of biotechnology

In the last decade genetic engineering technology has been used in a number of reared species (e.g. salmonids, carps), since it is believed that it will allow for a great improvement of brood stocks: e.g. in boosting fish growth, conferring freeze resistance, viral disease resistance, (Alestrøm, 1995; Zorpette, 1999; FAO, 2000). Along with the mounting concern for the release of genetic modified organisms in the environment, also in the case of aquaculture warnings and concerns have been expressed about the potential ecological risk (Naylor *et al*., 1998; 2000; Zorpette, 1999; Reichhardt, 2000; Marchant, 2001). The possible spread of genetic modified characters, along with the escaping of modified specimens (a very frequent event in real rearing structures), is seen as a serious treat to biodiversity and to the natural environment (Folke and Kautsky, 1989; Beveridge, *et al*., 1994; Naylor, *et al*., 1998; 2000; Zorpette, 1999).

vii) Pressure on fish stocks

As the demand for fish-meal (both for aquaculture and stockbreeding) increases, the cost of fish-meal is likely to rise. This is likely to further stimulate harvesting pressure on wild fish stocks. It has to be pointed out that the increase in the capture of fishery output in the mid 1990s was mainly due to species used for the production of fish meal and fish oil. This is an issue of major concern for notwithstanding continued warnings by scientists, stocks world wide continue to disappear at a frightening rate causing dramatic effects on the marine ecosystems (Folke and Kautsky, 1989; Law, 1991; Pauly and Christensen, 1995; Safina, 1995; Reinertsen and Haaland, 1995; Cook *et al*., 1997; Naylor *et al*., 1998; 2000).

Safina (1995) refers to fishery as a case of "*madhouse economics*", as: "*So to some extent, the economic law of supply and demand controls the cost of fish. But no low says fisheries need to be profitable. To catch $ 70-billion worth fish, the fish industry recently incurred costs totalling $ 124* *billion annually. Subsides fill much of the $ 54 billion in deficit. ... These incentives have for many years enticed investors to finance more fishing ships then the seas' resources could possibly support.*", (Safina, 1995 pg. 34).

In front of all these problems, aquaculture still seems to be an invaluable option to provide a supply of animal proteins in those populations having a diet poor in this key nutrient (Bailey, 1997). This applies to areas densely populated where the resource land is already saturated and where we can expect additional increase in human population in the next century. Actually, production from aquaculture has been to a large extent responsible for the expansion in the availability of food fish since the late 1980s (New, 1997; FAO, 1995; 2000). In fact, fish rearing is advantageous compared to land-raised animal: as fish are suspended in water and are cold-blooded, their consumption of energy is minimal and this improves the efficiency of their production (Brown, *et al*. 1994).

6.2 General characteristics of freshwater fish aquaculture in P.R. China and Italy

6.2.1 Freshwater aquaculture in China

According to historical documents, artificial fish ponds in China were dug as early as 1142 B.C. (Zhao, 1994). During the Western Zhou Dynasty (1066-771 B.C.) there most likely was already some kind of fishery management, as is suggested by the rules on fishery exploitation existing at that time. The treatise on pisciculture "Fish Breeding" dated 475 B.C. and ascribed to Fan Li deals with the spawning of captive carp and proves that fish farming was widely practised in China at that time (Borgese, 1980; FAO, 1980; Zhong, 1992; Li and Mathias, 1994).

Until about 1960, fish culture activities remained dependent on the sources of eggs and fingerlings from natural water bodies in the Yangtze and Pearl river valleys and areas close nearby. In the 60's, artificial spawning of the carp family was first developed and brought into use, in this way widely extending and improving fish culture in China (FAO, 1980). The yearly freshwater fish production has been increasing sharply in China: from 500 thousand tons in 1936 to 1 million tons in 1957, to 2 million tons in 1984, and to 4.2 million tons in 1990 (of which 3.3 million tons from pond fisheries) (Zhong, 1992; FAO, 1993). Production of total freshwater fish reached 6.5 million tons in 1993 (FAO, 1995)

Since the 1980's, China is the largest producer of inland fisheries and aquaculture output (FAO, 2000). Since 1990, it is also the largest fish producer in the world in terms of total production. Policy reforms that were implemented in the country during the 80's have been effective in enhancing the utilization of existing resources and resulted in a substantial increase of yields (FAO, 1980; Smil, 1985; Guan and Chen, 1989; FAO, 1993, PR China MABF, 1995). Nevertheless, to date fisheries are still a negligible sector of China's agriculture, accounting for less than 2% of the total value of agricultural production (Zhao, 1994).

Fish culture in China is practised in any kind of inland aquatic environment, including ponds, lakes, reservoirs, and rivers (FAO, 1980; 1993; Zhao, 1994; PR China MA, 1995; PR

China MABF, 1995) (**Figure 6.1**). Among these water bodies, pond fish culture has the highest productivity with an average production of about 2,400 kg/ha in 1990 (FAO, 1993; Qian, 1994; Chen *et al*., 1995) (**Table 6.2**). As noted earlier, China's aquaculture production accounts for almost half the total world production, and half of the Chinese production is from inland culture of freshwater fish. Chinese carps account for about 80% of this (FAO, 1995; 2000).

Fish polyculture literally means rearing several species of fish in the same water body. As different species have different ecological niches (they feed on different resources), a balanced polycultural system has the potential to reach full resource exploitation of the water body (Lin, 1982; Shan, 1987; Yan and Yao, 1989; Zhong, 1992; Li and Mathias, 1994). The fish pond is an artificial ecosystem (see for instance **Figure 6.1**), where external inputs of feed and fertilizer are important, but where internal characteristics of the managed ecosystem still play a fundamental role in the regulation of matter and energy flows (Li, 1987; Yan and Yao, 1989; Guo and Bradshaw, 1993; Chen *et al*., 1995).

Figure 6.1 *(see p. 113a) Integrated fishpond-agriculture landscape in South China (Pearl River Delta), leaded to this characteristic landscape (source FAO photo database)*

In the Chinese polycultural system, as many as 8 or even 9 fish species can be reared in the same pond in a balanced combination of size and number. Fish farming polyculture is performed at every rearing stage in China (Lin, 1982; Shan, 1987; Zhong, 1992; Li and Mathias, 1994). Generally, between 1 and 3 fish species are reared as principal species, with the other species considered secondary (FAO, 1980; Shan, 1987; Zhong, 1992). The choice of principal and secondary species depends on (i) fish environmental needs, (ii) feed and manure availability, (iii) farming techniques, (iv) pond conditions, and (v) market demand (Lin, 1982; Shan, 1987; Yan and Yao, 1989; Zhong, 1992; Li and Mathias, 1994).

The more important species cultivated in China are silver carp, grass carp, bighead carp and common carp (Yan and Yao, 1989; Zhong, 1992; FAO, 2000). These 4 species accounted for 86% and 80% of the total production in 1990 and 1993, respectively (FAO, 1995). The widespread adoption of these species in ponds and reservoirs throughout China is explained by the following factors (FAO, 1980; Lin, 1982; Shan, 1987; Yan and Yao, 1989; FAO, 1992; Zhong, 1992; Li, 1994):

i) Favourable feeding habits and ecological characteristics. Silver carp and bighead carp are filter-feeding (the former on phytoplankton, the latter on zooplankton), grass carp feeds on macrophyte and common carp feeds on organic material on the bottom. Hence, these species feed low in the food chain and rely on natural processes taking place within the waterbody for their feed. (See **Figure 6.3** for a comparison with the Italian production system). These species can therefore be produced through fertilization programmes that utilize local resources with little or no supplementary feed. These species have a short growth period and are easy to feed and harvest;

ii) Simple technologies for artificial breeding;

iii) Minimal requirements of capital inputs and technologies both for fry and fingerling rearing and for growing them to marketable fish; production techniques in polyculture tend to create a natural-like pond environment that imitates as much as possible the

Figure 6.1. *Integrated fishpond-agriculture landscape in South China (Pearl River Delta), leaded to this characteristic landscape (source FAO photo database)*

complex trophic structure with links between environmental resources, microorganisms, plants, herbivores, consumers and top predators.

6.2.2 Freshwater aquaculture in Italy

Ancient Romans, some centuries B.C., were familiar with methods of captive breeding of some species in small ponds: Remains of ancient fish breeding ponds can still be seen at Pola lake near Rome (De Murtas, 1993). Plinio, a roman writer 100 B.C., provided examples of well-managed ponds (CENASAC, 1987). Information on fish captive breeding in the Venetian lagoon can be traced back to 1,200 B.C. (De Murtas, 1993). Clearly, this was a form of extensive aquaculture. Fingerlings arriving from the open sea in springtime were trapped in basins ("*valli*") of the lagoon by artificial dykes. Much attention was paid to avoid overstocking and over-exploitation of environmental resources to avoid a disruption in the natural trophic chain (De Murtas, 1993).

In the Middle Ages, aquaculture underwent great development particularly in the Veneto region. The more important inland freshwater fish species were the common carp (*Cyprinus carpio*), tench (*Tinca tinca*), pike (*Exos lucius*) and trout (*Salmo trutta, Salmo gairdneri*). mullet (*Mugillidae* genus), eel (*Anguilla anguilla*), sea bream (*Sparus auratus*), and mediterranean bass (*Dicentrarchus labrax*) were exclusively reared in the "valli" of the Venetian lagoons (De Murtas, 1993).

Intensive aquaculture of the common carp and trout is first observed in the second part of the 19th century (CENASAC, 1987). In fact, by the 1960s aquaculture had changed from extensive to semi-intensive and finally to intensive practices (Melotti et al., 1994). In 1993, intensive aquaculture accounted for nearly all of the total freshwater fish production (Melotti et al., 1994). Due to the geographical characteristics of the Italian peninsula and its cultural traditions, marine aquaculture of molluscs (*Mytilus galloprovincialis*, *Ostrea edulis*) is the most developed kind of aquaculture in Italy (FAO, 1995). Italy has 150,000 ha of lagoons, 170,000 ha of inland freshwater basins and plenty of spring water potentially available for brackish and fresh water production. Among the European countries, Italy has probably the most favourable conditions to develop aquaculture (Melotti *et al*., 1994).

Intensive monocultural systems account for nearly all of the production of freshwater fish in Italy (Ghittino, 1983; Giordani and Melotti, 1984; De Murtas, 1993; Melotti et al., 1994). Artificial tanks are the major freshwater bodies in use. In artificial tanks the water flux is maintained constant by electric pumps and oxygen is continuously insufflated in the water (Ghittino, 1983; Giordani and Melotti, 1984) (**Figure 6.2**). Often, medium and large fish farms have also their own hatchery (Melotti *et al*., 1994).

Figure 6.2 *(see p. 114a) High tech intensive trout culture in Europe*

Italian intensive monocultural systems rely on carnivorous fish species for 85% of its production (**Figure 6.3** for a comparison with the Chinese system). A single species (trout) accounted for about 70% of the total production of freshwater fish, while the top-two species (trout and eel) together accounted for 77% of the total (Melotti, 1994; FAO, 1995). Trout and eel are carnivorous fish that are fed with industrial pellets with a high animal protein content

***Figure 6.2. H**igh tech intensive trout culture in Europe*

(about 40%) (Ghittino, 1983; Giordani and Melotti, 1984; Watanabe, 1986; Cho *et al*., 1994). Industrial pellets are made up mainly of fish meal obtained from marine catch (Watanabe, 1986). The conversion ratio of dry (marine) fish meal feed into wet fish biomass (the output of aquaculture) is 0.5 (kg/kg). Considering that 0.5 kg of dry fish meal used as feed in freshwater aquaculture requires 5 kg of fresh marine catch, we find that 1 kg of wet fish weight produced in this way requires 5 kg of fresh marine catch (Colombo, pers. com., 1996). Industrial pellets are used as feed for all species produced under intensive and semi-intensive culture. Manure and chemical fertilizers are used only in some semi-intensive and extensive production systems, while in some extensive water bodies (e.g., lagoons) no inputs are used at all (Giordani and Melotti, 1984; Perolo, pers. com., 1996).

6.2.3 Patterns of trophic niche exploitation

Feeding habits of species reared in China and Italy are compared in **Figure 6.3**.

Figure 6.3 *(see p. 115a) Distribution of biomass of the freshwater fish production in aquaculture according to the feeding habits of the species (from Gomiero, et al., 1997, modified)*

As noted earlier, Chinese production relies on species which feed low in the food chain: planktivorous, herbivorous and bottom organic detritus feeders (Li, 1987; Shan, 1987; Zhong, 1992; Li and Mathias, 1994). In 1993, phytoplanktivorous and macrophyte eating species accounted for about 63% of total Chinese production, zooplanktivorous species for about 14% and benthivorous species (feeding on organic detritus or bottom fauna) for about 21% (FAO, 1995).

Since only about 10-20% of energy from a trophic level can be converted into body mass of organisms belonging to the higher trophic level (Odum, 1983), the principal aim of fish culture in China is to enhance the utilisation of biological resources by keeping the food chain short. In this way it is possible to achieve a high efficiency in utilizing biological conversions within the ecosystem (Li, 1987, 1994; Zhong, 1992).

Italian production, on the other hand, relies almost exclusively on carnivorous species. Fishes feed on industrial pellets the protein content of which comes mainly from fish meal. With this solution the trophic chain becomes a step longer and the energy efficiency of the trophic chain is reduced by 80-90%. When we compare the tropic pyramid of the two productive systems with the flow of energy in natural fresh water systems, as in **Figure 6.4**, in structure Note that in high-tech intensive production system, protein-rich feeds are given also to those species that do not need it, such as common carp (Watanabe, 1986), to speed up their growth. In fact, under natural conditions this species feeds on bottom invertebrates and organic detritus.

Figure 6.4 *(see p. 115b) Energy flow along the trophic pyramid in a natural fresh water system (after Schmitz, 1995, modified)*

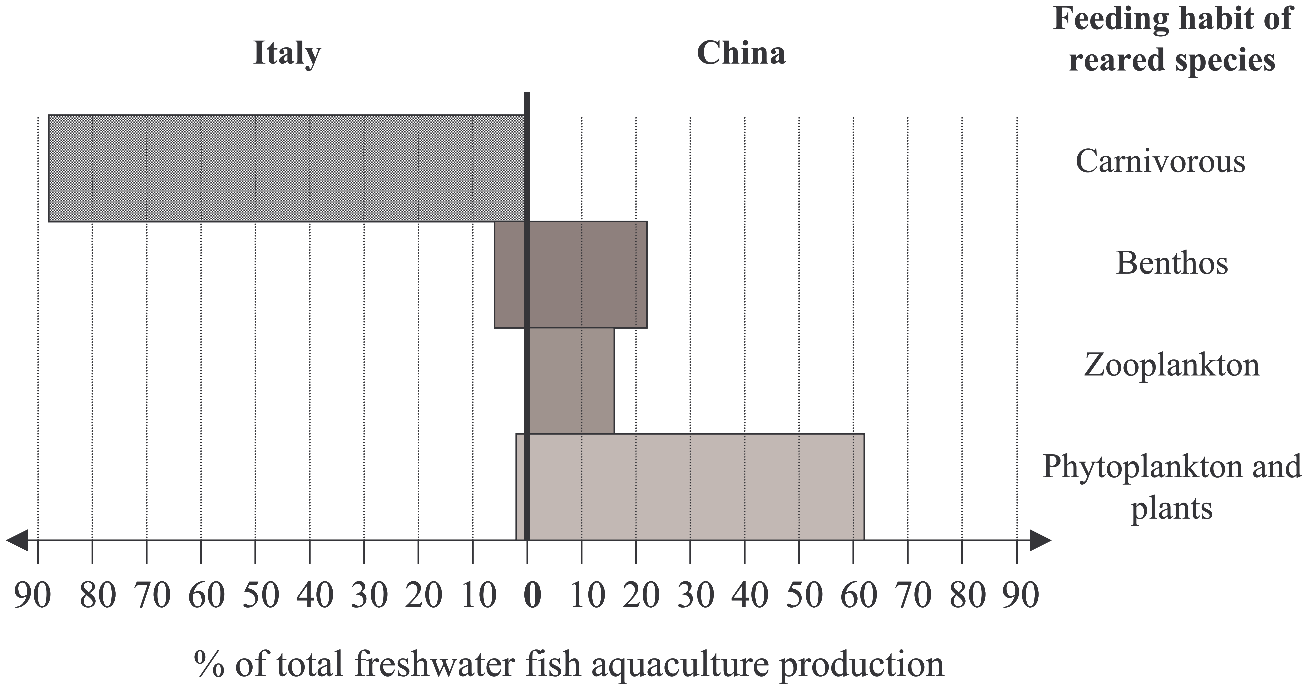


Figure 6.3 *Distribution of biomass of the freshwater fish production in aquaculture according to the feeding habits of the species (from Gomiero, et al., 1997, modified)*

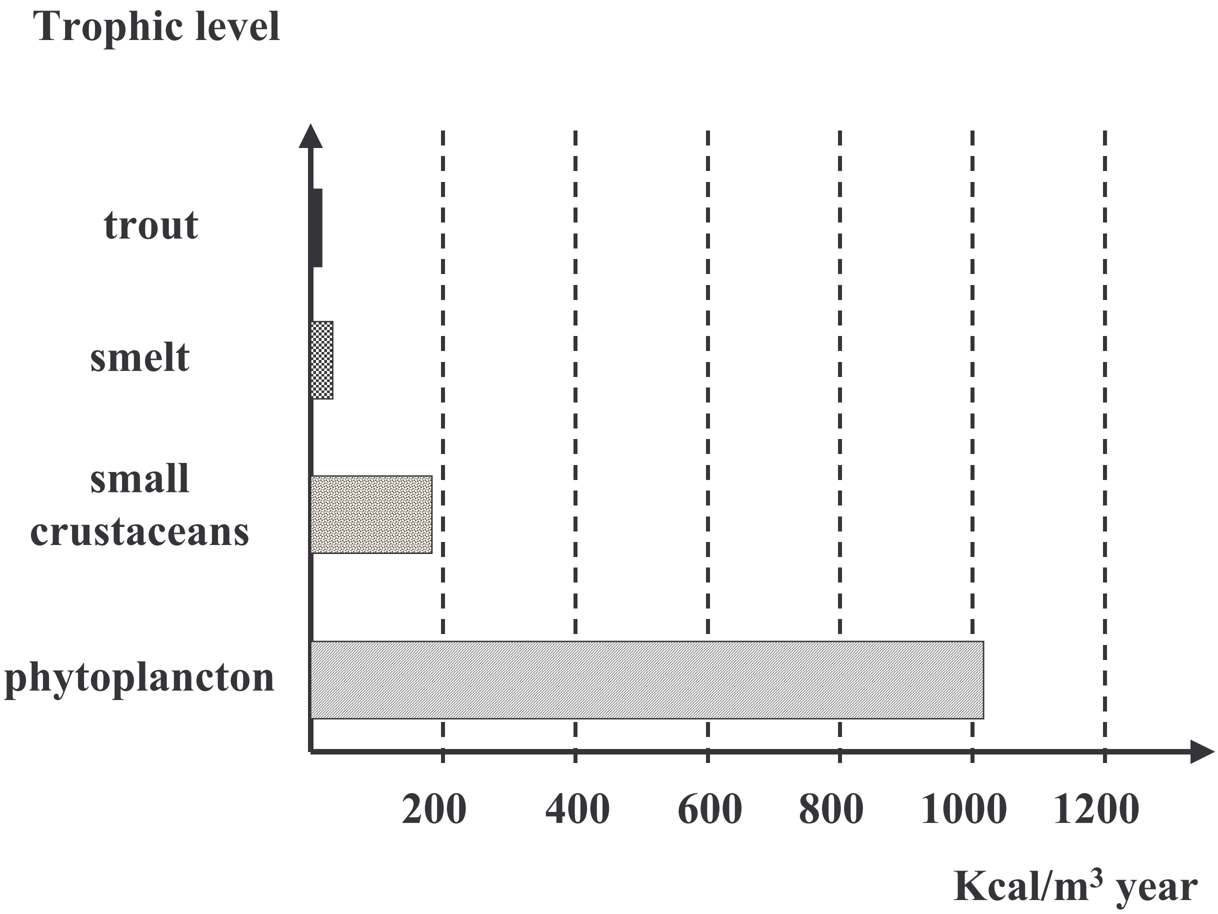


Figure 6.4. *Energy flow along the trophic pyramid in a natural fresh water system (after Schmitz, 1995, modified)*

6.3 Comparative Multicriteria analysis of aquaculture farming system: technological efficiency versus ecological function

The purpose of this section is that of: (a) establishing links between the socio-economic view and the ecological view of the performance of the production process, (b) putting the characteristics of a productive system in perspective with its larger context; and (c) discussing about trade-offs that different development strategies imply.

We will focus on the integrated characterization of two typologies production:

- ***Traditional Polyculture (carp) in P.R. China.*** It accounts for about 80% of world total inland fish aquaculture production (FAO, 1999a; 1999b). It has an important role in food production and food security in the considered socio-economic context. Coming to the relation with the ecological context, this system relies very much on ecological cycles and on recycling feed from the parallel agriculture activity (Lin, 1982; Guo and Bradshaw, 1993; Li and Mathias, 1994).

- ***Conventional market-driven intensive aquaculture (trout) in Italy***. It represents the common system of production in use in Europe, and in general in developed countries (Giordani and Melotti, 1984; Barnabé, 1990; Gomiero et al., 1997). Market mechanisms strongly affect the viability of these systems of production. The fish output has no longer the meaning of animal protein in shortage, needed to feed people. The future development of the sectors will have to rely on further increase in productivity (increase in the use of technology and energy consumption) and on marketing strategies (it is to say, being able to track additional meaning given by consumers to the produced fish output).

6.3.1 Using a Multicriteria approach as analytical tool

We present a model of integrated assessment of freshwater fish aquaculture providing a Multi-Objective Integrated Representation following the approach presented in Part 2. Such a characterization can be tailored on different socio-economic and ecological contexts (in this example the analysis is applied to the specific context provided by China and Italy). The goal of this approach is that of characterizing the techniques of production by: (a) taking into account the existence of non-equivalent constraints affecting the feasibility of the productive process (the existence of relevant but non-reducible dimensions of viability such as economic, technical, ecological); and (b) putting in perspective the resulting integrated assessment with the different socio-economic and ecological contexts in which aquaculture is performed (benchmarking). This is obtained by establishing a link between a description of production techniques, at the local level, and a description of the characteristics of either the socio-economic or the ecological context at a larger scale (the aggregate availability of human labour, quality of economic and natural resources, requirement of economic and natural capital, the impact of the productive system on the environment) - Giampietro, (1997a; 1997b; 2004). The integrated assessment is therefore based on a combined use of: (i) intensive variables (technical coefficients); and (ii) extensive variables (aggregate demand of technical, natural capital referring to the scale of operation of the basic element of production -e.g. farm, cooperative).

6.3.2 Choice of criteria and indicators and graphic representation for the MOIR

Criteria and indicators are chosen reflecting relevant characteristics of the system, that cannot be expressed in relation to each other (an integrated analysis relies on indicators which come from models of reality that are *non-equivalent* and *non-reducible*) - Rosen, (1991), Giampietro (2004).

Once a set of indicators has been chosen and the relative methods for quantification established, we can move to identify specific ranges of feasibility that we can expect for their values. That is we can imagine a "*viability domain*" for the values that can be taken by each indicator against which the specific values taken when considering a specific production system can be compared. For example the "viability domain" can be obtained considering the minimum and maximum value found for each indicator at regional, national or world level (e.g. average economic return of one hour of labour can go from 0.1 US$ to 30 US$).

Note that although numerical "values" can have an "objective" nature (e.g. the concentration of a chemical in the soil or food), that is they can be measured by technical means, the "feasibility" of values can only be defined by considering the perception of the stakeholders. It is to say the social "acceptance" of a given performance is always context and culturally dependent. A wage of one dollar per hour can be perceived as a great achievement – as a very good economic performance - by a farmer in a developing country, but the same value would be unthinkable to accept by a farmer in a developed country.

To avoid repetition and overlapping of information we wish to present the chosen criteria and indicators along with the graphical representation of the MOIR model. We wish to underline that the purpose of this work is that to present a model of integrated analysis, that we think useful to better deal with the complex issue of farming system analysis and multicriteria evaluation. Criteria and indicators that follows have been selected by the author. Further details are given along with the presentation that follow, when introducing the list of indicators used in the various MOIRs.

I still wish to stress that the quality of the analysis depends on: i) an adequate choice of the set of relevant criteria and indicators; ii) the ability of measuring the selected indicators of performance; and iii) an adequate understanding of the existing relations among them.

In this section, two different forms of graphic representation – MOIR – of the two system of production considered, are adopted. The two forms are used to deal with two different levels of analysis (local, national).

(1) a MOIR for the household typology. This refer to the local level, and it is based on a radar diagram crossed by two diagonal axis (**X** shape).

(2) a MOIR used to relate the characterization at the local level to the national context. This is based on a radar diagram crossed by two perpendicular axis (+ shape).

Both graphic representations include a reference system, against which the values taken by selected set of indicators are confronted.

In the examples provided below the viability domain, it is to say the range of possible values, of each indicator is divided in three quality zones (the question of data normalization has been discussed in section 5.4 in Part 2): (1) The inner dark-grey zone describes a "bad" system performance, (2) the light-grey median zone describes a "medium" system performance, and (3) the external zone describes "good" system performance.

It has to be recalled here, that the MOIR presented here has the only goal to make possible the handling of information referring to non-equivalent descriptive domains (e.g. handling heterogeneous indications of performance related to different dimensions of analysis). In spite of having a "quality indication" assigned to the value of each indicator, in term of overall multicriteria assessment such an approach does not carry any normative aspect. The quality assigned to the value of each indicator has the only goal of determining a shared meaning about the integrated representation. For this reason it is crucial that the stakeholders are involved in the preliminary step of definition of the MOIR. This is crucial to avoid having later on misunderstandings and systemic bias associated with the choices made in the selection of a given MOIR, in relation to the evaluation and selection of policies, ranking of options, selection and assessment of scenarios.

6.3.3 MOIR – at the local level for China and Italy – system of production

MOIR at the local level can be used to characterize a typology (or typologies) of farm and farming systems. Obviously, as noted earlier socio-economic and environmental constraints posed by the context do restrict the typologies which can result viable at the local level. For instance farming salmon in a developed country, to be viable, implies to operate within a specific range of values for different indicators - e.g. a minimum threshold on labour productivity, which translates into the need of adopting high-tech - energy intensive – techniques of production. This in turn brings in an additional economic constraint. Producers must be able to break even in economic terms, in relation to the consequent high level of capital investment. This implies that because of the various linkages among technical coefficients and economic aspects (e.g. productivity, economic return from investment, energy use) farming salmon cannot be done in an infinite number of ways. On the opposite, we can expect that because of this internal links a rather limited number of options are possible for a local entrepreneur within a given market context and a given ecological context.

Let's now consider the various indicators used in this MOIR, they are divided into 4 sectors (**Figure 6. 5**). Data concerning the sets of indicators are given in **Table 6.2**.

NORTH - Return on investment (Intensive indicators). This criterion provides (and requires) a set of indicators of performance based on output/input ratio

- *Product Output/hr (kg h^{-1})* - biophysical output per unit of investment of labour.
- *Output/ha of water body (kg ha^{-1} $year^{-1}$)* – output per unit of investment of land.
- *Productivity per unit of volume of water body (kg m^{-3} $year^{-1}$)* – output per unit of investment of water.
- *\$ Output/hr (US\$ h^{-1})* – added value per unit of investment of labour.
- *% Economic Return On Investment (US\$/US\$)* – economic return per unit of economic investment.

SOUTH - Requirement of investment at the productive unit level (Extensive indicators)

- *Total Work Supply (working hours $year^{-1}$)* - The total amount of working hours required by the activity at farm level, to run a given farm typology (at a viable productivity level).

- *Total Land in Production (ha)* - The total amount of hectares required by the activity at farm level, to run a given farm typology (at a viable productivity level).
- *Total Freshwater consumption (m^3 $year^{-1}$)* - Fresh water consumption in the rearing process is an indication of the demand on the environment generated by the specific typology of productive system.
- *Total Fossil Energy Invested (kcal $year^{-1}$)* - The amount of fossil energy (in kcal) spent in the various inputs consumed in the production process (e.g. electricity for pumping water and the functioning of the plant, for making available pellets, embodied in administered drugs and other chemicals, plus the building and maintenance of equipment). This can be assumed to be a proxy of the technical capital requirement.
- *Total Economic Investment (US$ $year^{-1}$)* - Fixed and circulating capital invested in the building and maintenance of the farm as well as to run the activity.

EAST - Indicators assessing environmental stress

- *Chemicals-drugs applied (kg $year^{-1}$ ha^{-1} or m^3 of water body)* - Quantity of drugs (e.g. antibiotics) that are release into the environment (because of different composition and environmental effects of the different sort of substances, a proxy have to be used)
- *Nitrogen residuals in water waste (kg $year^{-1}$ ha^{-1} of water body)* - Nitrogen in residual feed and excreta (e.g. in ammonia) that is release into the environment.
- *Index of stress on Biodiversity* - Biodiversity is rather complex a concept that is difficult to express with numerical indicators. Here we simply adopt an index based on the number of species cultured together in an individual process of fish production. Although arguable, this proxy for 'biodiversity use' is useful. As each species relies on its own ecological niche, the number of species cultivated together in a defined water body provides an indication of the complexity of the system of natural controls involved in the process.

WEST - System Openness (techno-boosting)

- *% of total feed energy imported* - This is a proxy of the dependency of the aquatic system of production on external inputs (e.g. wild stock of fishes in the oceans, by-products from animal processing, crops). This indicator assesses the relevance that local ecological services play in stabilizing the actual production.
- *Nitrogen input/output (imported/exported*) - This is another proxy of the dependency of the productivity on external inputs (proteins): nitrogen imported in feeds and exported and fish.
- *Fossil energy input/fish energy output ratio (kcal $kcal^{-1}$)* – This is a direct assessment of the dependency on fossil energy. The input equals the amount of fossil energy (in kcal) spent in the making of the various inputs consumed in the production process. The fish energy output measures the energetic value of the produced fish.

Table 6.2 *(see p. 120a) Criteria and indicators for an Integrated Representation of technical performance of the productive system*

See Technical Annex for details about the figures.

Figure 6.5 *(see p. 120b) MOIR at farm level (referring to freshwater aquaculture)*

6.3.4 MOIR – contextualizing the production in relation to the socio-economic and ecological dimensions – China and Italy

The MOIR establishing a relation between the characteristics of the system of production and the characteristics of the socio-economic and environmental context is divided in four quadrants (**Figure 6.6**). The quadrants on the ***left-side*** represent the technical characteristic of the production system in relation to the socio-economic variables: the upper quadrant referring to indicators at farm level, the lower quadrant referring to indicators at national level in which the farm is to operate. The quadrants on the ***right-side*** represent the technical characteristics of the production system in relation to the ecological and environmental variable: the upper quadrant referring to biophysical constraints on productivity, the lower quadrant referring to factors affecting the resilience /stability of the system (resilience is the ability to recover from stressor events – e.g. natural disasters, sudden collapse of the price of a market commodity. Stability is the ability to resists to stressor events – e.g. rising cost of inputs or decreasing market prices for crops). The relative importance of these characteristics obviously will change depending on the technological and economic characteristics of the context in which the farm is operating. This sort of information is important because it introduces a very relevant dimension that has to be considered by decision makers. The dimension concerns risk management (be it economic – e.g. debt -, biophysical, - e.g. loss of natural capital -, or social – e.g. social identity).

LEFT- SIDE

UP - Environmental pressure

- *Availability of cropland per capita (ha capita^{-1})* - This is proxy of the pressure on the existing resources, at the country level. When coupled with other indicators such as GNP per capita, energy use at national level it is possible to infer from these indicators a sort of threshold constraints on the levels of productivity of a farming systems (e.g. elevated productivities both per hectare and per hour of labour). That is, high demographic pressure or a high level of economic activity assessed at the national level imposes additional limitations on possible productive options at the local level.
- *Environmental loading (GJ ha^{-1})* - The level of fossil energy flow that are applied to the environment per unit of area can be used as a proxy of the level of disturbance implied by human activity on ecological processes. It can be accounted for by aggregating an assessment of inputs (fertilizers, pesticides, machinery, irrigation etc.) in fossil energy equivalent per unit of landscape.

Table 6.2 *Criteria and indicators for an Integrated Representation of technical performance of the productive system (see Annex for details about the figures)*

Criteria and Indicators	*P.R. China*	*Italy*	*Possible range Min.-Max.*
Return per unit of production factor (Intensive indicators)			
Output per hour of work (kg h^{-1})	1	50	0.1-50
Output/ha of water body (kg ha^{-1} $year^{-1}$)	2,400	80,000	400-100,000
Productivity per unit of volume of water body (kg m^{-3} $year^{-1}$)	0.15	35	0.05-40
Output per MJ fossil fuel (MJ MJ^{-1})	0.1	30	1-30
% Economic Return On Investment (US$/US$)	2	6	1-10
Requirement of investment of production factors (Extensive indicators)			
Total Work Supply (working hours)	1,200	5,400	500-6,000
Total Land in Production (ha)	0.5	1	0.2-2
Total Freshwater consumption (m^3 $year^{-1}$)	$7\ 10^3$	$16\ 10^6$	10^3-10^6
Total Fossil Energy Invested (kcal $year^{-1}$)	$\approx 2\ 10^6$	$\approx 10^9$	0-10^{10}
Total Economic Investment (US$ $year^{-1}$)	800	150.000	0-200.000
Indicators assessing environmental stress			
Chemicals-drugs applied (kg $year^{-1}$ ha^{-1} of water body)	≈0	5	0-5
Nitrogen residuals in water waste (kg $year^{-1}$ ha^{-1} of water body)	≈0	≈30,000	0-30,000
Biodiversity (no. of species)	6 (4-9)	1	1-10
System Openness (technoboosting)			
% of total feed energy imported	35	100	0-100
Nitrogen input/output (imported/exported)	2.5	30	1-30
Fossil energy input/fish energy output ratio (kcal $kcal^{-1}$)	0.1	30	1-30

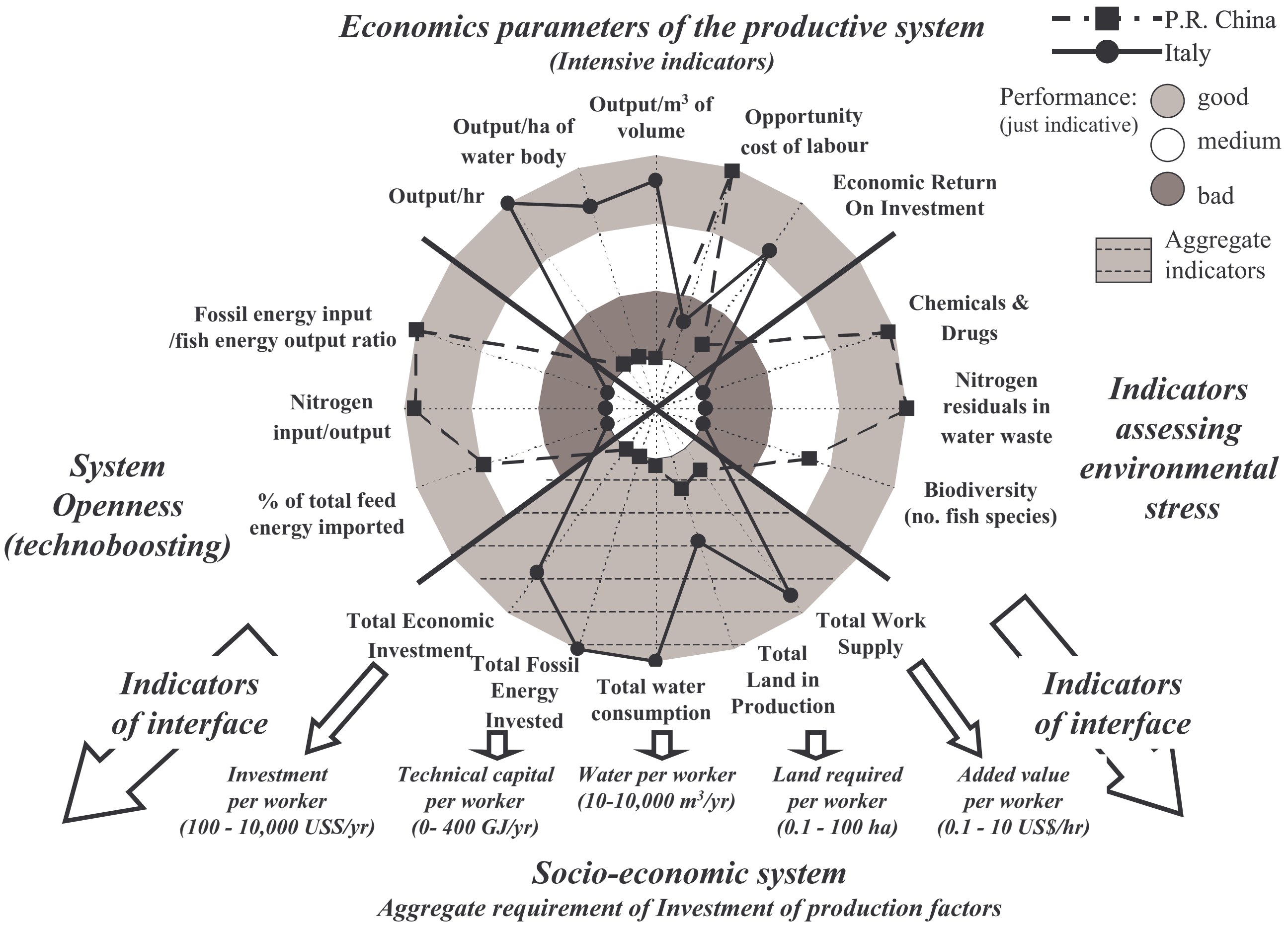


Figure 6.5. *MOIR at farm level (referring to freshwater aquaculture)*

- *Nitrogen use in agriculture (kg year^{-1} ha^{-1})* - It is a proxy for the boosting of the natural cycles of nutrients. High level of nitrogen are related to pollution (e.g. nitrates in the ground water), and increased stress on the ecosystem (e.g. disturbance to soil fauna).

DOWN - Social system buffering ability

- *% of the income (year basis) expenditure on food* - This indicator shows the relevance of activities non-related to food security in the organization of a society. The lower the fraction of the income spent in food, the lower is the preoccupation of food security in shaping the activities of a socio-economic system.
- *Role of trade in food system (% of consumption from import)* - This is an indicator referring to the level of dependency from external sources of food and therefore related to the protection against possible biophysical constraints affecting food supply.
- *Relevance of minimisation of risk in the definition of productive strategies (qualitative)* - This indicator points at the crucial criteria "minimization of risk" that wherever has a certain priority can imply a total re-discussion of other criteria (including that of maximization of return). This is one of the most important difference between farming systems operating within developed or developing countries.

RIGHT SIDE

UP - National Socio-economic level

- *GDP per capita (US\$/ capita year^{-1})* - A classic indicator of economic activity, with important implications on the presence of thresholds on economic parameters at the local level;
- *% of total labour force in agriculture (%)* - An indicator of economic development, with important implications on the availability of labour supply at the farm level;
- *% of protein from animal source in the diet (%)* - An indicator dealing with the actual quality of the diet, and possible shortages of nutrient supply at the national level.

DOWN - Household Socio-Economic Context

- *Biophysical Productivity of Labour – Biophysical Output/hour (kg hr^{-1})* - This is an indicator of biophysical labour productivity. It is related to the ability to control and boost natural cycles in the agro-ecosystem by applying technical inputs.
- *Economic Productivity of Labour – Economic Output/hour (US\$ hr^{-1})* - This is an indicator of economic labour productivity. It can be used to compare the relative economic performance of different sectors of the society (e.g. how the agricultural sector is doing compared with other sectors). It can also be used to compare the performance of a particular system of production with others or to compare a given level of Economic Productivity of Labour with the average value of a given society (a sort of opportunity cost of labour in that society).
- *% of the income in agriculture from subsidies (%)* - This indicator points at the role that the agricultural sector plays in an economy. High-subsidized agriculture means that farmers

and systems of production would not be economically viable if let to themselves. Completely different is the situation of farmers that not only have to produce for their subsistence, generate a cash flow, but also pay taxes to the government.

Table 6.3 *(see p. 122a) Integrated representation of production system in relation to the socio-economic and environmental context at national scale*

See Technical Annex for details about the figures.

Figure 6.6 *(see p. 122b) MOIR in freshwater aquaculture in relation to socio-economic and environmental contexts*

6.4 Integrated analysis of the two typologies of production

This section provides comments on the data presented in **Table 6.2** and **Table 6.3** and **Figure 6.5** and **Figure 6.6**, focusing in particular on the characteristics patterns that characterise the different system of production (their relation with the socio-economic system and environmental context both at local and national level).

Before it, however, it is important to provide the reader with an additional piece of information useful for a better comprehension of the information. This is related to the different level of demographic pressure on natural resources in the two systems.

6.4.1 Chinese polycultural integrated system

(1) General overview of the farming system typology

Fresh water aquaculture in China relies mostly on fish polyculture (Shan, 1987; Li and Mathias, 1994; Zhong, 1992). Polyculture means the rearing of several species of fish in the same water body, generally ponds. As noted earlier, as many as 8 or even 9 fish species can be reared in the same pond in a balanced combination of size and number. One to three species are reared as principal species, with the other species considered secondary. The four more important species reared in China are: silver carp, bighead carp (filter-feeding, the former on phytoplankton, the latter on zooplankton), grass carp (herbivoral feeding on macrophites), and common carp (feeding on organic material on the pond bottom).

In the 1990s these four species accounted for about 80% of the production (FAO, 1999a). These species can be reared with simple technologies and minimal requirements of capital inputs and technologies both for fry and fingerling rearing and for growing them to marketable fish.

As different species have different ecological niches (they feed on different resources), a balanced polycultural system has the potential to reach a very wide resource exploitation of the water body. This production system is based on the long historical co-evolution of Chinese farmers with their environment polyculture (Shan, 1987; Li and Mathias, 1994; Zhong, 1992). The fish pond is an artificial ecosystem where external inputs of feed and fertilizer are important, but where internal characteristics of the system still play an major role (Li, 1982; Chen *et al*., 1995; Gomiero *et al*., 1997). In **Table 6.2** are listed sets of indicators for different

Table 6.3 *Integrated representation of production system in relation to the socio-economic and environmental context at national scale (see Annex for details about the figures)*

Criteria and indicators	*P.R. China*	*Italy*	*Possible range* [GP] *Min.-Max.*
Environmental pressure			
Cropland per capita (ha capita^{-1})	0.1<	0.16	0.1-5.0
Environmental loading (GJ ha^{-1})[GP]	50	85	0-100
Nitrogen use in agriculture (kg year^{-1} ha^{-1})[N]	300[b]	300[EE]	0-350
System buffering ability			
% income expenditure on food	20[P]	7	6-60
Trade in food security economy (% of consumption)	0	40	0-50
Relevance of minimisation of risk	Very high	Low	Low-very high
National Socio-economic level			
GDP per capita (US$/ capita per year)*	470	21,050	100-36,000
% of total labour force in agriculture[G]	65	7	4-70
% of protein from animal source[G]	24	54	15-70
Household Socio-Economic Context			
Output/hour (kg hr^{-1})	1	50	0.1-50
Economic Labor Productivity in agriculture (US$ hr^{-1}) [G]	0.25	8	0.1-10
% of the income in agriculture from subsides	0	40	0-100

*World Bank; (C): Maximum amount based on intensive rice culture in China (Jing *et al*., 1999); (N): At about 400 kg per ha nitrogen becomes toxic to the soil; (a): Jing *et al*. (1999); (b): Kuangfei, *et al*., (1999); (EE) assuming an average for European estimate; (P): Pastore *et al*., (1999); (GP): Giampietro and Pastore, (1999).

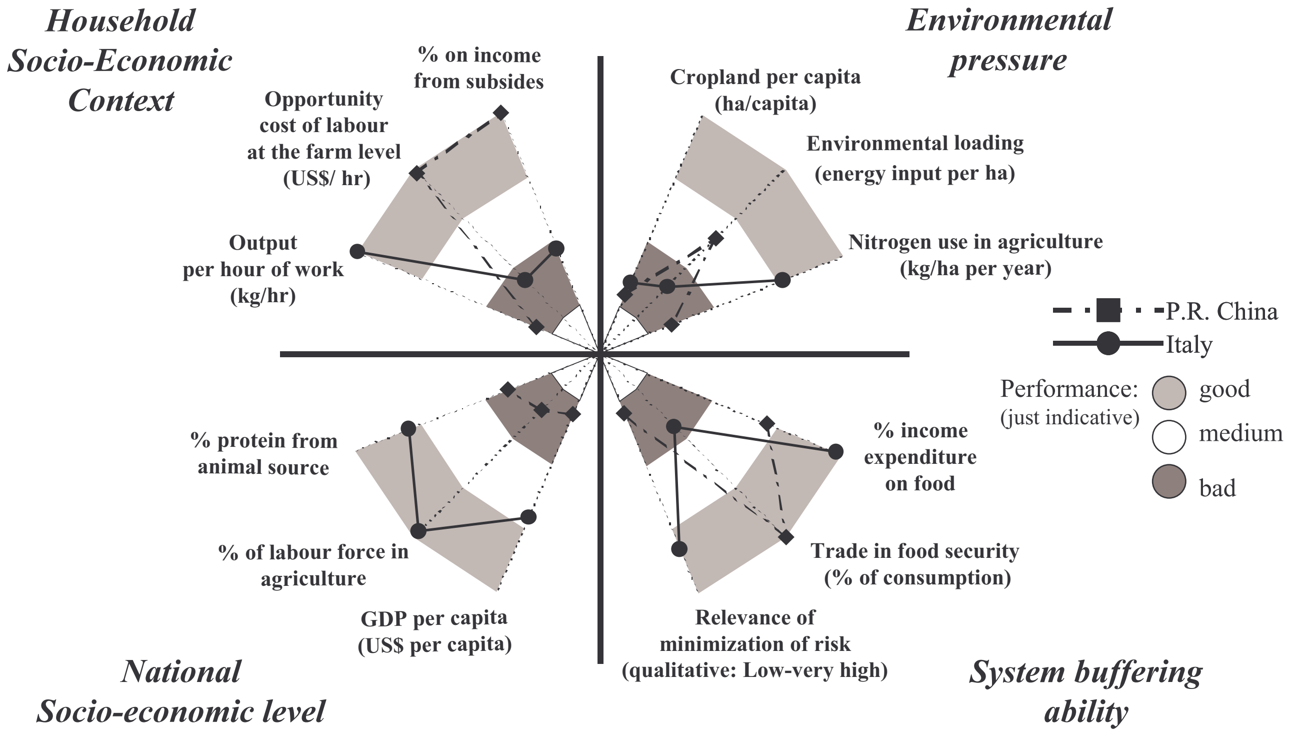


Figure 6.6. *MOIR in freshwater aquaculture in relation to socio-economic and environmental contexts*

criteria, and relative figures representing the technical performances of this typology of productive system.

In **Figure 6.5**, these indicators are graphically represented against references values so to inform about their relative performance.

(2) Basic characterization of production typologies

The species reared feed low in the food chain and rely on natural processes taking place within the waterbody for their feed. They have a short growth period and are easy to feed and harvest. These species can be produced through using (recycling) local resources with little or no supplementary feed imported from elsewhere.

(3) System's main goals

Integrated fish farming has been developed to fully utilize the scarce natural resources available (both land and feeds), taking advantage of cheap labour, and are characterized by a low demand of technical and economic capital. Human intervention is aimed at establishing a human-managed, but almost self-sufficient aquatic agro-ecosystems. External inputs are represented by wastes which are recycled in a way such to increase the food supply of a precious source of proteins in a context in which protein are scarce for the people. Labour productivity is low (compared with the standard of developed countries), but this is not a problem since the low level of economic development of rural areas implies a low opportunity cost of labour.

(4) Overview of pros and cons

Pros

i) Minimal requirements of capital inputs and technologies both for fry and fingerling rearing and for growing them to marketable fish. Aquaculture is integrated (to different extent) with agriculture activity, and labour can be supplied in periods of low labour demand.

ii) High efficiency on energy and food input/output (0.1<), low environmental impact.

Cons

i) Low productivity of labour and land when compared with intensive management options. This low productivity is linked to the limited speed of natural production cycles.

ii) Sensitive to environmental adversities (high risk).

(5) An overview of the socio-economic context

Since the early times in China, aquaculture has co-evolved as an integral part of the agriculture (Li and Mathias, 1994). Fresh water fish represented for farmers a precious source of animal proteins, poorly present in their rice based diet. At present about 2% of the protein consumption come from aquaculture (FAO, 1996b; Gomiero *et al*., 1997). It is to be noted that that this figure is an average that does not account for the large regional differences that are present in a country of the dimension of China (Zhao, 1994). In China aquaculture is marginal in terms of trade volume but it is strategically important in biophysical and economic terms. The economic performance of fish farming, as that of the agriculture sector, are in fact similar to that of the Chinese national average, making agriculture and fish farming still a relatively convenient activity in economic terms. **Table 6.3** presents sets of indicators about the socio-economic and environmental context at local and national scale within which the productive system operates.

Again the figures relative to the sets of indicators are graphically represented against references values in this case for the national level (**Figure 6. 6**).

6.4.2 Italian market-driven intensive aquaculture

Here we will give an account of the main characteristics of the Chinese polycultural integrated system.

(1) General overview of the farming system typology

In Italy aquaculture activity is mainly characterised by intensive monocultural production. A single, carnivorous, species is reared in artificial tanks, where it is stocked at high density (Melotti *et al*., 1994). Such intensive system requires high investment both in term of capital and energy inputs. Italian productive system rely on carnivorous fish species for 85% of their production with trout accounted for about 70% of the total production of freshwater fish (Melotti *et al*., 1994). Carnivorous fishes are fed with industrial pellets with a high animal protein content obtained from marine catch (from 20 to 50% of the total) (Giordani and Melotti, 1984; Cho *et al*., 1994; Nylon *et al*., 2000), (Table 6.3 and Figure 6.6). In Figure 6.5, these indicators are graphically represented against references values so to inform about their relative performance.

(2) Basic characterization

Artificial tanks are the major freshwater bodies in use. In artificial tanks the water flux is maintained constant by electric pumps and oxygen is continuously added to the water. Carnivorous species are reared at very high density (they are preferred because of both cultural and taste reasons). Fishes feed on industrial pellets, whose protein content comes mainly from fish meal, which implies a reduction in energy efficiency of the trophic chain of 80-90%. Drugs have to be used to prevent the outbreak of infectious disease, highly probable in monoculture (both of plants and animals species). The local environment still directly provides some services, such as water and support for the tank however input such as feeds and management are all external to the system.

(3) System's main goals

This productive system has the main goal of generating added value and job opportunities. Farm owners have to compete to stay alive (and possibly grow) in the market. To gain market share and increase profit, producers are pressured to reduce production costs and to follow the wants of potential consumers. Given the high cost of labour in developed countries, manpower represents a main burden for the overall economic efficiency of the production system, that is to say that an increase in the productivity per hour of work in the fish farm is one of the top priority. High investments in the equipments are therefore required to maintain at a minimum the numbers of workers.

(4) Overview of pros and cons

Pros

i) Very high productivity of the labour (kg per hr)

ii) Control on the various production steps

Cons

i) High environmental impact. High amount of freshwater required. High amount of waste products: residual feed, excreta (e.g., ammonia), drugs and other chemicals, pathogenic bacteria and parasites. High demand of fish meals, increases the pressure on wild stocks.

ii) Risk of spreading epidemics;

iii) High requirement of capital and high requirement of fossil energy;

iv) Low energy efficiency. Low output/input for global food conversion (about 1 kg of wet fish weight produced in this way requires 5 kg of fresh marine catch). Low input/output for global energy conversion (25-45/1).

(5) An overview of the socio-economic context

In Italy fresh water fish plays a marginal role in the diet, both from nutritional and cultural view (just 0.4 % of the total protein consumption). About one third of the trout production (nearly a quarter of the total fresh water fish production) is destined to sport fishing (Colombo personal comm.), which is a much more profitable activity than the selling of trout to human food market. Aquaculture, like the whole agricultural sector (both in Italy and in other developed countries), has also a relatively poor economic performance when compared with other economic sectors (economic return on the investment, economic labour productivity). The high opportunity cost of labour in Italy implies that those operating in aquaculture have to struggle to achieve an adequate labour productivity. The difference between the average economic labour productivity (added value per hour of labour) in the agriculture (and aquaculture) sector and the average economic labour productivity of the whole economy is so wide that the government (through EU funds) has to provide economic support to agriculture (and aquaculture too). Subsidies are in fact required to raise the income of farmers closer to the average in society (**Table 6.3** and **Figure 6.6**). Again the figures relative to the sets of indicators are graphically represented against references values in this case for the national level in **Figure 6.6**.

6.5 Linking different perspectives

In this section I will try to link the different perspectives (e.g. socio-economic dimension of the society, food policy, environmental issues), to supply a broad picture of the relation between the farming system strategies and the context in which they are performed.

6.5.1 Demographic pressure on natural resources

Demographic pressure is an important factor that threatens the food security of China through the continuous reduction of arable land available per capita for food production. The arable land per capita in China is about 0.09 ha per capita (FAO, 1994) and is much lower than the threshold of 0.5 ha per capita indicated by some scientists as the minimum requirement to guarantee a varied food supply without causing to much environmental stress (Lal, 1989; Kendall and Pimentel, 1994). Dependence on food imports is increasing in China, but the high demographic pressure still makes food self-sufficiency a primary and difficult goal to achieve.

Population pressure may explain why Chinese fish pond culture is closely integrated in the farming system, and why aquaculture should be considered an integral part of agriculture (FAO, 1980; Lin, 1982; Shan, 1987; Zhong, 1989; Luo and Han, 1990; Li, 1992; Guo and Bradshaw, 1993; Lo, 1996). First, Chinese integrated fish farming was developed to fully utilize the scarce natural resources available. Its goal is to establish a human-managed, self-sufficient ecosystem where wastes are recycled to increase the food supply for the people (Shan, 1987; Yan and Yao, 189; Li, 1992; Lo, 1996). Apart from fish culture, water surfaces are used to raise goos and ducks. Pond dikes are used for fruit tree and mulberry cultivation, bottom slopes for fodder crops (Shan, 1987; Zhong, 1989; 1990). In the complex pond-dike system in the Pearl River Delta, in southern China (see **Figure 6.1**), pond and dike are treated as integrated unit, a system that has being co-evolving so to maximize the efficient use of natural energy and minimise wastes among component of the system (Zhong, 1989; 1990; Lo, 1996; Wong Chor Yee, 1999).

The continuous effort to increase the productivity of natural resources has stimulated the use of low-cost feed in China, such as waste from agriculture, animal and human manure, weeds and feeds of low economic value (Lin, 1982; Shan, 1987; Zhong, 1992; Li and Mathias, 1994). A study on conversion rates of manure in fish biomass reported a ratio of 8.3 kg of manure to obtain 1 kg of wet fish weight (Zhu *et al*., 1990). From this perspective freshwater aquaculture can be seen as an effective method of waste recycling, since agricultural wastes represent the main source of feeds for fish (Lin, 1982; Shan, 1987; Luo and Han, 1990; Zhong, 1992; Gou and Bradshaw, 1993).

A second reason why population pressure favours freshwater aquaculture concerns the optimization of surface use. The demand of land for the production of animal protein is relatively high compared to plant protein. For instance, large ruminants rarely produce more than 200 kg of protein per ha of land per year (Beets, 1996), whereas soy beans can produce from 300-400 up to 800-900 kg crude protein per ha per year (Beets, 1996; Rehm and Espig, 1997). Cassava protein content is about 1 g crude protein per 100 g fresh cassava, the average production range from 30-40 ton to 80 tons per ha per year (Rehm and Espig, 1997). Given the shortage of land in China, aquaculture is an interesting option to produce animal protein as it uses (water) surfaces that do not directly compete with plant protein production. Chinese pond fish farming has an average production of 2,385 kg/ha and a protein production of 190 kg protein/ha (Technical Annex Chapter 6).

Also in Italy, demographic pressure is high, but not as severe as in China. About 0.16 ha of arable land are available per capita (FAO, 1994). However, what is more important is that land availability is not as important for food security in Italy as in China, since food import, for Italy, is a feasible option (actually about 50% of food in Italy is imported). In the next sections we will deal with others constraints and options that characterize aquaculture in Italy.

6.5.2 Multiple role of fish farming

The overall contribution of fishery and aquaculture to the global economy – in terms of fraction of the GDP - is negligible, as it is negligible the economic contribution of freshwater aquaculture to the national economy of both China and Italy. Yet there is an important difference between the roles of aquaculture in these two countries. Whereas freshwater aquaculture is completely marginal in Italy, in China it is marginal only in terms of trade volume. On the contrary, it is strategically important for it guarantees high quality, cheap proteins as well as generating job opportunities with low economic investment. Furthermore when breaking down average figures we see that for Southern China aquaculture is also an important economic activity.

Chinese polycultural systems rely mostly on the functioning of pond ecosystems. They require a limited input of commercial energy, have a much smaller environmental impact, and reach a higher efficiency in the use of natural resources. This better biophysical performance is due to the reliance of the production process on natural mechanisms of regulation of aquatic ecosystems. However, this dependence on natural processes represents also a limit to their productivity (e.g. a biophysical productivity of labour of 1 kg/h). By relying on polycultural pond systems Chinese producers can increase the naturally occurring biophysical efficiency to some extent, but can never reach a productivity (throughputs per hour and per hectare) typical of intensive monocultural systems.

In developed countries like Italy, aquaculture, in order to be possible at all, must be economically viable at the producer level. This basic prerequisite is reflected in the widespread adoption of intensive, artificial monocultural systems which have a high productivity per hour of labour (20–80 kg/h). This depends on the complete control of the rearing environment through the use of feeds and water exchange and implies intensive use of commercial energy mainly in form of fossil energy. In other words, because of the pressure exerted by its socio-economic context, intensive aquaculture is forced to boost the productivity of the aquaculture system (tanks) by somehow bringing in the activity of distant aquatic ecosystems (i.e., marine ecosystems that generate fish meals used as feed input) and by replacing natural mechanisms of control in the habitat.

6.5.3 The ecological view

A comparison of the Eltonian pyramid (pyramid of values of biomass or energy flowing among trophic levels - Odum, 1983; Pianka, 1994) of a typical natural aquatic ecosystem, as in **Figure 6.4**, with the pattern of biodiversity use in China, **Figure 6.3**, shows that Chinese producers basically replace top carnivores in the natural aquatic ecosystem. Fulfilling the role of upper compartment of the ecosystem, they take full advantage of the natural processes of conversion of solar and biochemical energy into edible biomass. Hence, in the Chinese system of production the natural structure of the aquatic ecosystem provides both the control of energy and matter flows and a large part of the needed inputs. In exchange, humans harvest biomass and protect the integrity of the system as a whole.

A comparison of the Eltonian pyramid, with the pattern of biodiversity use in Italian aquaculture (**Figure 6.3**) shows the absence of any similarity in shape. In the Italian system, the lower-level compartments are entirely missing and the size of the top carnivore compartment is huge.

The large compartment of top carnivores in the Italian aquacultural system implies the existence of a corresponding huge compartment of phytoplankton in an *external* aquatic ecosystem that is exploited to convert solar energy into fish biomass (through natural cycling of nutrients) for use as feed (the pellets) for the top carnivores in the aquacultural system. The choice of boosting the productivity per hectare (or per unit of volume) in form of intensive aquaculture implies the use of piscivorous species (more than 80% of total production in Italy) that are (at least) two levels higher in the trophic chain than phytoplanktivorous species. (Latter species constitute more than 60% of the total production in Chinese aquaculture). This choice is paid for by an increased requirement (hundreds of times) of *external* ecosystem activity per kg of biomass produced (some ecosystem elsewhere has to produce the huge flow of fish used to make feed – Folke and Kautsky, 1989; Pauly and Christensen, 1995; Folke *et al*., 1998; Nylon *et al*, 1998; 2000). Energy requirement is dramatically skyrocketing as well (Pimentel *et al*.,1996).

Since in the artificial water body (tank) used in Italian intensive aquaculture all trophic levels but the upper one are missing, human management must take care of (i) the regulation of the food input required by the carnivores, (ii) the disposal of wastes and excess nutrients, and (iii) the provision of a control system that stabilizes all other conditions, such as water quality, oxygen content and medical care.

Thus, not only does intensive aquaculture in Italy still depend on the activity of (external) natural ecosystems for the production of feed, but it is also forced to consume large amounts of fossil energy per unit of food output in managing the system releasing in this process a considerable amount of waste in the external environment. In other words, because of the pressure exerted by its socioeconomic context, Italian intensive aquaculture is forced to boost the productivity of the aquacultural system (tank) by somehow bringing in the activity of distant aquatic ecosystems (i.e., marine ecosystems that generate fish meals used as feed input) and by replacing natural mechanisms of control in the habitat. Clearly, a side effect of this intensive process is the release of effluents into the external environment, the recycling of which would require the activity of an aquatic ecosystem of a size similar to that exploited for the generation of the imported feeds (Folke and Kautsky, 1989; Pauly and Christensen, 1995; Folke *et al*., 1998).

6.5.4 Role/function of aquaculture for the socio-economic context

The rate of the throughput of produced biomass is a fundamental parameter defining the role/function of aquaculture for the socio-economic system in which the activity takes place. When the throughput is slow, the main role of aquaculture is to recover agricultural wastes and use low-quality resources in the production of high-quality animal protein. The slow throughput, both per hour of labour and per hectare, makes it possible to maintain a structure of the managed system that is similar to that of natural aquatic ecosystems. Under these conditions, aquaculture plays a useful role in integrating agricultural production, recycling wastes and by-products, and contributing to the biodiversity at landscape level. However, the limited rate of the throughput implies a low compatibility with intense economic activity.

When the rate of the throughput of produced biomass is much higher than the typical flow of aquatic ecosystems, aquaculture merely has the role to produce high-valued species for sale on the market (at high biophysical and ecological costs). The fast throughput of nutrients and energy per hour of labour and per hectare requires a dramatic reduction of biodiversity used in the production process (monoculture), and a high consumption of fossil energy and environmental loading per unit of produced biomass. In general the more intensive is the activity larger is its impact on the natural ecosystem (Folke *et al*., 1998). Government policies and interventions are required to mediate between the need to somehow preserve a minimum of ecological compatibility and the need to achieve economic viability. On the other hand, existing subsidies to unsustainable fishery, and the missing account of externalities create incentives for the misuse and overexploitation of natural resources (Folke *et al*., 1998). Such a mediation requires an integrated assessment of the performance of aquaculture. In order to be able to provide such an integrated assessment the analysis must be able to adopt several parallel perspectives, as illustrated in this chapter, to relate costs and benefits, expressed both in economic and ecological terms, to the socio-economic context in which aquaculture is performed.

6.5.5 Ecological farming systems: options and scenarios

The transition from a system of production based on natural cycles (polyculture, low- input, traditional type), to a system of production based on linear flows of nutrients and other inputs kept artificially at a very high density by human technology (monoculture, high-input, high-tech type) entails a few problems of viability. The existence of this link comes out crystal clear when performing integrated analysis. In this way, it becomes possible to confront the stakeholders with different perceptions and representations of trade-offs implied by the adoption of a given farming system.

In fact, production techniques in polyculture are wonderful in relation to their ability of creating a natural-like pond environment that imitates as much as possible the complex trophic structure with links between environmental resources, microorganisms, plants, herbivores, consumers and top predators. This production system follows the so-called paradigm of "ecological agriculture". Ecological agriculture "*…emphasizes the relationship between components within the system and the relationship between agroecosystems and their natural and social environments.*" (Luo and Han, 1990, p. 305). This paradigm has been rediscovered in recent years, as a way to answer to the dramatic trends in environment degradation and pollution, but is based on the long historical co-evolution of Chinese peasantry with their environment (Luo and Han, 1990; Shi, 2002b; Ye *et al*., 2002).

However, the economic reading of the performance of such a system presents us with the other side of the medallion. The set of technical coefficients and economic indicators associated to this typologies does not candidate it as the solution able to dramatically change the unsatisfactory economic condition typical of many rural areas in China. So that the recipe for the future of aquaculture in China (and other crowded developing countries) cannot be that of a returning to past farming systems, an unthinkable option to feed a population of 1.3 billion people striving for a better life. Rather the goal should be that of integrating and complementing, sound ecological techniques of farming with innovative technologies within a proper system of land tenure and public care for the environmental issues. It requires individuating a satisficing and viable profile of indicators of performance for a sound integrated analysis. At this regard it should be noted that a balanced achievement in relation to a set of relevant but contrasting criteria of performance [as considered in the examples given so far] have been basically disregarded in the recent race for fast economic development in this sector (Luo and Han, 1990; Shi, 2002a; 2002b;Ye *et al*., 2002).

6.6 Conclusion

Many authors claim that technological development in agriculture has led to a diminished use of biodiversity in form of species reared, and a reduced efficiency in energy use (eg. Pimentel, *et al*., 1992; Pimentel and Pimentel, 1996; Giampietro, 1997b; 2004). Intensive cultivation practices trough land appropriation and pollution, have also led to a dramatic reduction of the biodiversity in general. This analysis of aquaculture made by using the MOIR approach confirms this trend pointing at the existence of some systemic properties related to the productivity of natural systems managed by humans. Shifting from more environmental integrated activities to high-intensity ones (of the kind carried on in developed countries) seems to imply the following of the same path. The dramatic transformation of the famous dike-pond system in the Zhujiang (Pearl River) Delta is an example (see Zhong, 1982; 1990; Wong Chor Yee, 1999, for a review of the issue).

6.6.1 Implication for policies

The relatively poor economic performance of Chinese “ecological friendly” aquaculture systems indicates that a future development of aquaculture in developed countries, such as Italy, into the direction of ecological compatibility and rational use of natural resources would dependent on governmental protection policies guaranteeing economic support (Gomiero *et al*., 1999).

Vice versa the boosting of productivity of the Chinese system, to get closer to the levels achieved by industrialized countries, seems to be a difficult task, especially when considering the necessity of not disturbing the delicate equilibrium of this integrated fish farming and the lack of economic resources to provide subsidy to the development of high-tech systems on large scale. China faces a huge demographic pressure and as a consequence of this a severe shortage of land (at the same time when striving for economic development), so that social and environmental problem must be seriously taken into account (Giampietro and Pastore, 1999; Wong Chor Yee, 1999; Shi, 2002a; 2002b; Ye *et al*., 2002).

Policies aiming at just boosting productivity, without maintaining a critical perspective on the strategy adopted, will inevitably lead to embrace intensive, high input, monoculture. A productive strategy that may seriously affect the carrying capacity of the environment both at the local, and at the global level. What would be the impact on marine fish stocks, if China should switch its internal production of aquaculture to protein-rich fish pellets as fish feed? (Gomiero *et al*., 1999; Naylon *et al*., 2000). We believe that maintaining and improving the traditional pond-system management model is essential to preserve long-term productivity of Chinese's natural resources. Improvement of the socio-economic condition of peasants and of the diet of urban population should not (and cannot) entirely rely on increased stress on the environment, which is already under heavy stress. As pointed out already by Chinese scholars (Luo and Han, 1990; Shi, 2002a; Ye *et al*., 2002), it is important that the government will give priority to the criteria of developing environmentally friendly activities.

6.6.2 The importance of aquaculture and the need for a more effective integrated analysis

The importance of an effective procedure of integrated analysis cannot be stressed enough. The use of economic performance (assessed by market value) as the only relevant criterion of evaluation implies missing the importance (and even the existence) of all those resources that are used by farmers for self-consumption. These resources, although crucial, are neither detected or considered by market indicators even though in many regions of the world, aquaculture is a way for farmers to produce, in a simple, sustainable way within their farming system, a supply of animal proteins for the self-consumption. In these contexts, the health status of children (enhanced by the precious nutritional elements provided by eating fish: thiamine, riboflavin, niacin, vitamin A and D, iron and calcium – Latham, 1997) can be for instance, used as a non-equivalent proxy to assess the impact of the aquaculture sector in those farming systems.

Of course for a developed country, the sustainability of the aquaculture sector depends more on economic indicators, such as the return on the investment, determines the viability of the system within a given market.

In more general terms, it can be said that whatever analysis based on a single mapping (= monocriterial definition of performance) is always biased. In fact, it is just reflecting a given definition of priorities among contrasting goals. Focusing only on the economic aspect of aquaculture means neglecting its ecological aspect, and vice-versa. This implies that multiple mappings have to be employed, to account for the unavoidable presence of legitimate but different relevant perspectives in human affairs.

In reality each system is something unique. As such it does not fit completely to our mental models, those models used to define in "substantive terms" what the "reality should be". Actually, quite on the contrary, the context within which a system is found can give to that system a specific meaning to an extent that the relative model ends up by having nothing to do with the reality. A Chinese carp polyculture is something that we can imagine. However the very specific meaning and behavior of this system at a particular point in space and time, is given by the context in which it is found to operate and by those actors that make choices within it. Meaning is given by the sets of objectives and constraints that characterize this special system as well as its history. It may be the case, as in many region of Asia, that aquaculture is an integral part of farmers' farming system. In some other contexts (e.g. Italy, Chile, USA, etc.) aquaculture is a economic specialised activity geared to the market, and sometime it becomes a recreational activity (e.g. sport fishing). This sudden change in meaning (emergence) poses a very deep challenge for the analyst. When talking of carp aquaculture in China and in Italy, are we talking about the same thing? Should we approach the relative analysis in the same way?

Large-scale generalizations can miss important “location specific” characteristics. In the same way, focusing on “location-specific” issues carries the risk of loosing the “big picture”. This poses a major issue related to the use of science in the management for sustainable development. A fruitful integration of different perspectives is not only desirable, but also possible and necessary when dealing with complex issues and sustainability. On the one hand, those experts that are used to deal with classes of situations using models can quickly recognize some sort of patterns, and quickly find hidden relations (generate valid local models) based on a selection of relevant and effective indicators. On the other, it is only from the inside (by involving local stakeholders), that there is the required knowledge about the history, values and identity of the system. This view from the inside is required to make it useful and to validate the set of analytical tools proposed by the outsiders/experts. This implies the necessity of a participatory approach in the process of generation of a MOIR.

Technical Annex Chapter 6: Assumptions and assessments

(a) Freshwater fish biomass production

In 1990 total freshwater fish production in China reached 4,459,114 tons on a surface of 4,575,550 ha (FAO, 1993; Qian, 1994), resulting in a gross average production of 975 kg/ha per year. Average productivity of Chinese polycultural pond systems is higher and has been estimated at 2,400 kg/ha per year (FAO, 1993; Qian, 1994) (Table 4). A recent study on integrated fish farming ponds for 7 provinces in east China reports that it is possible to achieve higher yields up to 6,100 kg/ha by an intensive recycling of farm by-products and some use of feed (Chen et al., 1995).

In 1993 Italian trout farming had an average productivity of 100,000 kg/ha and eel farming an average productivity of 65,000 kg/ha. Other species such as sea bream, Mediterranean bass and mullets had an average productivity of 20,000 kg/ha (Melotti et al., 1994; Perolo, pers. com., 1996). The weighted average of the productivity of the main cultivated species is about 80,000 kg/ha. As the Italian monocultural system is based on artificial water throughput, productivity in Italy may be better expressed in terms of fish weight per cubic meter of water rather than per unit of surface. If the above values of productivity in kg/ha are converted to kg of fish per cubic meter of rearing space, water exchange becomes a pivotal parameter. With a typical rate of water exchange of 4-6 liter/sec per ton of fish stocked (Melotti *et al*., 1994), productivity is about 30-40 kg/m^3 per year.

(b) Freshwater fish biomass production per hour of labour

To assess the labour productivity in the aquacultural sector, we divided the aggregate production of the sector by the aggregate labour supply (assuming an average of 1,800 labour hours per worker per year). As this method provides a rather rough approximation, we checked the results against values available from published case studies and actual production sites where possible and submitted estimates to experts in both countries. For China, we heavily relied on data from Qian (1994) that refer to 1990 estimates of human power in inland aquaculture. The estimated labour productivity is reported in Table 4.

Chinese pond culture requires 2 full-time workers per ha of pond surface (Qian, 1994). Considering an average pond productivity of 2,400 kg/ha and an average workload of 1,800 hours per worker per year, we obtain a labour productivity of about 0.7 kg/hour.

In Italian intensive fish farming, that accounts for almost the entire freshwater fish production, yields per worker are in the range 40,000–100,000 kg per year depending on the type of production (Perolo, pers. com., 1996). With a work load of 1,800 hours per year per worker, the labor productivity is in the range of 20– 60 kg/hour.

(c) Nitrogen conversion index

The nitrogen conversion index is here defined as the nitrogen input/output ratio, where the input equals the amount of nitrogen introduced into the system, including fertilizer and feed (in kg), and the output equals the amount of nitrogen in the produced fish biomass (kg).

Guo and Bradshaw (1993) provide a nitrogen conversion index of 2.2 for a Chinese integrated fish farm and a value of 3.1 for ponds in Jangsu province in east China. These assessments consider as input only nitrogen from outside the farming system and do not include nitrogen from recycled organic material within the fish farming system. Given these assessments, we adopted an estimate of the nitrogen index of 2.5.

Cho *et al*. (1994), provide a nitrogen conversion index of 30 for intensive trout monoculture in Italy. Note that whereas the nitrogen input in Chinese ponds is in the form of both fertilizer and feed, here all nitrogen input is in form of industrial pellets.

The nitrogen input/output ratios for China and Italy differ markedly and consequently the ecological implications of the nitrogen flow are different for these two countries. In Chinese polycultural systems, the nitrogen applied in excess of the amount required by the cultured fish is not lost nor does it represent pollution. It remains inside the closed rearing system and contributes to conserving the aquatic ecosystem structure. On the other hand, in industrial fish farming in artificial water bodies, surplus nitrogen in form of uneaten feed and fish excreta is lost with the water waste to the *external* environment, thus contributing to the eutrophication and degradation of lotic water bodies (Sumari, 1986; Cho *et al*., 1994; Oberdorff and Porcher, 1994). Reduction of species richness, both fish and bottom invertebrates, becouse of depletion of dissolved oxygen in the water was also reported (Oberdorff and Porcher, 1994). Intensive monocultural practices likewise for agricultural systems (Paoletti and Pimentel, 1992) affects indigenous biodiversity richness.

Here the simplification of using the number of reared fish species as indicator of biodiversity becomes evident. In reality, the difference between the biodiversity present in Chinese polycultural ponds and Italian freshwater tanks is much more pronounced than the numerical indication reported in **Table 6.4**. Many species belonging to lower taxonomic groups are behind the production of fish in the polycultural pond system. Most of these species are absent in the artificial environment typical of "high tech" freshwater aquaculture.

(d) Efficiency in using the natural trophic chain

Efficiency in using the natural trophic chain can be assessed by the percentage of feed energy generated *within* the system itself.

In a study of energy and element flows for some Chinese fish pond cultures (Guo and Bradshaw, 1993) the amount of fish biomass energy generated by natural processes within a pond was found to be 65% (**Table 4**).

In intensive systems of production in Italy, the amount of feed energy generated within the system itself is negligible (Ghittino, 1983; Giordani and Melotti, 1984; De Murtas, 1993; Melotti at al., 1994) (**Table 4**).

(e) Dependence on fossil energy

Dependence on fossil energy can be defined by an energy input/output ratio where the input equals the amount of fossil energy (in kcal) spent in the various inputs consumed in the production process and the output equals the biomass energy produced in form of fish (kcal).

For China, Guo and Bradshaw (1993) report that the amount of fossil energy embodied in imported inputs is about 3% of the food energy output. Other energy inputs required to run the ponds (e.g. industrial artefacts, transportation) are in the same order of magnitude. Hence the input/output ratio will be smaller than 0.1 (**Table 4**).

In Italy, the inputs involving consumption of fossil energy include:

- Electricity for pumping water and the functioning of the plant: 3.5 kwh/kg of trout = 9,000 kcal of fossil energy.
- Energy for making available pellets, including marine catch, processing, packaging, and transportation. Given that 1 kg of dry pellets corresponds to 8,000 kcal of marine fish, the fossil energy spent per kg of pellet will be in the range of 10,000–20,000 kcal.
- The fossil energy embodied in administered drugs and other chemicals, plus the building and maintenance of equipment can be estimated at 5,000 kcal/kg of trout produced.

Summing al these inputs we obtain a rough estimate of 20,000 to 40,000 kcal of fossil energy input per kg of trout produced. Hence, the input/output energy ratio will be in the range 25/1–45/1 (Pimentel and Pimentel, 1979).

(f) Demand on the environment: Freshwater requirement

Fresh water consumption in the rearing process is an indication of the demand on the environment generated by the production system.

In China, external fresh water is needed to off-set evaporation in the fish pond and to refill the pond after fish harvest. With an average pond depth of 1.5 to 2 meters (Shan, 1987; Zhong, 1992) and an average yearly productivity of 2,400 kg/ha, we find that 0.12 to 0.17 kg of fish are stocked per square meter of surface. This results into a water requirement of about 6-8 cubic metres or 6,000 - 8,000 liters per kg of fish produced per year.

In Italian intensive fish farming (e.g., trout and eel), an average of 5 l per second per ton of fish stocked are required (Melotti *et al*., 1994). As the average stocking time to obtain marketable fishes is 15 months, it means a water consumption of about 200,000,000 l of freshwater per ton of fish output or 200,000 l per kg of fish.

(g) Environmental stress: Release of waste products

Waste products from intensive fish farming include residual feed, excreta (e.g., ammonia), drugs and other chemicals, phathogenic bacteria and parasites (Sumari, 1986; Oberdorf and Porcher, 1994). The amount of waste produced varies greatly depending on feeding activities, season, management, etc. Accuracy in monitoring effluents would imply a sensible increase in operating costs (Cho *et al*., 1994) and consequently up to date little has been done to estimate the load of waste products released into natural water bodies (Oberdorf and Porcher, 1994).

In any case, we can safely state that the release of waste products into the environment is much lower in the Chinese polycultural system where the very rationale of the management tends to prevent this kind of problem. Stocking together complementary species prevents water pollution from faecal waste, for instance, Wuchan bream (*Megalobrama amblycephala*) feeds on grass carp excreta (Shan, 1987; Zhong, 1992). Also, the stocking of fish species in Chinese ponds at a much lower density than that adopted in intensive monocultural systems in

Italy makes the outbreak of epidemic diseases less probable in Chinese systems thus allowing the Chinese to use only few drugs and other chemicals (Shan, 1987; Zhong, 1992).

(h) Performance of freshwater aquaculture in the national economy

The gross domestic product (GDP) per capita is a commonly-used indicator of economic development. In 1992, the GDP per capita in China was 470 USD and in Italy 21,050 USD (Table 5). The relevance of an economic activity to the national economy can be assessed by its contribution to (percentage of) the gross domestic product (GDP). In Italy (1992), inland aquaculture accounted for 0.8% of the agricultural GDP. As agriculture accounted for 3.2% of the national GDP (Table 5), inland aquaculture represented a mere 0.025 % of the national GDP. In China (1992), inland aquaculture accounted for 2.0% of the agricultural GDP (Zhao, 1994). As agriculture accounted for 28.4% of GDP (World Bank, 1995), inland aquaculture accounted for 0.6% of the national GDP.

Dividing the GDP generated by a country in a year by the labour supply (in hours) in that year we obtain a rough idea of the average return of human labour in the country. In this way, we find for 1992 an average return of labour of 0.43 USD/hour for China and 28.50 USD/hour for Italy; a difference of more than 66 times. In order to achieve an acceptable standard of living, farmers must somehow achieve an income that is reasonably close to the average income in the society to which they belong.

In Italy, the added value per worker in freshwater aquaculture can be assumed to be similar to the added value per worker in agriculture (Perolo, pers. com., 1996). In 1992, this value was about 19.6 million Italian Lire (ITL) or 14,000 U.S. dollars (USD) per worker per year (based on the 1992 exchange rate of 1 USD = 1,400 ITL). [The total added value in agriculture in 1992 was 41,801.6 billion ITL and the total number of persons employed in agriculture 2,132,100 (INEA, 1994)]. The average GDP per capita in Italy was 21,050 USD in 1992 (World Bank, 1995). Therefore, the added value per worker in agriculture was 35% lower than the national average. We may assume for workers in aquaculture a similar situation. If we divide the amount of added value per worker in agriculture (14,000 USD) by the number of hours worked on average in a year (1,800) we obtain an average opportunity cost of labour in that sector of almost 8 USD/hour.

In China, the added value per worker in freshwater aquaculture has been estimated at 2,320 Yuan or 470 USD per worker per year (Qian, 1994), (based on the 1992 exchange rate of 1 USD = 5 Chinese Yuan). This value matches the average GDP per capita of the country in 1992 (World Bank, 1995). Dividing this number by the hours worked in a year (1,800) we obtain an average opportunity cost of labour of about 0.25 USD/hour.

In Italy, as in other developed countries, there is a large difference between the added value per worker in the agricultural sector and the national average. The relatively poor economic performance of the agricultural sector requires governmental policies of support to raise the income of farmers to the average income achieved in society. In China, the economic performance of fish farming and that of the agricultural sector are similar to the Chinese national average, which is basically due to the large percentage of the labor force engaged in agriculture.

These data show why labor productivity is a fundamental parameter in examining the economic feasibility of any form of production in the food system. A high opportunity cost of labor in society coupled to a high GDP per capita translates into the need to achieve high labor productivity in the production process (Giampietro, 1996a). In developed countries, such as Italy, the agricultural sector, to which aquaculture is closely related, struggles to achieve a labor productivity that provides an income comparable to that achieved in the rest of society. This issue is particularly relevant in Italy where aquaculture does not receive the same extent of governmental protection as does agriculture (Melotti *et al*., 1994).

(i)Role of freshwater fish in food security

A comparison of the composition of the Chinese and Italian food supply available for human consumption indicates the existence of sensible differences between the two countries (FAO, 1996). In China, 24.2% of the total daily protein supply is from animal sources. Fresh water fish accounts for 8% of the animal protein supply and 2% of the total protein supply. The relatively low supply of total protein and in particular of high-quality animal protein makes the contribution of freshwater fish to the Chinese diet important in providing essential amino acids. The situation in Italy is very different. Total protein supply is well over 100 g/day per caput of which 54% from animal sources. Freshwater fish accounts for only 0.4% of the total protein supply.

When the internal requirement for food exceeds the internal supply, a country needs to resort to food import in order to achieve food security—at least where basic food items are concerned. Food import has two negative aspects: It implies dependence on the international market and represents a burden on the national economy. In China and Italy the economic and political pressure to avoid recourse to food imports is very different. China, with its huge population (1.2 billion people) and relatively poor economic development can not afford (economically) to heavily rely on food imports (leaving apart the delicate issue whether sufficient surplus would be available on the international market). This is particularly true for highly nutritious food items (meat, fish, dairy products) that are expensive to import. It is therefore of strategic interest to China to maintain and strengthen fresh water fish production because of its important role in providing high-quality protein and hence guaranteeing food security.

In Italy, on the other hand, fresh water fish plays a marginal role in the diet, both from the nutritional and cultural point of view. When fresh water aquaculture is no longer economically rewarding then there is no strategic interest in either keeping or developing this sector. In fact, in 1996, about 35% of the trout production (which covers 24% of total fresh fish production) was destined to sport fishing which is a more profitable end than the human food market (Colombo, pers. com., 1996; Perolo, pers. com., 1996).

Data on import and export of freshwater fish for Italy and China confirm these considerations. In 1986 in Italy, the ratio total fish import/export (in monetary value) exceeded 30/1 (Melotti *et al*., 1994). Imports from Europe accounted for 70% of the total Italian import (Melotti *et al*., 1994). For freshwater and lagoon fish the ratio between import/export (in monetary value) was 4/1 (Melotti *at al*., 1994). We find a quite different situation in China where imports of aquatic products were never reported to exist until the last few years (FAO, 1989; Qian, 1994). Exports in 1986 amounted to 180,000 tons for a value of 51,033 USD. In 1992, Chinese export reached 515,000 tons for a value of 1,678,112 USD (Qian, 1994). It should be noted that these values are negligible when compared to the size of the Chinese economy.

Chapter 7

Case study 2

Multi-Objective Integrated Representation of the farming system in Thuong Lo commune, Vietnamese uplands

Summary

In this section I present an ex-post analysis of a program of rural development carried out by FAO in 1996. The focus is on farming system analysis of one of the two pilot communes (Thuong Lo) included in the project. The MOIR analytical tool is used to describe the effect of the implemented policy in terms of rural development: (a) in parallel on distinct descriptive domains (economic, social and ecological); and (b) in relation to different hierarchical levels (household, village, and the "whole commune" comprising 3 villages). In this analysis MOIR provides an integrated package of socio-economic and environmental indicators across scales. The adoption of MOIR provides new insights about the nature of the problems experienced with the implementation of the program.

7.1 Introduction

The analysis presented in this section is based on data collected in 1997 in a village in the Vietnamese uplands by the author and other members of a research team (see acknowledgment), working within the activities of a FAO assessment program of the running Forest Land Allocation program (FLA). A description of the case study and of the analysis developed in this assessment program is available in other publications (Faggi *et al*. 1998 and Gomiero *et al*., 2000). In this section I will shortly introduce the Thuong Lo village and then I will focus specifically on the application of MOIR methodology.

There is a large technical section in this chapter, represented by the technical annex (coming after the section References). The Technical Annex presents the assumptions, estimates and calculations made to support the analysis presented in this chapter.

Being the present study an ex-post analysis, I could not build a sample of households according to typologies useful for MOIR. Therefore, I had to cluster the households according to household typologies emerged from data analysis when focusing on their profiles of time allocation. Then the overall data collected are interpreted using the typologies emerged when adopting the MOIR approach. In this way, it is possible to see how structuring the original data set using "household types" defined according to the MOIR approach can help to gain additional insight in the "reading" of the experienced problems.

7.1.1 A brief overview of the case study: The Thuong Lo village

Thuong Lo commune (the commune is basic unit of rural life in the Vietnamese wet rice based culture - Popkin, 1979; Fford, 1988). is located in the central plateau of the Nam Dong district, Thua Thien Hue Province in the Central Vietnam at 300 abose the sea level, about 50 km from the city of Hue, the third city of Vietnam. However because of the mountainous nature of the area and the means of transport - old buses and motorcycle - it takes more then two hours to get from Hue to the Thong Lo commune. Thuong Lo territory is characterised by a complex and hilly topography dissected by many streams. Out of the 156 households of the commune, 68 (44%) have cultivated land in the slash-and-burn area for a total 40 ha yearly in use, about 1 ha per household (for about 200-250 ha under rotation), (Faggi *et al*. 1998 and Gomiero *et al*., 2000).

Because of slash-and-burn is officially strictly banned in Vietnam, local authorities are not considering this "marginal" area which is not considered in the FLA activities. During the fieldwork the role of the area in the food supply production was investigated. Production of cassava and rice, the main crops in the slash-and-burn area, were calculated to understand their role in the food production of the commune. The results were particularly interesting: the area under slash-and-burn supplied at least 55-60% of the food production (in kcal), and probably more taking into proper consideration the collection of NTFPs, small animals, fish and wild plants collected in the forest, an important integration of the diet. In the area decreasing land productivity is forcing the shortening of the fallow period, from 10-20 years to the actual 4-5 years. Farmers were well aware that in the future they may have to move further in the forest to clear new land (Faggi *et al*. 1998 and Gomiero *et al*., 2000).

At a first view Thuong Lo commune could appear rather an "homogeneous" entity: a very poor commune on the Vietnamese uplands. However, when "scaling down" for a close look, at the household level, large differences and an heterogeneous reality emerges. Different households deal with rather different resources and constraints, they are forced or have the opportunity to adopt different farming system strategies. Importance of niche differentiation has already be pointed out by scholars in the field of farming system analysis (e.g. Altieri, 1987; Beets, 1990; Conelly, 1992; Brookfield and Padoch, 1994; Cleveland *et al*., 1994; Chambers, 1997; Ellis, 1998; Pastore *et al*., 1999; Dillon and Gulliver, 2001; Dillon *et al*., 2001). To understand in which way a local reality would respond to changes caused by a specific policy, it is of crucial importance to be conscious of the different farming strategies specific of different households. For practical purposes it is necessary to cluster farmers into typologies according to some representative characteristics of their farming system (e.g. time allocation, working time allocation, land use, money allocation, family structure).

7.1.2 Data collection

Data were obtained by interviews with about seventy farmers, (men and women), with whom the researchers interacted both individually (in their home and in the field) to obtain data on farming system activities and their perceptions on the ongoing change, and in-groups, to discuss some general questions with the active involvement of the whole family members. Additional interviews included local staff involved in the Forest Land Allocation project, representatives of the institutions and other relevant social figures (another ten people) (see Faggi *et al*., 1998 and Gomiero *et al*., 2000 for more details).

Because of the differences in the approach used for analyzing this farming system during the activities of the original program, some data and information required by MOIR (applied ex-post during my work at the Universitat Autonoma de Barcelona) were not available in the original data set collected in Vietnam. Missing information has been looked for in literature and then cross-checked, for reliability and applicability to our case study, through personal contacts with Vietnamese researchers (references in the section of acknowledgments).

7.2 Building a MOIR for our case-study

7.2.1 Definition of household types: the "Working time-Land budget"

The analysis presented here follows the theoretical approach proposed by Giampietro and colleagues (e.g. Giampietro, 1994b; 1997a; 1997c; Giampietro *et al*., 1997; Gomiero *et al*., 1997; Giampietro and Pastore, 1999; 2001; Pastore *et al*., 1999; Giampietro, 2004) applied in a farming system analysis in rural central China (see Giampietro and Pastore, 1999; Pastore *et al*., 1999).

A given farming system is characterized in terms of a set of relevant farming activities (e.g. land management, cropping, husbandry). Each one of these activities has, then, to be characterized in terms of technical coefficients (e.g. productivity of land, return of labour, return of land). These activities are then arranged into typical mixes (in relation to the constraints imposed on households by the given budget of working time and land). At this point, the profile of working time invested by each household in relation to the considered set of activities is used to characterize typologies of households, or "*household types*". Household types are then considered in relation to the total sample of households (crossing different villages), with no reference to the village they belong to. That is, typologies of households reflect only: (1) the characteristics of the set of activities considered for the farming system, and (2) the profile of working time allocation within the household.

The criterion for defining "household type" is the profile of the working time invested in a particular mix of relevant activities.

Household types have been defined as allocating about 60% or more, of their Total Worked Time, 15% or more of their Total Disposable Working Time, on the two main activities among the characteristic "activities mix" included in the set of "activities packages", which are used to label them (see **Table 7.1**). The set of "activities mix" is specified in **Table 7.1** along with the fraction of time allocation over them for each household type. The set of relevant "activities mix" characteristic of the farming system of this area is characterized in terms of technical coefficients (and their resulting effect in terms of land and labour productivity both in biophysical and economic terms) in **Table 7.1**. The fraction of the available budget of working time which is allocated over them is used to describe household typologies – **Table 7.2**.

Table 7.1 *(see p. 141a)Technical coefficients (Productivity), and economic performances (Average Return of Work and Land) of the relevant activities of the investigated farming system*

Table 7.2 *(see p. 141b)Time allocation per household type*

In detail, the procedure that has been followed (from Giampietro and Pastore, 1999, and Pastore *et al*., 1999), is based on the assessment of:

(i) "***Total Human Time***" available to the household, it is to say the 8,760 hours in a year, multiplied by the number of individuals in the household;

(ii) "***Non Working Time***" assuming that 12 hours per day per person (for the 365 days of the year) were allocated in sleeping and personal cares;

(iii) the amount of time spent in "***Chores***", it is to say on the activities for the household self-maintenance (cooking, fetching water, collecting fuelwood etc.) (see Technical Annex for assumptions). The time allocated to chores is similar for all the household types (16-18% of the Total Available Working Time), and can be considered a sort of constant;

(iv) "***Total Available Working Time***" as the Total Human Time of the household minus: 1) the Non Working Time of the household, and 2) the time accounted for the non-working people (defined as those with an age < 8 years old and >70);

(v) "***Total Disposable Working Time***", the time truly available to be invested in productive activities, as the Total Available Working Time of the household minus the time allocated in subsistence chores;

(vi) the profile of ***relevant productive activities*** characteristics of this farming system;

(vii) (for each household type) the profile of the time allocation in those activities.

Table 7.1 *Technical coefficients (Productivity), and economic performances (Average Return of Work and Land) of the relevant activities of the investigated farming system*

Activities	Type 1 Off farm-Crop.$_{mix}$ (kg/ha/yr)	Type 2 Husb.-Crop.$_{mix}$ (kg/ha/yr)	Type 3 S&B-Crop.$_{mix}$ (kg/ha/yr)	Type 4 NTFP-Crop.$_{mix}$ (kg/ha/yr)
Home Garden				
Starchy roots	-	-	2,000	2,000
Corn	-	400	400	400
Beans	200	200	200	200
Vegetable	500	500	500	500
Fruits	1,000	1,000	200	200
Paddy field				
Rice^{wr}	2,200	2,200	2,200	2,200
Crop land				
Rice^{dr}	-	1,000	1,000	1,000
Cassava	-	4,000	4,000	4,000
Corn	400	400	400	400
Beans	200	200	200	200
Vegetable	1,000	-	-	-
Husbandry	-	40^H	40^H	-
Slash&Burn^{SB}				
Rice	-	1,000	1,000	-
Cassava	-	3,500	3,500	-
NTFP^{NT}	-	-		
Rattan			300 (≈100 km2)	300 (≈100 km2)
Honey			3 (≈100 km2)	3 (≈100 km2)
Economic performance	*Type 1* *Off farm-Crop.*$_{mix}$	*Type 2* *Husb.-Crop.*$_{mix}$	*Type 3* *S&B-Crop.*$_{mix}$	*Type 4* *NTFP-Crop.*$_{mix}$
Home Garden				
AR_W (VND/hr)	4,000	2,000	500	500
R_L (VND/ha)	7,000,000	5,000,000	1,000,000	1,000,000
Paddy field				
AR_W(VND/hr)	2,400	2,400	2,400	2,400
AR_L(VND/ha)	6,600,000	6,600,000	6,600,000	6,600,000
Crop land				
AR_W(VND/hr)	1,000	1,000	800	800
AR_L(VND/ha)	5,000,000	5,000,000	4,000,000	4,000,000
Husbandry				
AR_W(VND/hr)	-	1,000*	1,000*	-
AR_L(VND/ha)	-	125,000	125,000	-
Slash&Burn				
AR_W(VND/hr)	-	2,080	2,080	-
AR_L(VND/ha)	-	1,000,000	1,000,000	-
NTFP				
AR_W(VND/hr)	-	-	1,750	1,750
AR_L(VND/ha)	-	-	1,000	1,000
Off farm				
AR_W(VND/hr)	3,000	1,500	2,000	-
AR_L(VND/ha)	0	0	0	-

Notes:

(wr): wet rice, generally with two crop per year; (dr): dry rice, one crop per year; (SB): considering a cycle of 2 years of cultivation (rice-cassava) and 4-5 years of fallow; (H): assuming a cow pasting on 8 ha of pasture land (NT): this activity is carried on over several hundreds km2 of forest (Rattan is a claimbing palm, of the *Calamus* genus, used to make forniture); (*): considering two cows; (&): excluded and included both as land and income. (#): the very low values of AR_L are due to the large quantity of land used by NTFP and husbandry activities.

***Table 7.2** Time allocation per household type*

INDICATORS	*Total sample*	*Type 1 Off farm Crop.mix*	*Type 2 Husbandry Crop.mix*	*Type 3 S&B Crop.mix*	*Type 4 NTFP Crop.mix*
Total Time Allocation					
Total Worked Time per HH (hr/yr)	3,630	4,016	4,550	3,236	2,066
% Worked Time/ Tot.DisposableWorking Time	27	32	32	24	19
Worked time per capita (hr/cap/yr)	706	854	820	619	428
Worked time (hr/worker/yr)	932	1,107	1,059	815	612
Chores (as % Tot Available Working Time)	17	18	18	16	16
Worked time allocation (%of Total Worked Time)					
Home garden	13	10	9	14	49
Paddy	5	3	4	7	8
Crop land	23	7	25	30	13
Husbandry	21	13	37	10	0
S&B	17	4	10	33	5
NTFP	4	0	2	5	23
Off farm	15	62	12	0	0

In this case, I considered all the households, with no reference to the village they belong, and tried to arrange them into clusters representing the profile of working time allocation significant in terms of typology.

In this farming system Total Worked Time ranges from 15 to 30%, rarely exceeding 40% of the Total Disposable Working Time. This is a value much lower then the 70-80% found in a farming system assessment of some villages of rural central China (Pastore *et al*., 1999).

This can be explained by 2 facts: (1) Agricultural activities, in the study area, are strictly dependant on climatic events, and therefore very seasonal, and (2) shortage of good work opportunities in Thuong Lo commune, as indicated by the very low return per hour of labour for all the activities performed by the households considered. As illustrated by the analysis of Pastore *et al*. (1999), when the availability of cropland is very small (as in China or in Vietnam), the possibility of saturating to a large extent Total Disposable Working Time requires two conditions: (1) off-farm jobs available in the area (to avoid the constraint implied by shortage of land to work with), and (2) an economic return per hour of labour in off-farm higher or comparable to that obtained with farming activities. In relation to these two conditions the situation in Thuong Lo is very bad, for instance, the activities considered in husbandry could include a person (generally children or elderly) taking care **of a single cow** for 6/8 hours a day!

The set of 4 household types considered in this analysis (see **Table 7.2**) are:

- **Type 1: Off farm+Crop$_{mix}$**: It relies mostly on off farm activity (mainly in the public sector), but crop land still is an important part of the household activities. This type accounts for 18% of the sample of households.
- **Type 2: Husbandry+Crop$_{mix}$**: Husbandry (cows) plays a crucial part in money supply. Tending cows grazing is carried on by children or elderly who could not be employed in other activities. Cropland has both the meaning of securing food and some cash. This type accounts for 31% of the sample of households.
- **Type 3: Slash&Burn+Crop$_{mix}$**: slash-and-burn activity plays a crucial role in assuring food security. Cropland contributes to food supply. There is no cash availability. This type accounts for 36% of the sample of households.
- **Type 4: Non Timber Forest Product (NTFP)+Crop$_{mix}$**: NTFP is the only source of cash used to buy food during food shortage (a few months per year). This activity is a sort of "ultimate resource" for poor households with scarce land and labor. Because of the very hard work conditions, no more that one-month/year can be afforded. Cropland provides also food, but insufficient to cover food needs. This type accounts for 14% of the sample of households.

Note - Crop$_{mix}$ is defined as the mix of activities in home garden, paddy and cropland. Basically, all the households manage all these resources although in different manner and purposes (with different priorities in working time allocation). For example, home garden can be important for some households as a source of cash crop while for other it is seen only as source of food supply. This is why we define different packages of crop-mix for different households (as specified in **Table 7.2**).

7.2.2 Definition of an integrated set of objectives-criteria and resulting indicators of performance

As noted before the main goals of the government supported program of development in the upland were: (i) achieving and stabilizing food security; (ii) generating income; (iii) preserving upland environment. The set of criteria of performances, shown in **Table 7.3**, were selected in order to reflect these main goals (according to the information gathered on the field).

Table 7.3*(see p. 143a) Overview of indicators of system performance*

Obviously, since this is an ex-post analysis, such a choice has not been checked using an input given by stakeholders through participatory methods. It should be noted, here that also the allocation process within the original program, in spite of the official claims - Vu Van Me, 1997; MARD, 1998 - was not participatory at all.

In a real application, criteria would be debated with and within the stakeholders involved in the representation exercise. The same for the selection of relevant indicators. While some may be, or should be, provided by the experts on special fields (e.g. agronomist, economist, ecologists), others may be, or should be, provided by the stakeholders according to their perception of the system functioning, concerns and goals. Others may also come up by an historical reading. In the case of this work, the selection of criteria and indicators has not been directly discussed with the stakeholders. However, through my field work in Vietnam I had the opportunity to hear concerns and wishes from a numbers of stakeholders (e.g. local farmers belonging to various typologies, local institutions, FAO representatives), so that here I selected the indicators that according to my understanding (based both on general literature and experience gained through the field work), could significantly make consistent this work. Again the methodological nature of this work accounts for the limited number of criteria used to describe the farming system, and for the fact that only three representative indicators have been used for the graphical representation exercise (although longer lists are, of course, possible).

Domain-Criteria I*: Performance of the productive system*

(i) Return of land per unit area = VND/ha/year;

(ii) Return of time (per unit area) = VND/hr;

(iii) Saturation of the working time = % Worked Time/Total Disposable Working Time;

Land scarcity and poor productivity in term of crop biomass (because of poor soil condition, lack of inputs such as fertilizer, and technical knowledge) make of cash availability the key elements in order to overcome periods of food shortage.

Because of the many different activities carried on by farmers it would have been also rather difficult to give an aggregate figure of biomass production (the complexity of production patterns for subsistence farmers in the tropics is widely reported in literature, Altieri, 1987; 2002; Beets, 1990, Conelly, 1992; Landau and Brazil, 1992; Brookfield and Padoch, 1994; Ellis, 1998). For these reasons I used a monetary indicator of productivity of the farming system (for land and working time). Moreover, the Vietnamese Ministry of Soldier Invalid and

***Table 7.3** Overview of indicators of system performance*

System performance according to:	Indicator set	Unit of measure
Throughput density	• Economic return of land • Economic return of time • Saturation of the working time	VND/ha/year VND/hr % Worked Time/Total Disposable Working Time
Environmental stress	• Soil loss • % Biophysical Capital loss by replaced ecosystem • Pesticide use	tons/ha/year W/m2 kg/ha/yr
Dependence on external inputs	• % Food from market • Industrial fertilizers (N) input	% of total food from the market kg/ha/year
Socio-economic benefits	• Social conflicts (within the county and with authorities) • Income per capita • Quality of diet	qualitative, accounting for the number and intensity of the conflicts (negligible, very low, low, medium, high, very high) VND/capita/year as % of the average income per capita in Vietnam (300 US$ - 1997) kcal/capita/yr

Social Affairs (VMSISA) for households living in the rural areas, classified levels of poverty according to the income equivalent of the rice supply (Do Dinh Sam, 1994).

Saturation of the working time indicated the work load of the household. The low values may be explained in two very different ways: (1) because of household is carrying on activities with very high return per hour that for instance allows children to attend school instead of taking part in the farming activity, and (2) because of lack of working opportunities. That is to say that it is not worth for the household to invest more time (or energy) in other activities because their poor economic (or energetic) return. The reading of the other two indicators of performance supports very much the latter hypothesis.

***Domain-Criteria II:** Indicators assessing environmental stress*

(i) Soil loss = tons/ha/year;

(ii) % Loss of the Biophysical Capital = fraction of the BC of the actual agroecosystem compared with the previous natural ecosystem;

(iii) Pesticide use = grams of active product/ha/year;

This allows assessing how the farming system performs according to a set of environmental variables. The choice of the indicators aims at assessing the degradation of the productive system (soil loss), the loos of the ecosystem structure-function (Biophysical Capital), and the level of contamination caused by agricultural practices (pesticide use).

***Domain-Criteria III**: Indicators assessing dependence on external inputs*

(i) % Food from market = % of total food from the market;

(ii) Industrial fertilizers (N) input = kg/ha/year;

In this section I try to depict the level of external dependency of the household type concerning for food supply and industrial fertilisers (can be also energy) input in its productive system.

***Domain-Criteria IV**: Socio-economic performance: assessing the performance according to socio-economic benefits*

(i) Social conflicts (within the commune and with authorities) = (qualitative) number and intensity of the conflicts;

(ii) Income per capita = VND per capita per as % of the average income per capita in Vietnam (300 US$ - 1997);

(iii) Quality of diet = % of the minimum standard set for Vietnam (2,100 kcal per capita per days.

These criteria describe the performance of the actual farming systems in relation to socio-economic benefits. A qualitative indicator to assess the social conflict generated by each typology of farming system. An economic indicator to assess the level of income provided by the household activities, and the level of wealth ("physiological") by assessing the quality of the diet (in energetic terms). In a way the latter indicators may respond to the objective of the land allocation policy for the uplands reported at the beginning of the section.

7.2.3 Integrated characterization of performance for household types

An integrated representation of the farming system, at the household level can be obtained by looking at the values taken by the various indicators included in the set for each household type (**Table 7.4**).

Table 7.4 *(see p. 145a) Indicators of performance per household type*

An overview of such an integrated assessment can be obtained for each household type in a graphic way, as in **Figure 7.1a** (HH Type 1), **Figure 7.1b** (HH Type 2), **Figure 7.1c** (HH Type 3), **Figure 7.1d** (HH Type 4), **Figure 7.1e** present all four radars together for to easy the comparison.

Figure 7.1a *(see p. 145b) (HH Type 1), Off farm+Crop*$_{mix}$

Figure 7.1b *(see p. 145c) (HH Type 2), Husbandry+Crop*$_{mix}$

Figure 7.1c *(see p. 145d) (HH Type 3), Slash&Burn+Crop*$_{mix}$

Figure 7.1d *(see p. 145e) (HH Type 4), Non Timber Forest Product (NTFP)+Crop*$_{mix}$

Figure 7.1e *(see p. 145f) The four radars together for comparison*

The various axes of the radar diagram are divided in equal segments representing performance: bad (dark background), medium (grey background), and good (light grey background). The qualitative limits in this case are, of course, both arbitrary and indicative, actually they refer to "terciles", as the range of values has been equally divided in three parts, the lower third has been considered indicative of "bad" performances, and the higher third of "good" ones. Although figures here reported are somehow "real", their qualitative assessment can be made only through the participation of the stakeholders as in most of the cases they are those who can express the valuation of what is good or bad or acceptable in their own context of reference. Therefore, this work is an exercise giving an idea although in some way arbitrary, using quality zones (see the discussion given in Chapter 5).

A sector of the graph carries indicators that can be related to environmental impact of the farming activity. In relation to these criteria it is crucial that the integrated analysis of performance at this level includes also information about land use pattern linked to each household type. This information is provided in Table 7.5 (Land-use pattern per household type).

Table 7.5 *(see p. 145g) Land-use pattern per household type*

It is important to note that slash-and-burn land (located in the forest area outside the commune boundaries), accounts for as much as the 76% of the total land under cultivation (considering land actually in use and land under fallow). The assessment of land per capita

Table 7.4 *Indicators of performance per household type*

Indicator	Household types				Value range considered	
	Type 1	Type 2	Type 3	Type 4	Min.	Max.
Environmental stress						
Soil loss (tons/ha/yr) [sl]	5	30	120	5	13	150
% Biophysical Capital loss[BC]	0	20	20	0	0	100
Pesticides use (g.a.i./ha/yr)[P]	100	50	0	50	0	1,000
Dependency from outside						
% food imported	50	10	10	30	0	100%
Nitrogen flow (kg/ha/yr)[N]	50	40	25	25	0	200
Socio-economic performance						
Conflicts	0	High	High	Medium	Negligible	Very high
%hh income/av. inc. VN	50	20	12	12	0	100[a]
Quality of diet (kcal/capita/day)	2,300	2,100	1,800	1,800	2,100*	2,700-3,000
Performance of productive system						
return/ha/yr (VND/ha/yr)	8,700,000	2,300,000	800,000	3,100,000	0[b]	11-12 million VND[bb]
return/hr VND/HR)	2,370	1,085	1,175	1,036	250[c]	2,500[cc]
%TWedT/TDWT	32	32	24	19	10	100[d]

(sl): Soil loss-tolerance level for tropical areas have been suggested by Hudson (in Clark and Morrison, 1987), to be around 13-14 ton/ha/yr. However studies on soil erosion for slash-and-burn areas (Do Dinh San, 1994), indicate that with 15-25° slopes the soil loss ranges from 115 to 130 tons/ha/yr. Vu and Nguyen (1995) for central highlands give values ranging from 100 up to 150 t/ha/yr. A very large amount indeed; (BC): it is a measure of the energy dissipation trough plant water flow, data refer to the effect of the land use change on BC, as 100% it is considered the value of the forest cover 55 W/m2, 12 W/m2 have been assumed for trapical grassland (Giampietro *et al*., 1992); (P): grams of active ingredient are compared to the average for Mekong delta where pesticide use in maximun in Vietnam (Nguyen and Tran, 1998); (N): Nitrogen saturation level has been reported ranging from 170-230 kg per ha (Smil, 1987, p. 287); (a): 3.7 million VND average for Vietnam; (b): land belonging to a household but not in use; (bb): for paddy rice/ha/yr = 11-12 million VND (3.8 tons/ha/yr for a 3,000 VND/kg); (c): we assume that 250 VND or 250 gr of rice (about 350 kcal, 1 kg of rice provides for about 3,600 kcal) as the minimum return for a hour of work in the field; (cc): for public employ (about 500,000 VND/month); (d): with an average 1,600 working hour per year for Vietnamese households, (*): the average minimum energy intake per day sat for Vietnam is at 2,100 kcal/capita/day (Nam *et al*., 2000).

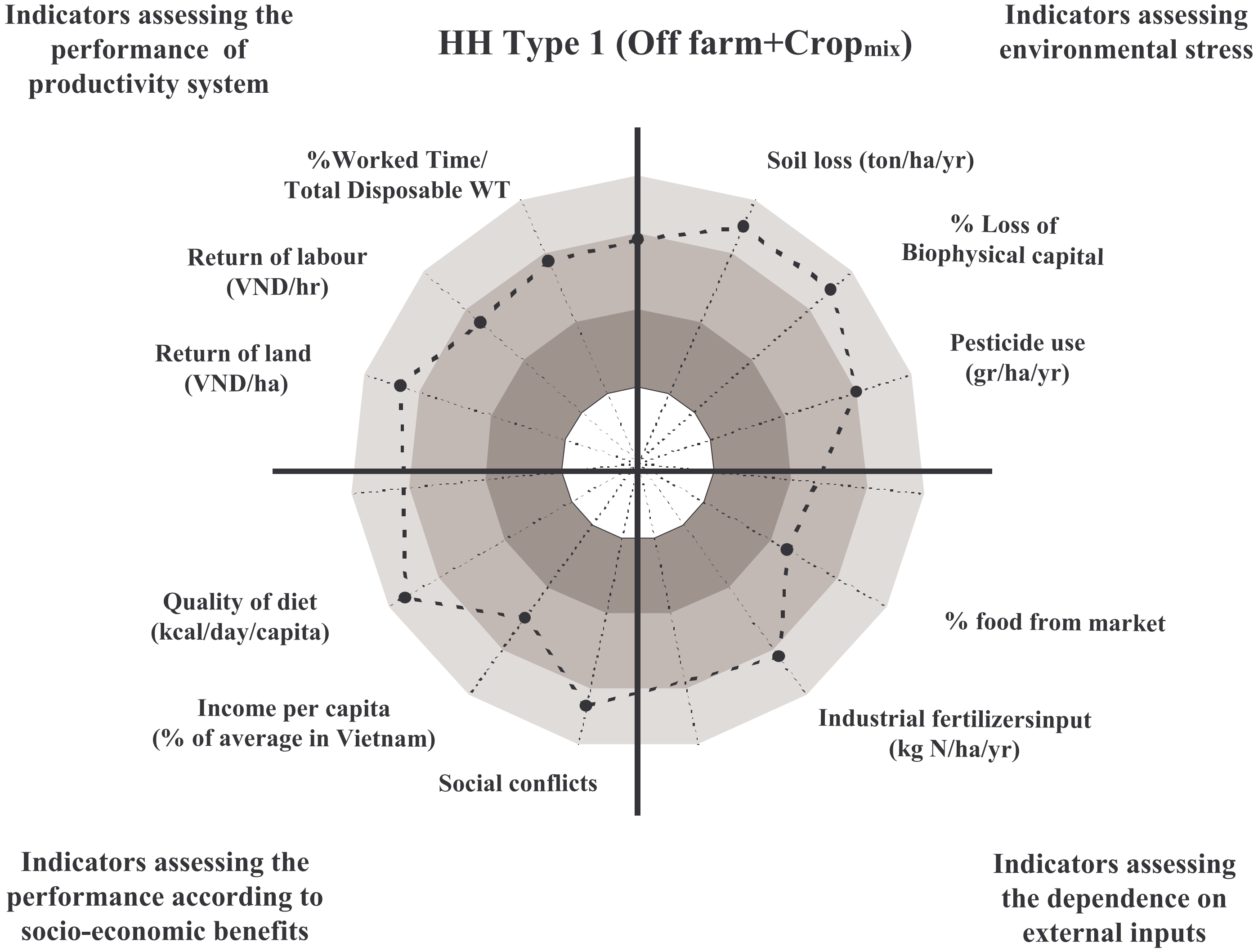


Figure 7.1a *(HH Type 1), Off farm+Crop*$_{mix}$

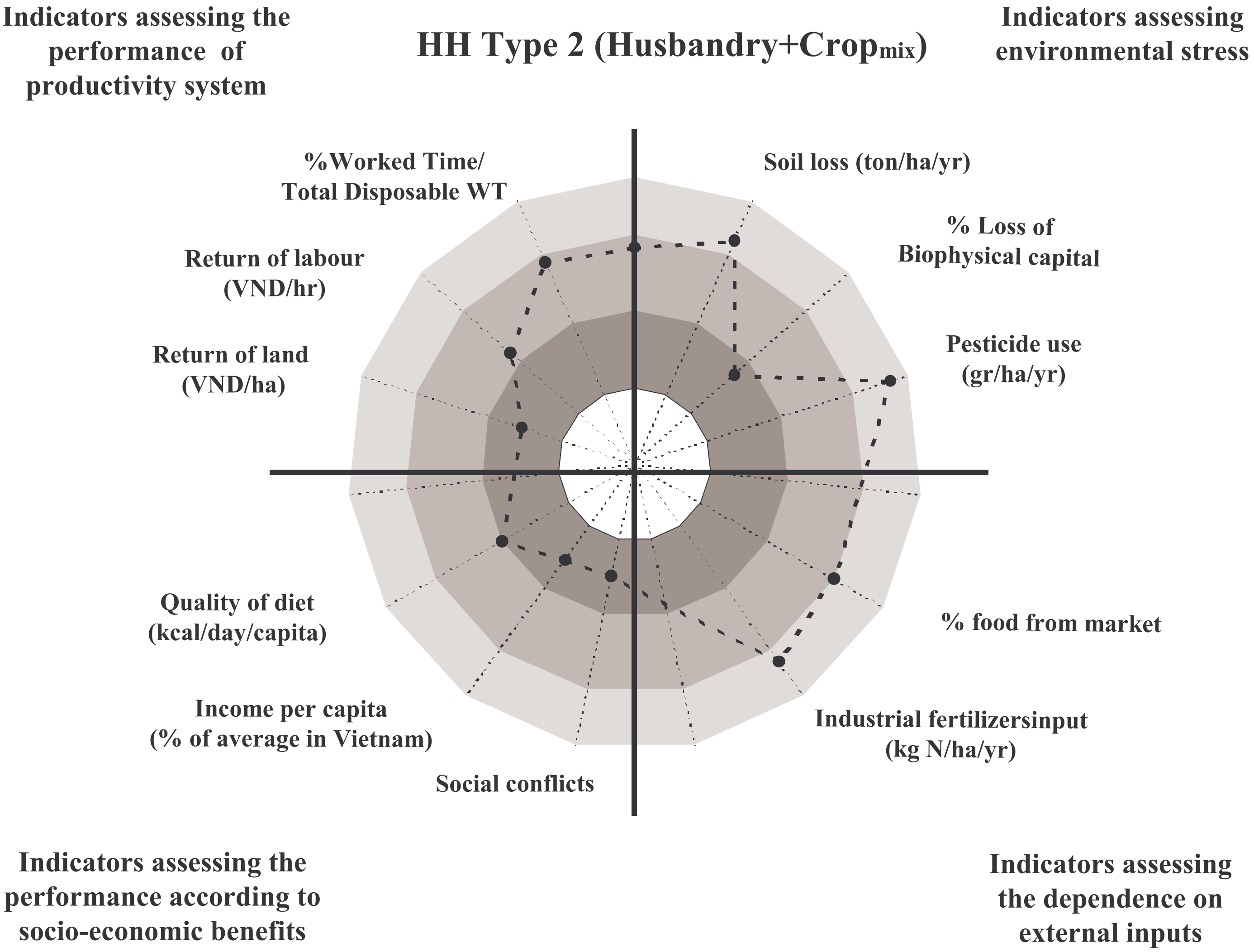


Figure 7.1b *(HH Type 2), Husbandry+Crop*$_{mix}$

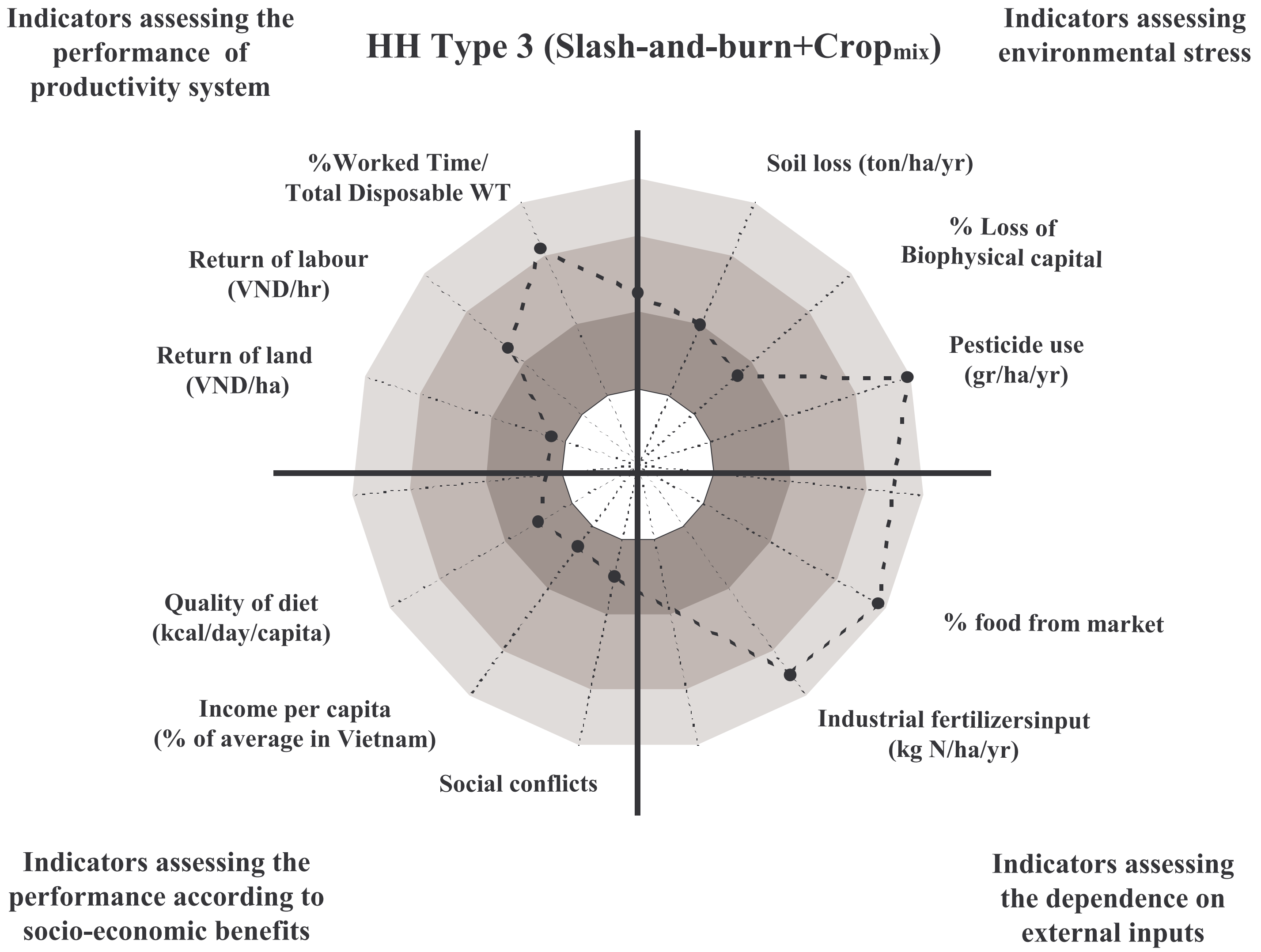


Figure 7.1c *(HH Type 3), Slash&Burn+Crop*$_{mix}$

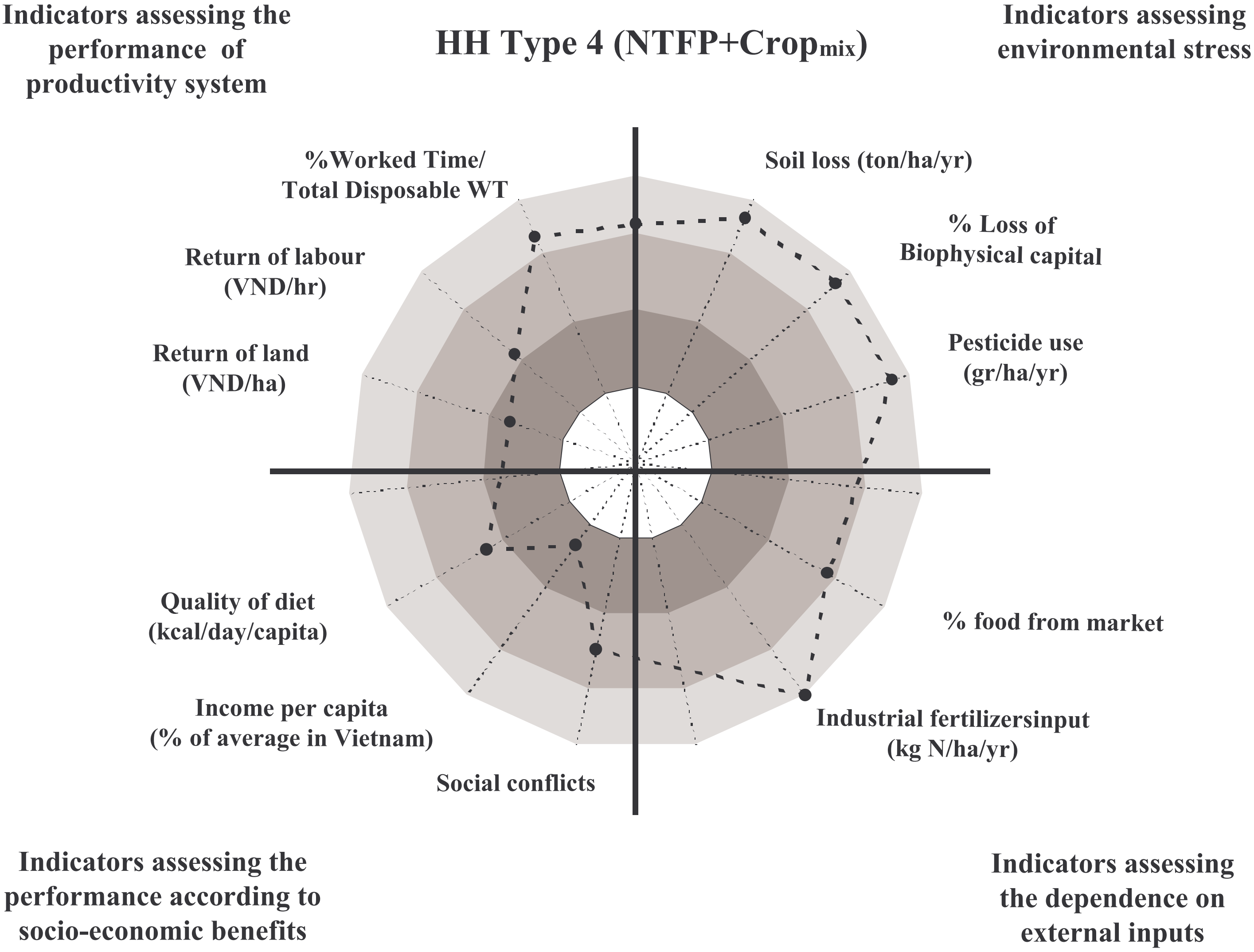


Figure 7.1d *(HH Type 4), Non Timber Forest Product (NTFP)+Crop*$_{mix}$

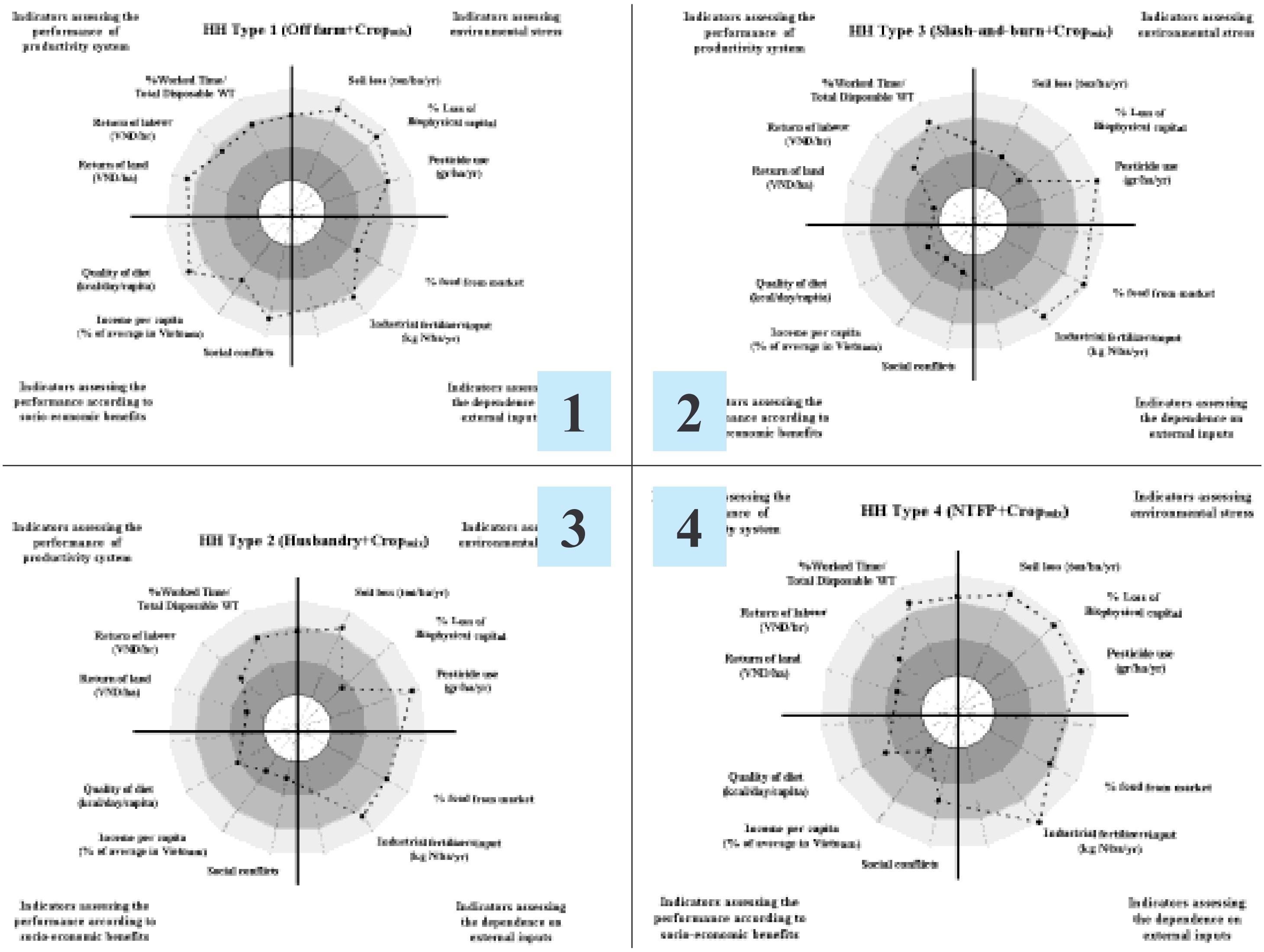


Figure 7.1e The four radars together for comparison

***Table 7.5** Land-use pattern per household type*

LAND USE (ha)	Total sample	Type 1 Off farm Crop.$_{\text{mix}}$	Type 2 Husb. Crop.$_{\text{mix}}$	Type 3 S&B Crop.$_{\text{mix}}$	Type 4 NTFP Crop.$_{\text{mix}}$
Total land					
TOT	85.3	2.4	25.0	52.1	3.3
per HH	2.19	0.34	2.10	3.57	0.66
per capita	0.32	0.13	0.26	0.52	0.14
%	100	100	100	100	100
Land outside of the commune S&B land					
TOT	64.7	0.7	16.3	44.6	1.0
per HH	1.66	0.10	1.36	2.97	0.20
per capita	0.24	0.02	0.18	0.41	0.04
%	76	29	16	86	31
Land within the county					
TOT	20.6	1.7	8.7	7.5	2.3
per HH	2.04	0.24	0.73	0.50	0.46
per capita	0.08	0.05	0.09	0.07	0.09
%	24	71	84	14	69
Home garden					
TOT	8.3	1.0	2.8	2.9	1.6
per HH	0.21	0.14	0.23	0.19	0.32
per capita	0.03	0.03	0.03	0.03	0.07
%	10	41	11	6	50
Paddy					
TOT	4.1	0.4	1.3	2.0	0.4
per HH	0.11	0.06	0.11	0.13	0.08
per capita	0.02	0.01	0.01	0.02	0.02
%	5	16	5	4	12
Crop					
TOT	7.8	0.3	4.6	2.6	0.2
per HH	0.20	0.05	0.39	0.18	0.05
per capita	0.03	0.01	0.05	0.03	0.01
%	9	14	18	7	7
Note:					
*Pasture land**	*5.8*	*1*	*12*	*5*	*0*
*Forest land for NTFP***	*230*	*0*	*166*	*300*	*500*

(*): Assuming 8 ha pasture per cow per year feeding in low quality pasture (Vu and Nguyen, 1995). Pasture land in Thuong Lo in quite degraded, most of it on sloping fallow land that surround the commune.

(**): NTFP, mainly rattan a climbing palms (e.g. *Calamus* gen.), and cap leaves. Forest surrounding Thong Lo commune is secondary forest, impoverished by the collecting pressure exerted in the last decades. For that reason rattan collection requires long time to be spent in the forest, a very harsh and risky activity.

drops dramatically from 0.32 ha per capita - when considering slash-and-burn fields - to 0.08 ha per capita when considering only the land cultivated in the commune. Paddy field, the main source of rice in the commune area, accounts for a 0.02 ha per capita!

An example of this information is given in Figure 7.2 presenting a comparison of land use pattern: HH Type 1 - Off farm+Crop$_{mix}$ versus HH Type 3 Slash&Burn+Crop$_{mix}$. This will be discussed later on.

Figure 7.2 *(see p. 146a) Comparison of Land use pattern: HH Type 1 - Off farm+Crop$_{mix}$ versus HH Type 3 Slash&Burn+Crop$_{mix}$ (see figures in* ***Table 7.5****)*

7.2.4 Possible alternative MOIR for Household Types

It is important to note that this approach is not to be intended as a fix routine or procedure that has to be followed as it is. MOIR has more to do with a way to approach farming system analysis and to help a discussion over useful methods of representation. MOIR should be intended as a tool helping systemic thinking in relation to local goals, local constraints and the context (e.g. socio-economic, environmental) of the system under analysis. In this sense MOIR approach calls for flexibility and creativity according to the context, goals, and stakeholders involved. In this section I provide a couple of examples of other useful representations that can be constructed with the data previously presented (**Table 7.1-7.5**).

- **Land-time allocation**

It may be convenient for instance to construct a graphic representation for the integrated representation of the land use and working time allocation in productive activities. This may be a valuable way to compare household typologies focusing on their use-allocation of precious resources such as land and time. Data on working time allocation (**Table 7.2**) and land use (**Table 7.5**) are represented graphically by a double histogram (in this case I do not use a radar representation) as in **Figure 7.3a**, **Figure 7.3b, Figure 7.3c, Figure 7.3d, Figure 7.3e** (comparison of the previous figures). On the lower part I report the working time allocation, and on the upper part the land use. Land use and time allocation refers to the working activity previously defined: home garden, paddy field and crop land activity (carried on within the official farm boundaries), slash-and-burn, NTFP and off farm work (carried on outside the official farm boundaries or on the common land). It has to be noted that Sleeping although is not (in this case) considered a productive activity, it is notwithstanding all, an essential human activity without which human life cannot be sustained. The same reasoning applied to Chores. In fact, although the time that an household allocates in Chores is not "productive" in the strict, economic, sense of the term, it is all the same an vital activity for the management of the family and all the other productive activities.

Figure 7.3a *(see p. 146 b) Graphical representation of time-land budget for HH type 1*

Figure 7.3b *(see p. 146 c) Graphical representation of time-land budget for HH type 2*

Figure 7.3c *(see p. 146 d) Graphical representation of time-land budget for HH type 3*

Figure 7.3d *(see p. 146 e) Graphical representation of time-land budget for HH type 4*

Figure 7.3e *(see p. 146 f) Comparison of the previous graphics*

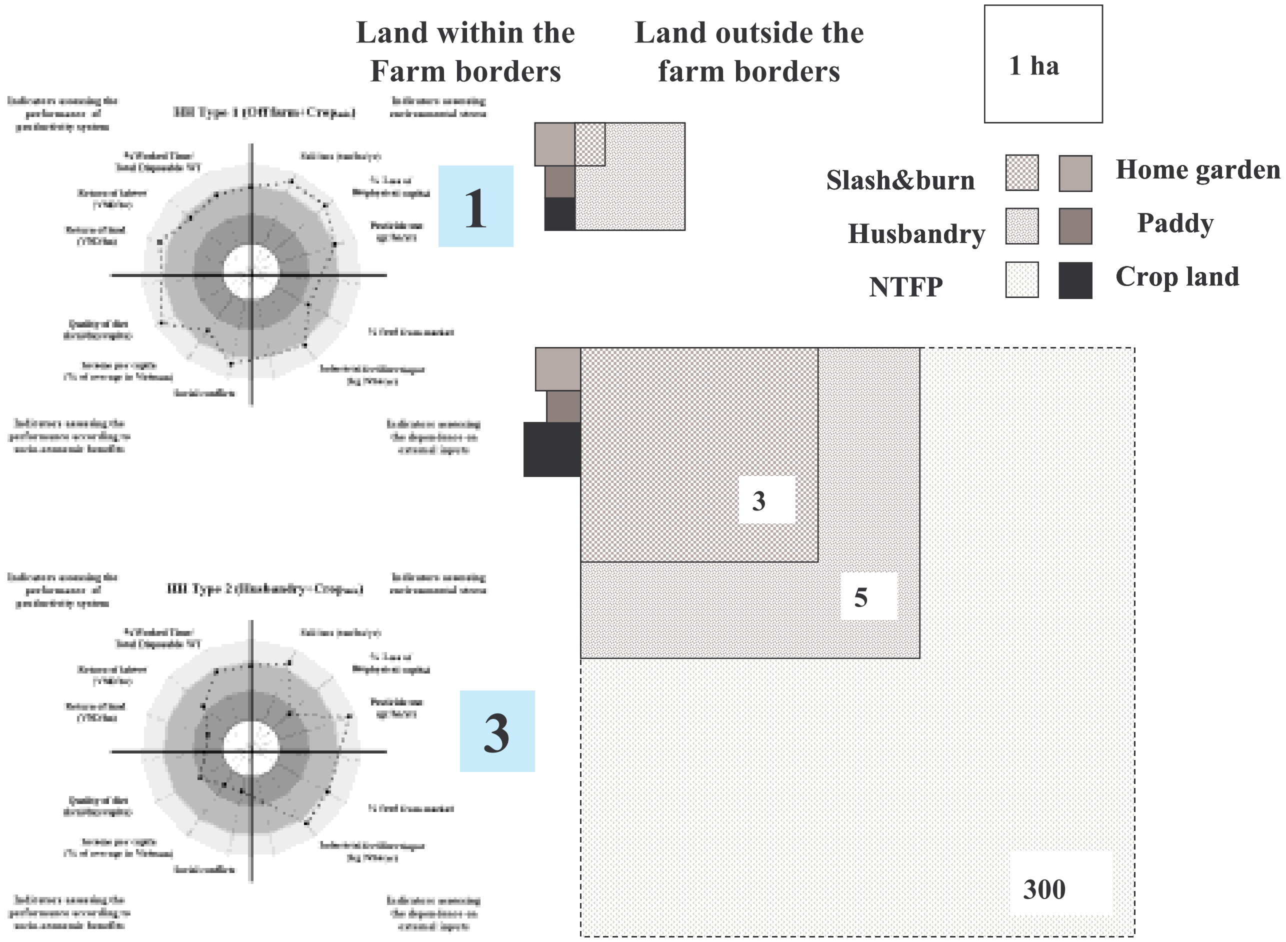


Figure 7.2 *Comparison of Land use pattern: HH Type 1 - Off farm+Crop$_{mix}$ versus HH Type 3 Slash&Burn+Crop$_{mix}$ (see figures in Table 7.5)*

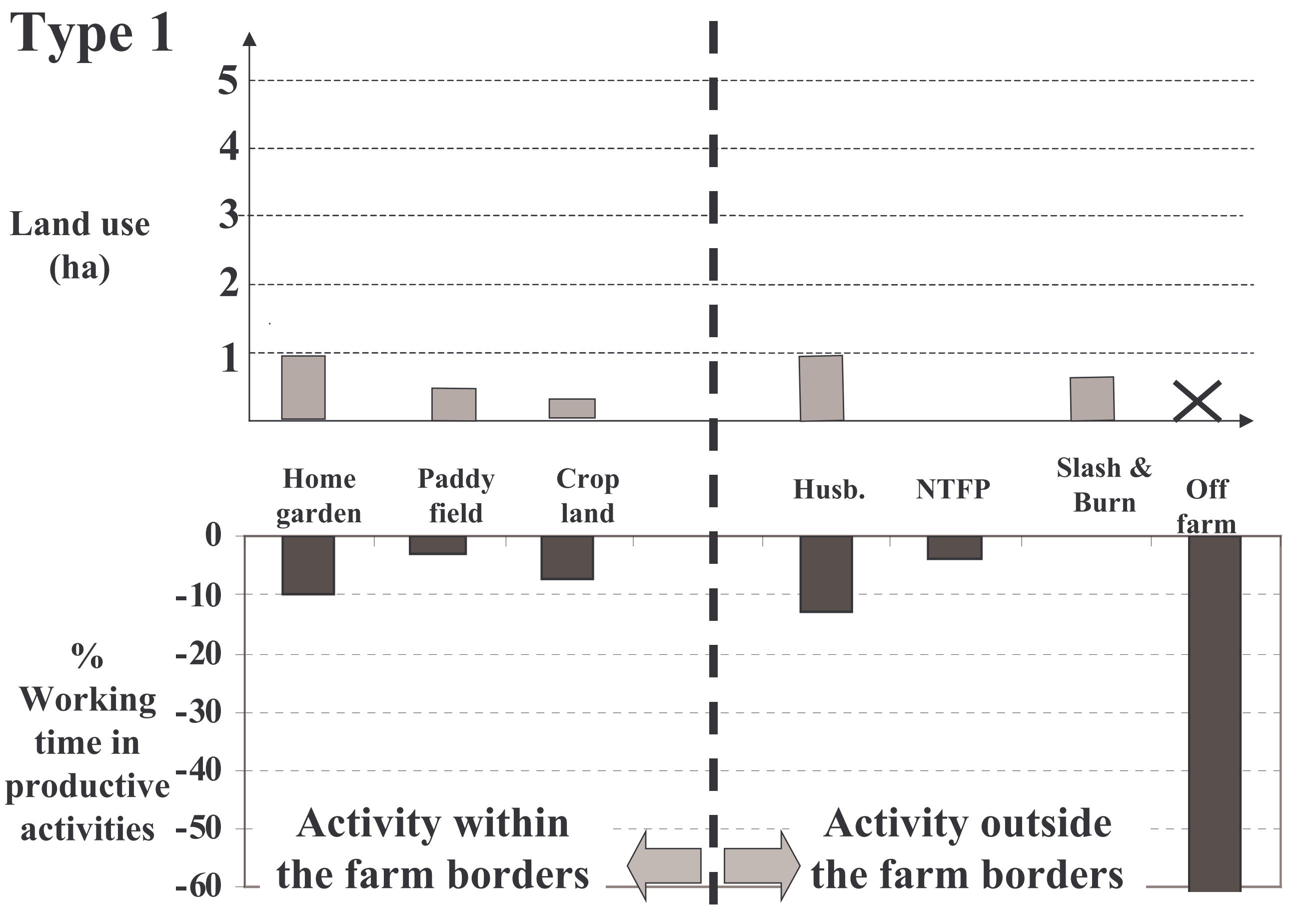


Figure 7.3a *Graphical representation of time-land budget for HH type 1*

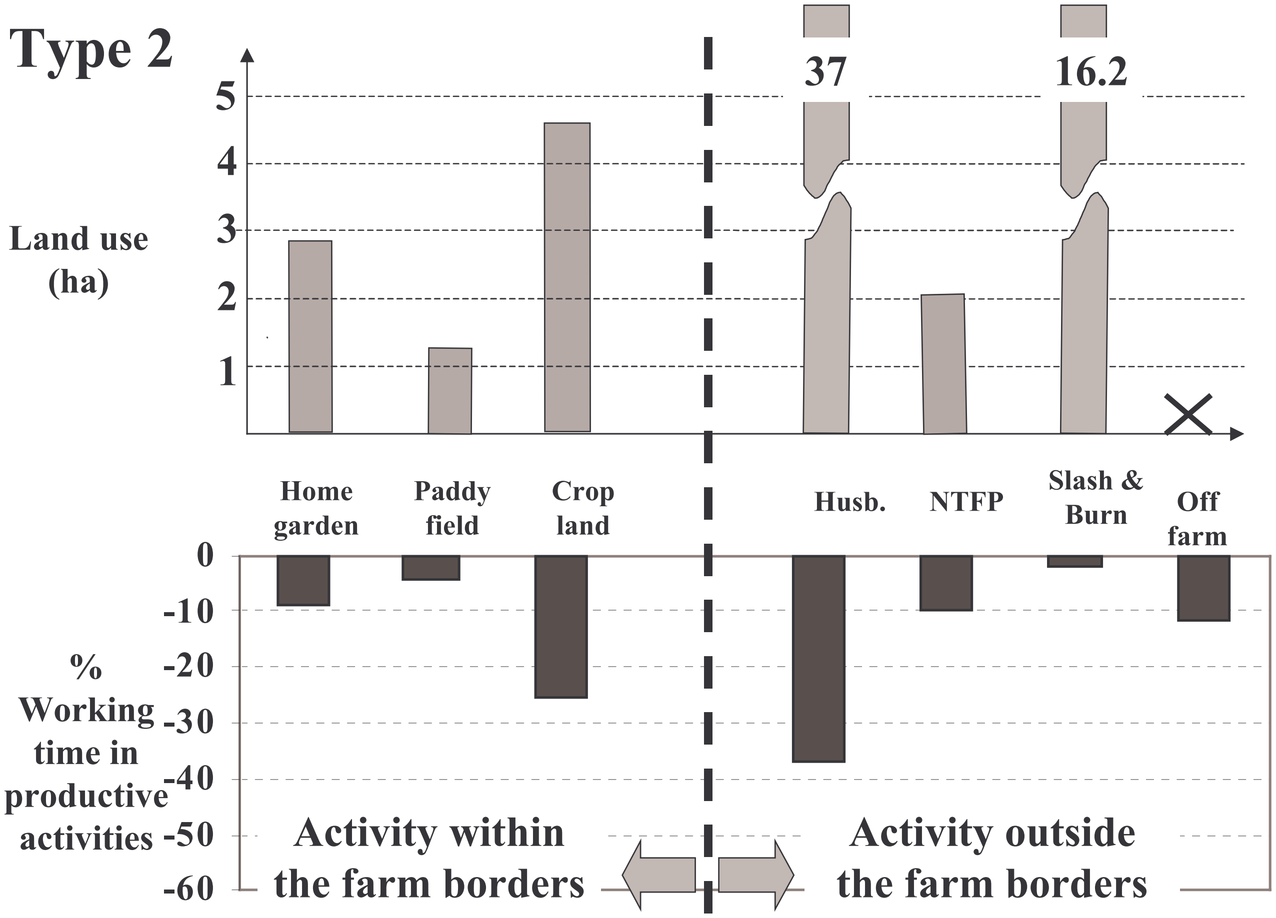


***Figure 7.3b** Graphical representation of time-land budget for HH type 2*

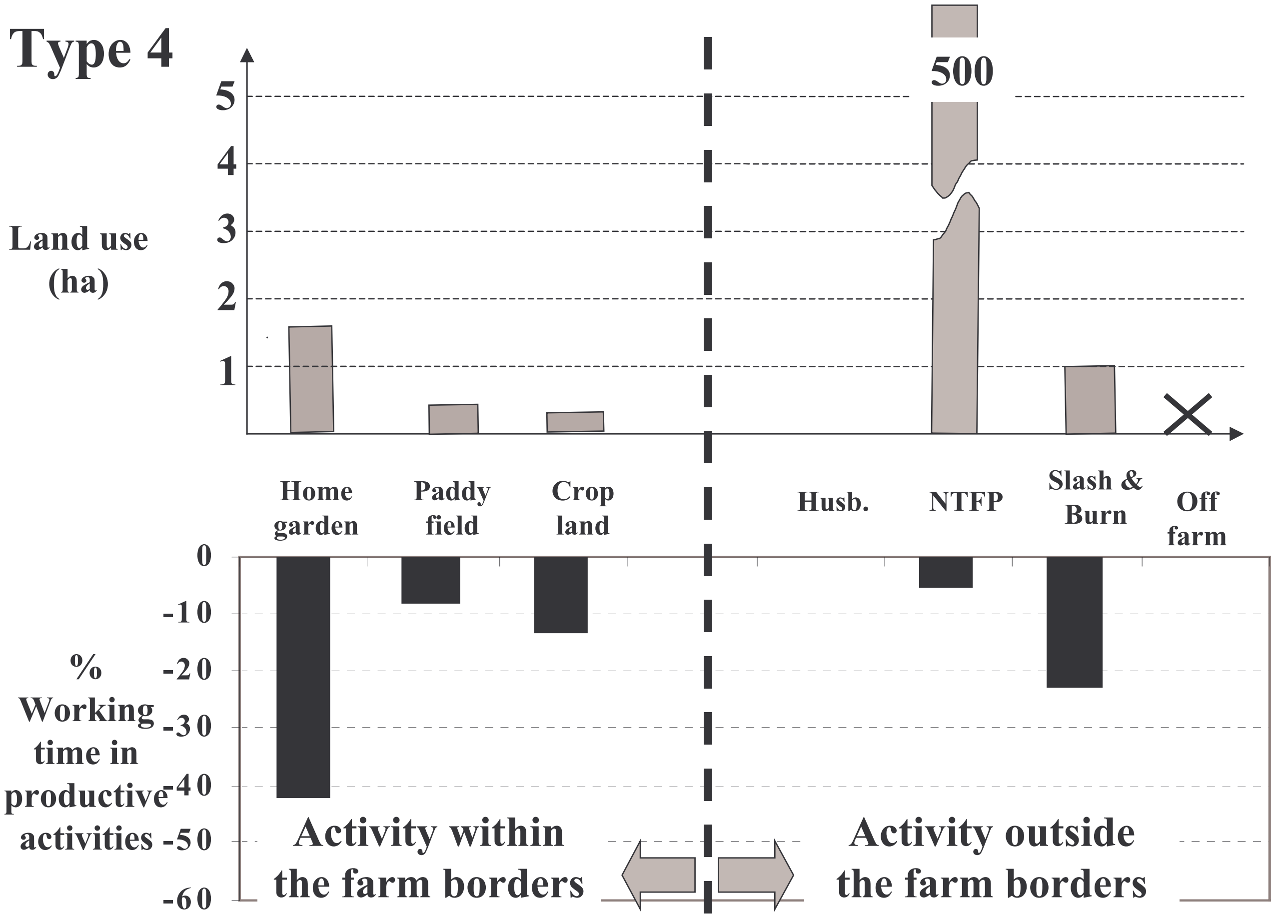


Figure 7.3d *Graphical representation of time-land budget for HH type 4*

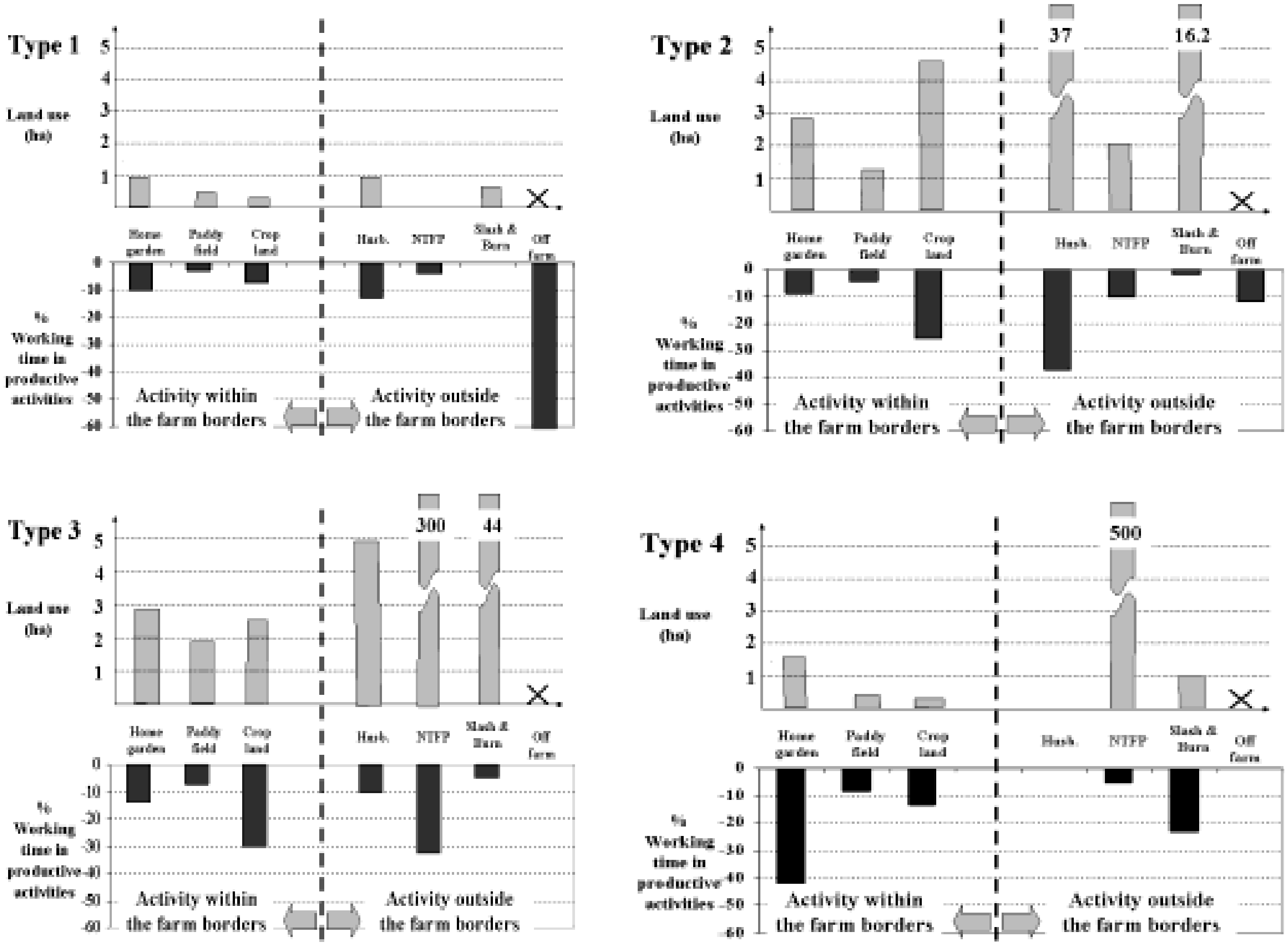


Figure 7.3e *Comparison of the previous graphics*

- ***Facilitating the scaling up***

Another way to represent household farming system is that presented in **Figure 7.4** "St Andrew's Cross" representation, using data from **Table 7.2** and **Table 7.4**.

Figure 7.4 *(see p. 147a) Hierarchical representation using "St Andrew's Cross"*

On the bottom we have the distribution of the time allocation among the different working activities, represented also by the histogram. On top we have a set of indicators considered (just as an example) relevant to inform about the effects of the household farming activity on the higher level, e.g. village, commune. On the left we have a set of indicators though relevant to assess the socio-economic performances of the household. Finally, on the right, we have a set of indicators thought relevant to assess the level of environmental stress caused by the actual farming system practices. (I used the same indicators as those presented in **Table 7.4** just differently organised, one referring to the contribution to tax payment has been added in the graphic). This representation aims at delivering the sense of hierarchical organization of the system. Of course there is a relation of reciprocity between lower and higher levels (one affecting the other and vice versa), even if at different space-time scale. **Figure 7.5a, Figure 7.5b, Figure 7.5c, Figure 7.5d,** presents a comparison among the household types using this type of graphical representation.

Figure 7.5a *(see p. 147b) Hierarchical representation using St Andrew's Cross for HH Type 1 (Off farm+Crop$_{mix}$)*

Figure 7.5b *(see p. 147c) Hierarchical representation using St Andrew's Cross for HH Type 2* ***(****Husbandry+Crop$_{mix}$)*

Figure 7.5c *(see p. 147d) Hierarchical representation using St Andrew's Cross for HH Type 3* ***(****Slash & Burn+Crop$_{mix}$)*

Figure 7.5d *(see p. 147e) Hierarchical representation using St Andrew's Cross for HH Type 4* ***(****NTFP+Crop$_{mix}$)*

7.2.5 Scaling up from the household to the village level

As noted several times in this thesis, different indicators of performance (reflecting the set of given goals) require the use of different space-time scales. That is, a real integrated analysis requires the ability of scaling within our description of the farming system.

The characterization of household types previously discussed (see **Table 7.4**) makes possible to associate at each "household type" a selected set of characteristics referring to: (1) a unit of human activity belonging to the household type, when dealing with indicators of socio-economic performance. and (2) a unit of managed land, when dealing with indicators linked to ecological impact.

At this point, we can characterize a village (made of households belonging to the set of types) by extrapolating its characteristics from the knowledge of: (1) characteristics of the various household types found in it; (2) curve of distribution of the population of households

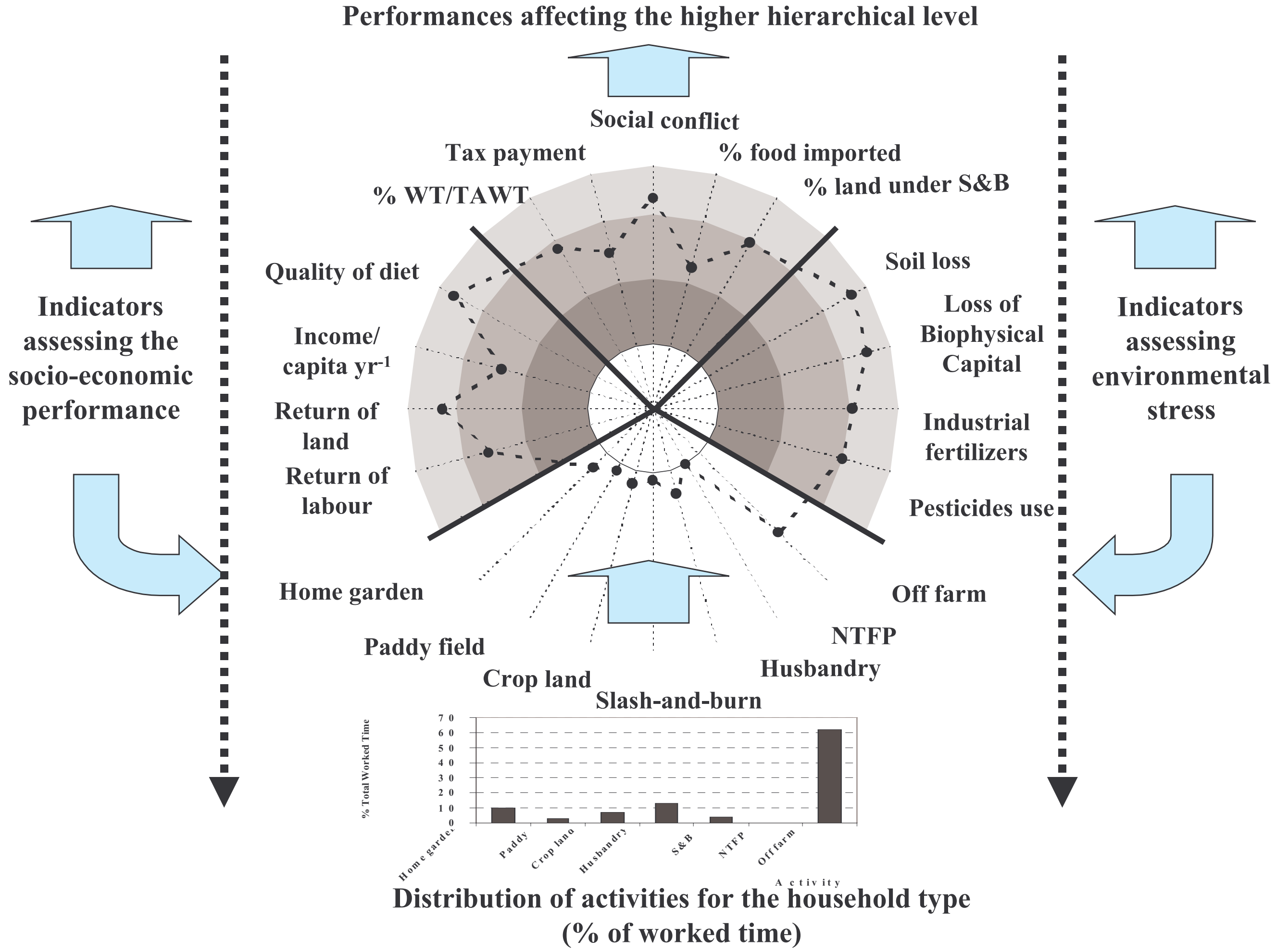


Figure 7.4 *Hierarchical representation using "St Andrew's Cross"*

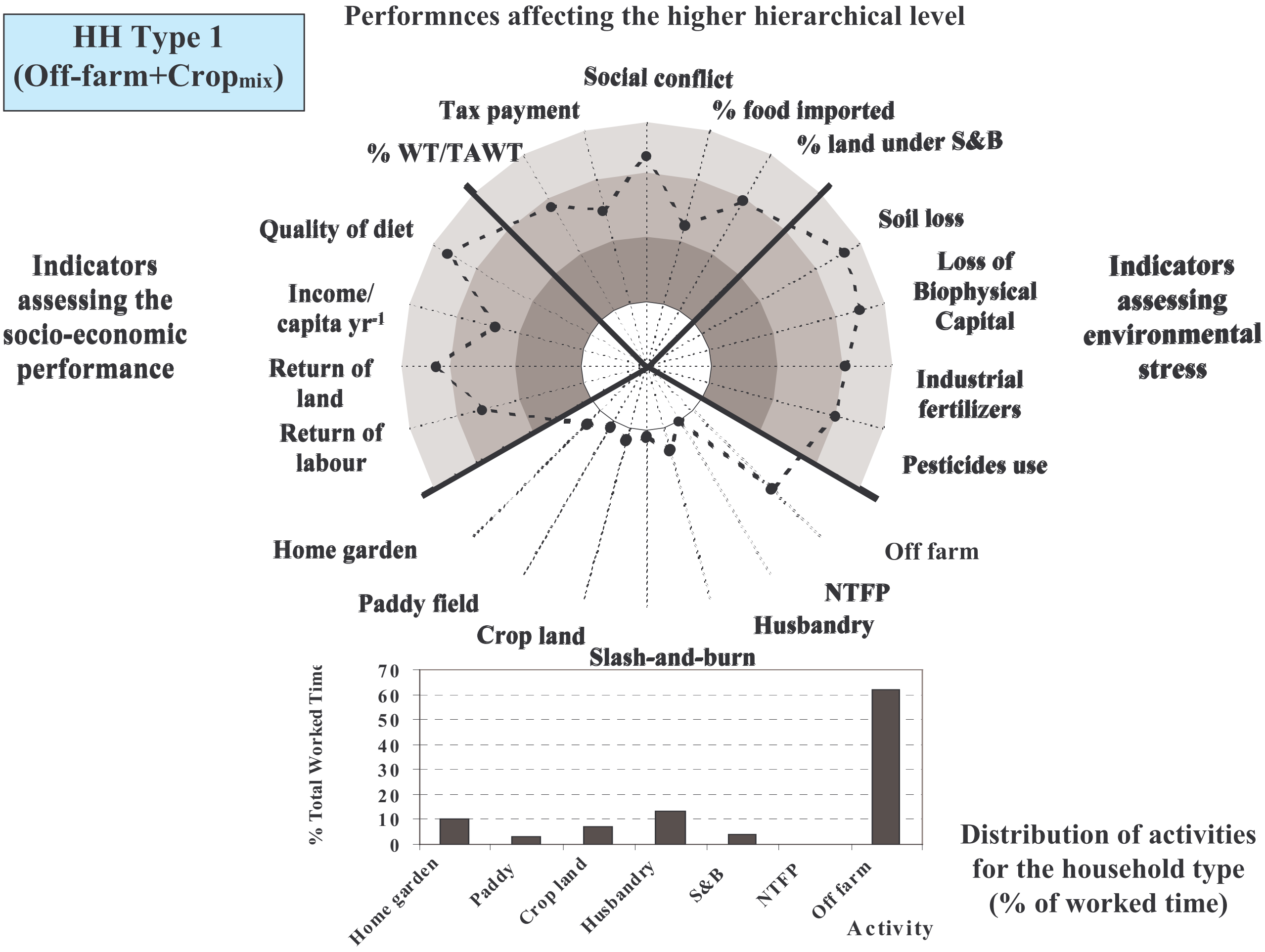


Figure 7.5a *Hierarchical representation using St Andrew's Cross for HH Type 1 (Off farm+Crop$_{mix}$)*

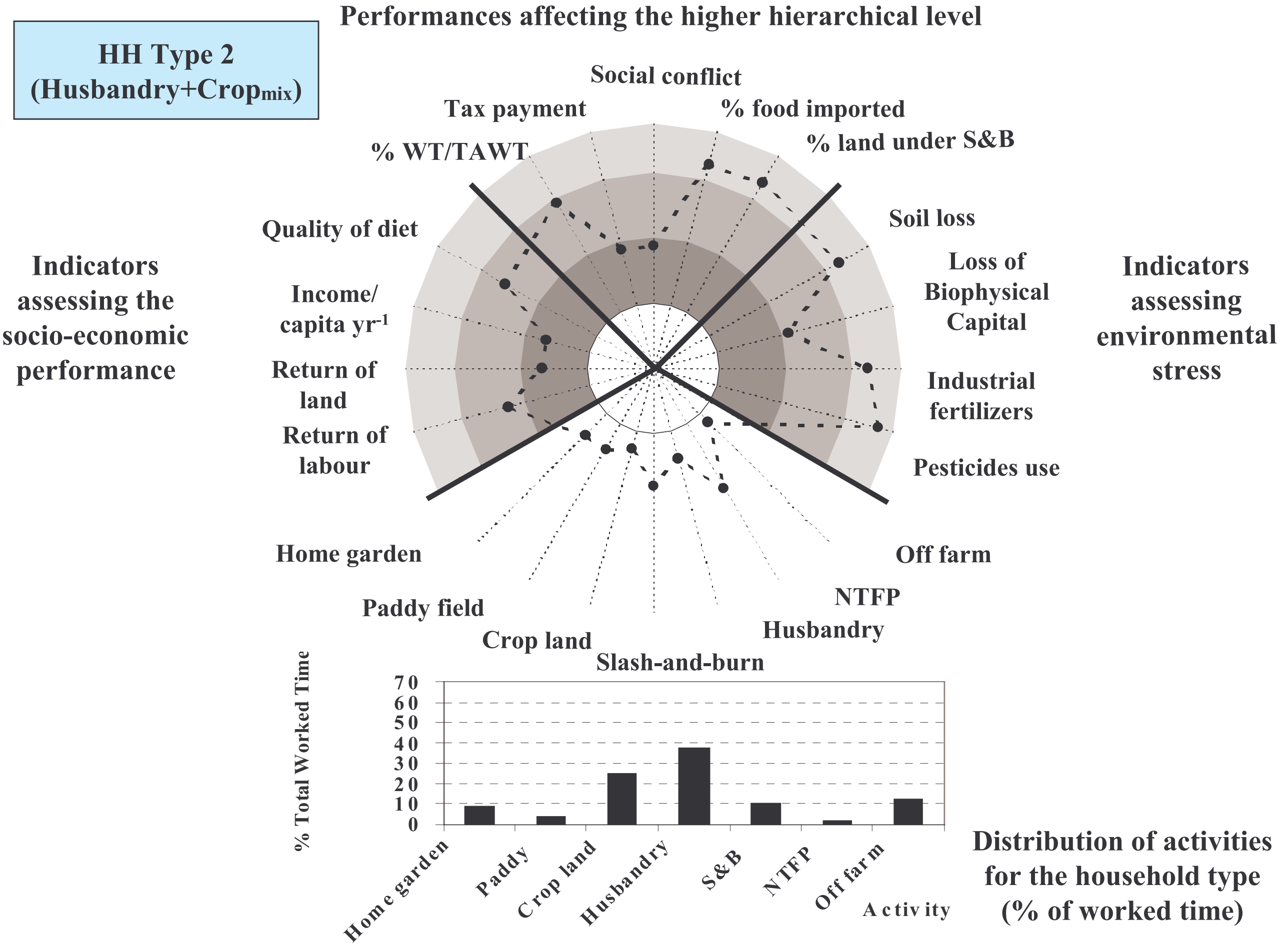


Figure 7.5b *Hierarchical representation using St Andrew's Cross for HH Type 2* **(***Husbandry+Crop*$_{mix}$*)*

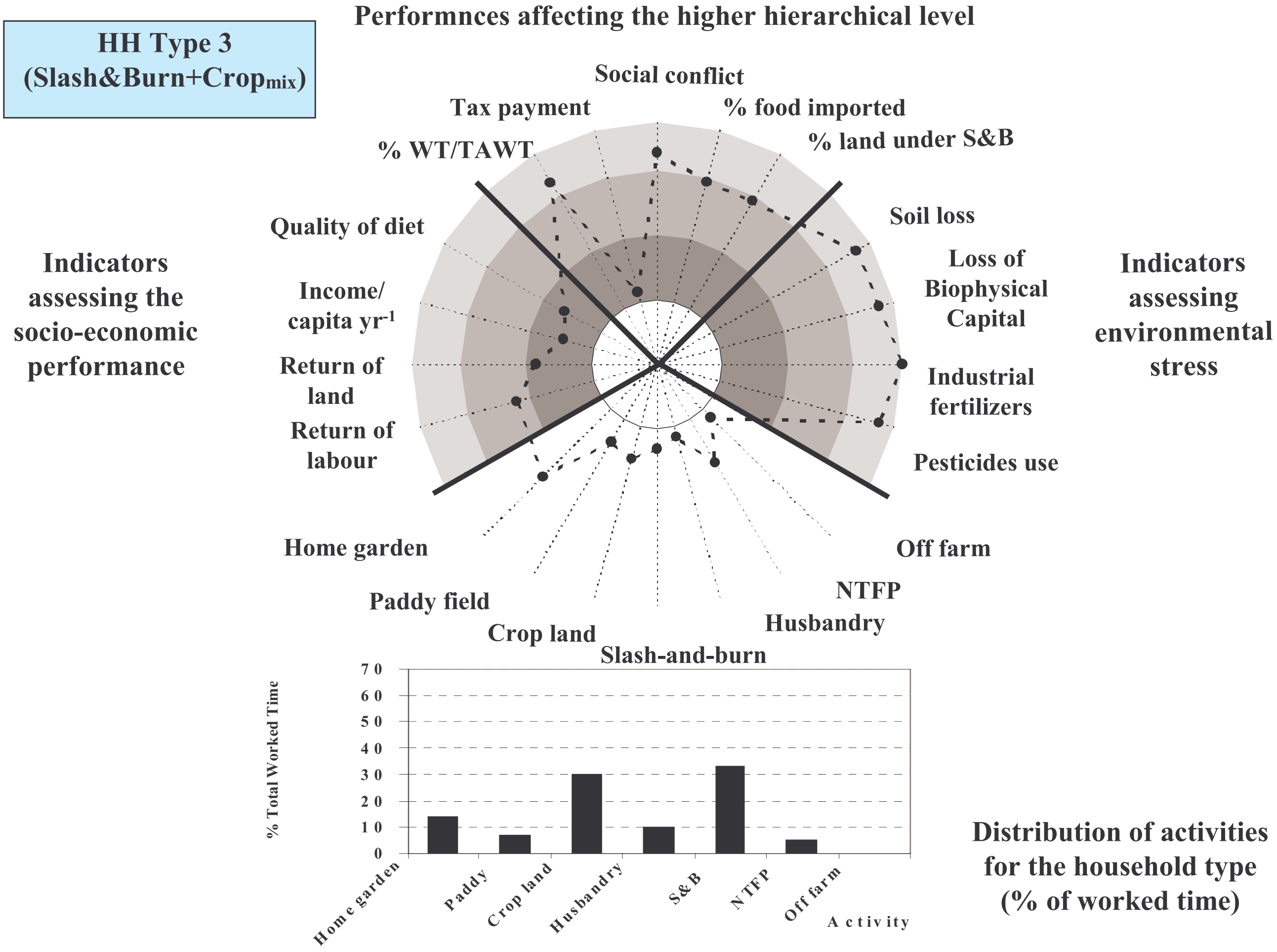


Figure 7.5c *Hierarchical representation using St Andrew's Cross for HH Type 3 (Slash & Burn+Crop$_{mix}$)*

over the set of types; (3) additional information referring to relevant socio-economic processes and land-uses whose agency is at the level of the village, and therefore out of the control of the household considered in step (1) and (2).

This requires processing the information given in: **Table 7.1** and **Table 7.2** - time demand per activity. That can be combined in the information given in **Table 7.5** - land demand per household type and **Table 7.6** - assessments of the economic performance of each household type, according to technical coefficients and economic variables – (e.g. costs, revenues).

***Table** 7.6 (see p. 148a) Socio-economic parameters*

Finally, one has to know the profile of distribution of household types in the 3 villages. In this case study, such a profile is reported in **Table 7.7**. Note that the figure for total households is omitted in the table for this is intended more as an exercise then a statistical analysis (the total households are 39 of which from 15 from Chaman, 9 from Laho and 15 from Doi).

***Table** 7.7. Household type distribution in the three villages*

Village	Type 1 (as % of total)	Type 2 (as % of total)	Type 3 (as % of total)	Type 4 (as % of total)
(1) Chaman	20	33	13	33
(2) Laho	11	44	44	0
(3) Doi	20	20	60	0

Having all the required information, it is possible now to calculate various indicators of performance of the farming system, as resulting at the hierarchical level of village.

That is, the actual distribution of household types found in each of the 3 villages of Thuong Lo has been used to calculate indicators of performance for these three villages, starting from the characteristics of economic revenue and patterns of landscape use known at the household level. In this way, information referring to the village level, can be inferred (in a large extent) from the knowledge of lower level elements (households), and on information not gathered directly at the village level. This requires also, however, additional information, which refers to the village level (reflecting the fraction of land use and human time activity out of the control of the relevant agents defined in the selected set of farming system typologies). In this way, it is possible to establish a link between our knowledge/description of the farming system at the household level with the knowledge/description obtained gathering information at the village level. The parallel use of this information can generate new insights. For example, we can study how gradients in boundary conditions existing among the 3 villages can be associated to different clustering of household types.

That is, in this way we can obtain an integrated assessment of the performance of the farming system in parallel on two distinct levels: (1) **at the household level**, when looking at data organized as in **Table 7.4** and in a family of figures such as **Figures 7.1**, **Figure 7.2**, that

Table 7.6 *Socio-economic parameters*

INDICATORS	Total sample	Type 1 Off farm Crop.$_{mix}$	Type 2 Husb. Crop.$_{mix}$	Type 3 S&B Crop.$_{mix}$	Type 4 NTFP Crop.$_{mix}$
Socio-economic					
Income per HH (1,000VND/yr)	3,166	6,109	3,542	2,077	1,419
Income per capita (1,000VND/yr)	482	1,221	499	301	295
Income per worker (1,000VND/yr)	634	1,584	590	384	443
Income per capita as % of the country (330 US$*= 4.06 mill. VND)	12	30	12	7	7
Income per capita as % of rural area (200 US$*=2,46 mill. VND)	20	50	20	12	12
Av. per cap. inc. equiv. (kg rice/month)$^{\&}$	13.4	34-36	13-14	8-9	8-9
Source of income					
Tot crop land (%)	27	13	31	31	26
Home garden	18	7	25	22	21
Crop land	5	6	6	9	5
Paddy	0	0	0	0	0
NTFP (%)	11	0	6	20	59
S&B (%)	0	0	0	0	0
Husbandry (%)	23	8	37	29	6
Salary/Subsides (%)	44	85	25	20	8
Net Disposable Cash (1,000 VND/yr)					
Per HH	850	1,700	1,100	500	110
Per capita	120	240	150	70	20
*Average return of work (*AR$_W$*) and land (*AR$_L$*)*					
AR$_L$ (1,000 VND/ha/yr) (excluded NTFP and husbandry both for land and income)	2,985	8,737	2,300	800	3,130
AR$_W$(VND/hr) (all the activities are considered)	1,343	2,370	1,085	1,175	1,036
AR$_L$ (VND/ha/yr)$^{\$}$ (included NTFP and husbandry both for land and income)	18,055	8,737,000	35,875	12,346	5,092

Note: 850,000 VND=70 US$ (1US$=12,300 VND - 1997)

(*): UNDP, 1998; World Bank (1997) reports 300 US$; 1US$ (1997) = 12,300 Vietnamese Dong, (&): The Vietnamese Ministry of Soldier Invalid and Social Affairs gives the following classification for HH in the rural area (Do Dinh Sam, 1994): i) Hungry: average per capita income equivalent to 8 kg of rice/month; ii) Poor: average per capita income equivalent to 15-20 kg of rice/month, ($): the large ammount of land required for NTFP lead the average return of land to a dramatic drop.

are available per each household type, and (2) **at the village level**, when looking at data organized as in **Table 7.8** and in a family of figures **Figure 7.6a**, **Figure 7.6b**, **Figure 7.6c**, for each one of the 3 villages.

Table 7.8 *(see p. 149a) Indicators of performance per Village as composed by a mix of household types*

Figure 7.6a *(see p. 149b) MOIR village 1 (Chaman)*

Figure 7.6b *(see p. 149c) MOIR village 2 (Laho)*

Figure 7.6c *(see p. 149d) MOIR village 3, (Doi)*

At each one of the **Figures 7.6** we can associate a map of landscape use as in **Figure 7.7** (the figure is just indicative for I did not have the possibility to get a real GIS analysis of land use).

Figures 7.7 *(see p. 149e) MOIR for a Village and relative land use map (just an example using MOIR for village 2 - Laho)*

7.2.6 Scaling up from Village level to commune level

By following the same procedure used to scale-up from the household level to the village level, we can move up to an integrated representation of the farming system referring to **the commune level** (data still in **Table 7.8**). Expressing again the characteristics of Thuong Lo commune as a combination of the characteristics of the villages making up it. The profile of household types resulting at the hierarchical level of the commune is (**Table 7.9**):

Table 7.9 *Household types distribution in the commune*

	HH Type 1 (as % of total)	HH Type 2 (as % of total)	HH Type 3 (as % of total)	HH Type 4 (as % of total)
Thuong Lo Commune	18	31	36	13

Again this implies:

(1) ***for socio-economic indicators*** - characterizing the Commune as a combination of the characteristics of lower level households, as resulting from the profiles of households in the villages and the profile of villages in the Commune. In this case this new hierarchical level is not requiring significant additional information related to socio-economic processes not reflected by the characteristics of lower level households.

(2) ***for ecological indicators*** - integrating the various maps of land use referring to the 3 villages (as reported in the example given in **Figure 7.7**) at the commune level. The areas considered in the maps describing the village level have to be integrated with those land uses which are out of the control of individual villages.

***Table 7.8** Indicators of performance per Village as composed by a mix of household types*

Indicator	Household types					Values Range	
	Chaman	Laho	Doi	Total Sample		Min.	Max.
Composition as % of household types							
Type 1	20	12	20	18		0	100
Type 2	33	44	20	31		0	100
Type 3	14	44	60	38		0	100
Type 4	33	0	0	13		0	100
Environmental stress							
Soil loss (ton/ha/yr)[sl]	28	67	79	56		13	150
% Biophysical Capital loss[BC]	10	19	17	15		0	100
Nitrogen flow (kg/ha/yr)[N]	50	40	25	25		0	200
Socio-economic performance							
Conflicts	low	very high	very high	very high		Negligible	Very high
% hh income/av. inc. VT	22	20	21	21		0	100[a]
Quality of diet (kcal/capita/day)	2,000	2,000	1,950	2,000		2,100*	2,700-3,000
Performance of productive system							
return/ha (1,000 VND)	3,649	2,344	2,680	2,986		0[b]	11,500[bb]
return/hr	1,337	1,266	1,396	1,344		250[c]	2,500[cc]
%TWedT/TDWT	27	28	27	27		10	100[d]

For note and assumptions see **Table 7.4** (and Annex at the end of the chapter).

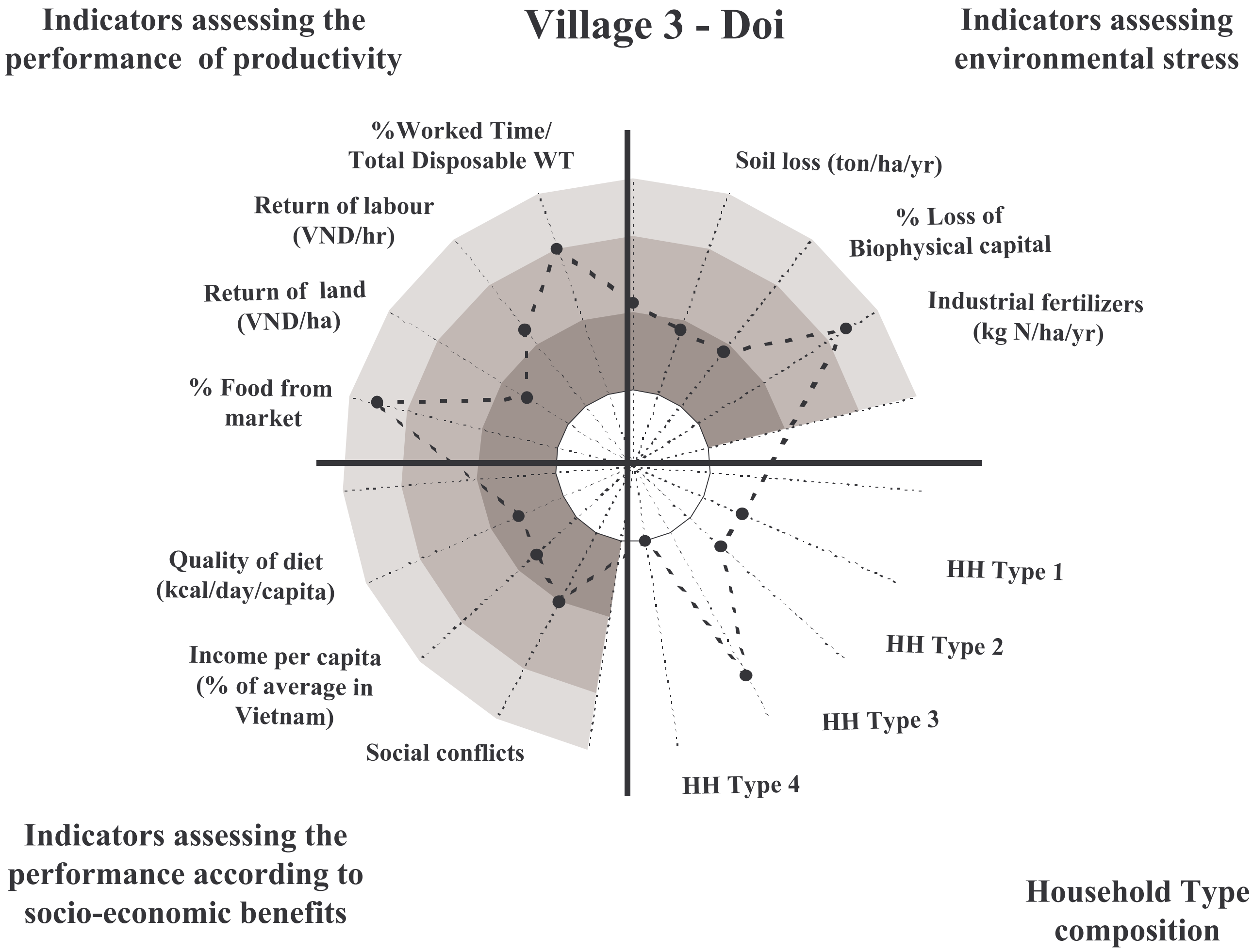
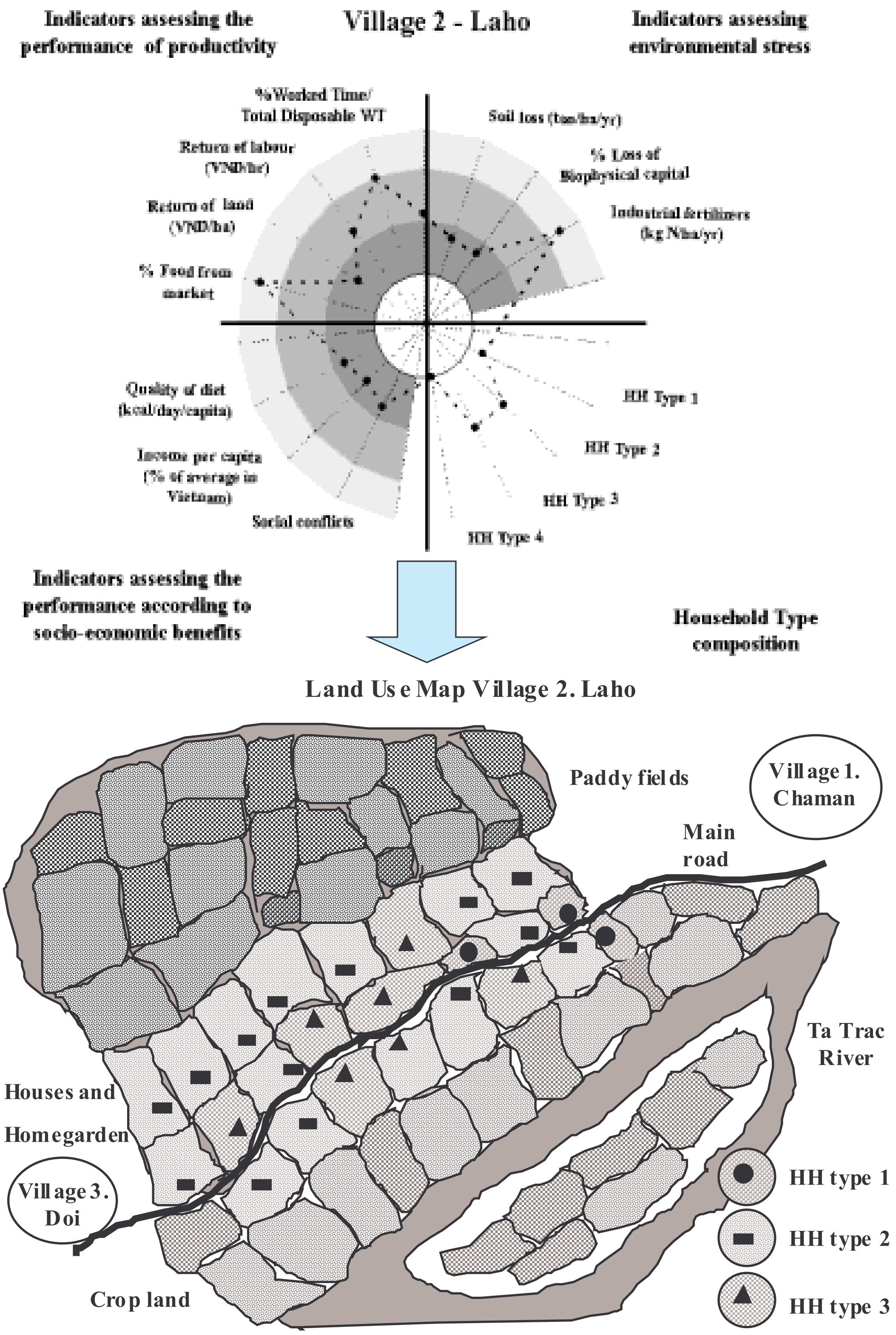


Figure 7.6c MOIR village 3, (Doi)



***Figures** 7.7 MOIR for a Village and relative land use map (just an example using MOIR for village 2 - Laho)*

A multi-objective integrated representation of the Thuong Lo commune is given in **Figure 7.8**.

Figure 7.8 *(see p. 150a) MOIR for Thuong Lo Commune*

The set of data used in **Figure 7.8** to describe the socio-economic performance of the Thuong Lo commune can be compared, at this point, to average values achieved in Vietnam or in the rest of the world, to have an idea of the "big picture" (e.g. how poor is, according to western standards, the richest person in Thuong Lo?). Again MOIR can be integrated with a map of landscape use as done in **Figure 7.9** (just for example).

Figure 7.9 *(see p. 150b) MOIR for Thuong Lo Commune and relative land use map (just an example)*

7.2.7 Possible alternative MOIRs at the Village and commune level

As done in section 7.2.4, also in this case I wish to present a different sort of representation, based on "St Andrew's Cross" to focus on the hierarchical nature of the farming system. Here, again, the figures taken by the indicators result from a weighted average of those of the household types belong to the specific village.

Figure 7.10a *(see p. 150c) Hierarchical representation using St Andrew's Cross for Village 1 (Chaman)*

Figure 7.10b *(see p. 150d) Hierarchical representation using St Andrew's Cross for Village 2 (Laho)*

Figure 7.10c *(see p. 150e) Hierarchical representation using St Andrew's Cross for Village 3 (Doi)*

Again we can infer characteristics of the commune by combining information referring to the households of the sample (**Figure 7.10d**)

Figure 7.10d *(see p. 150f) Hierarchical representation using St Andrew's Cross for Thuong Lo commune*

7.2.8 An overview of MOIRS across scales of this farming system

An overview of the nested hierarchical nature of the integrated representation of farming system described until now is given in **Figure 7.11**.

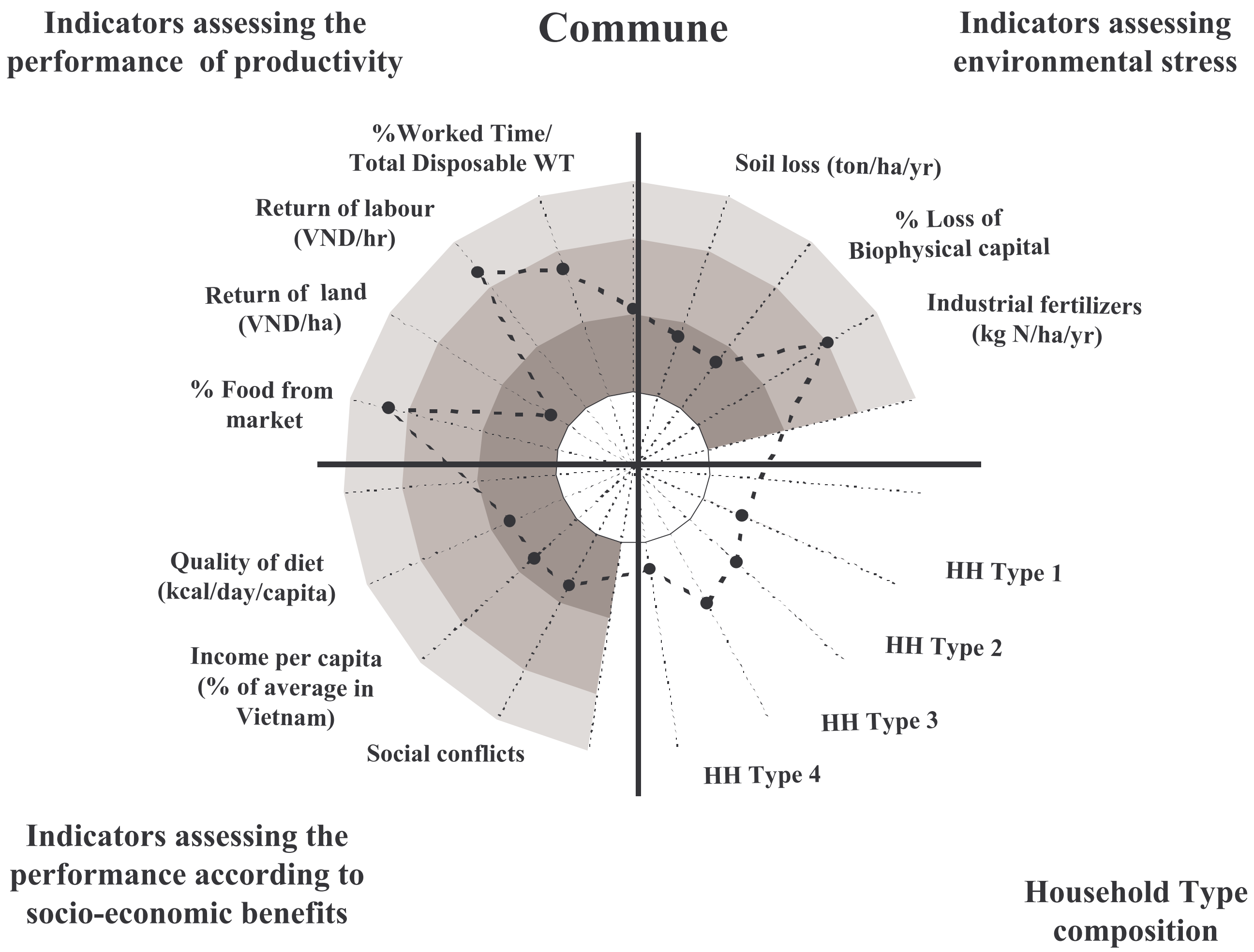


Figure 7.8 MOIR for Thuong Lo Commune

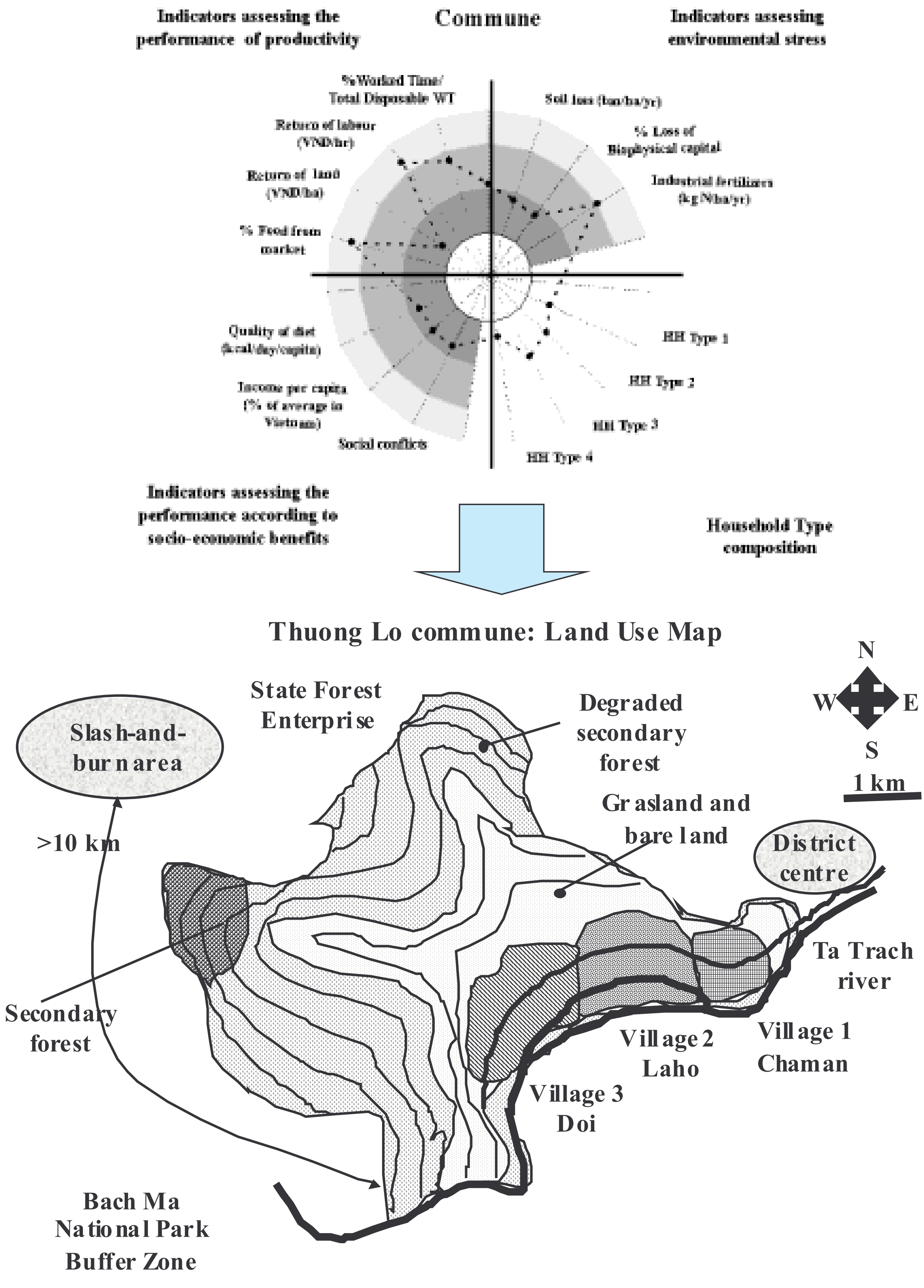


Figure 7.9 *MOIR for Thuong Lo Commune and relative land use map (just an example)*

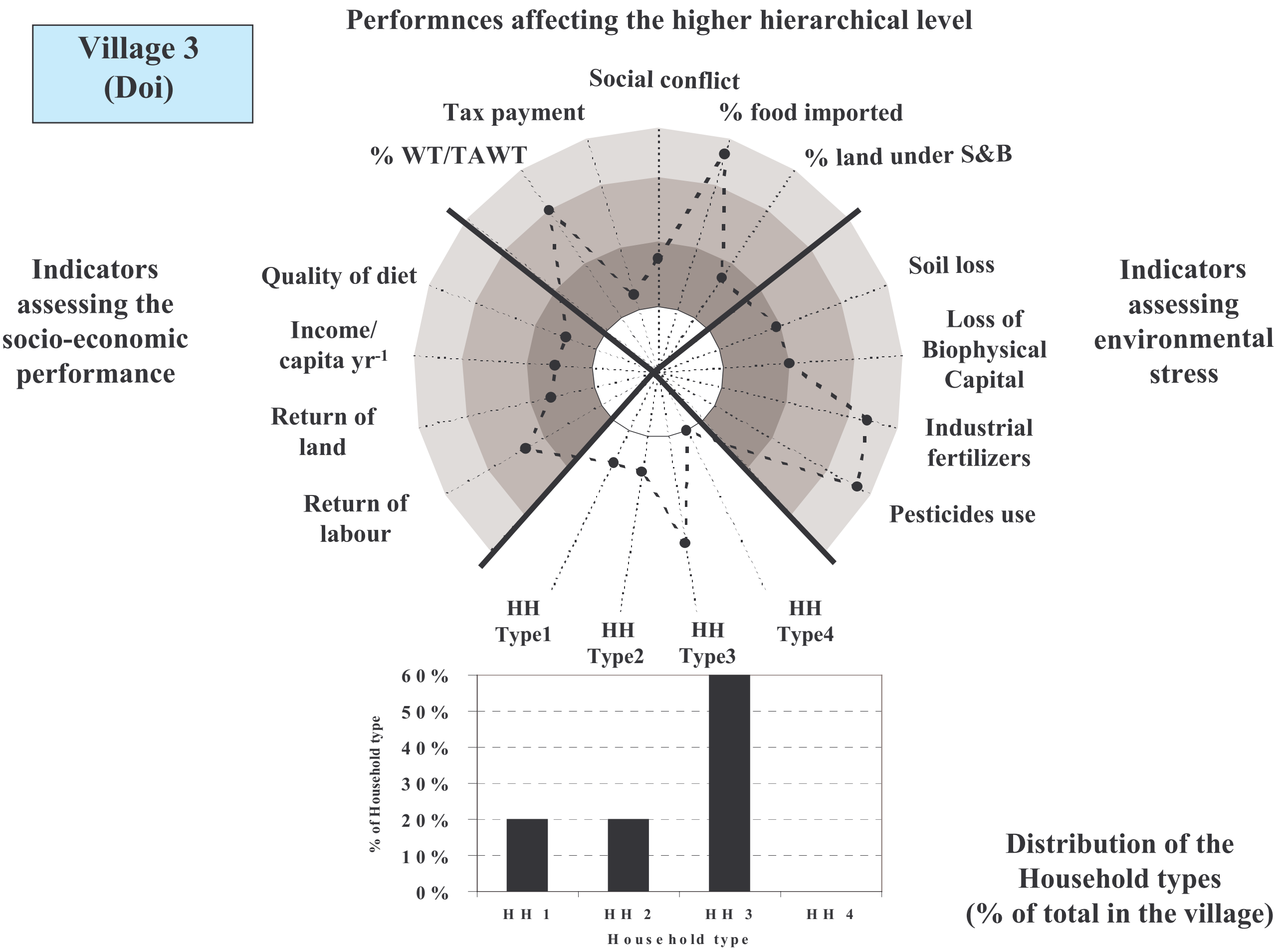


Figure 7.10c *Hierarchical representation using St Andrew's Cross for Village 3 (Doi)*

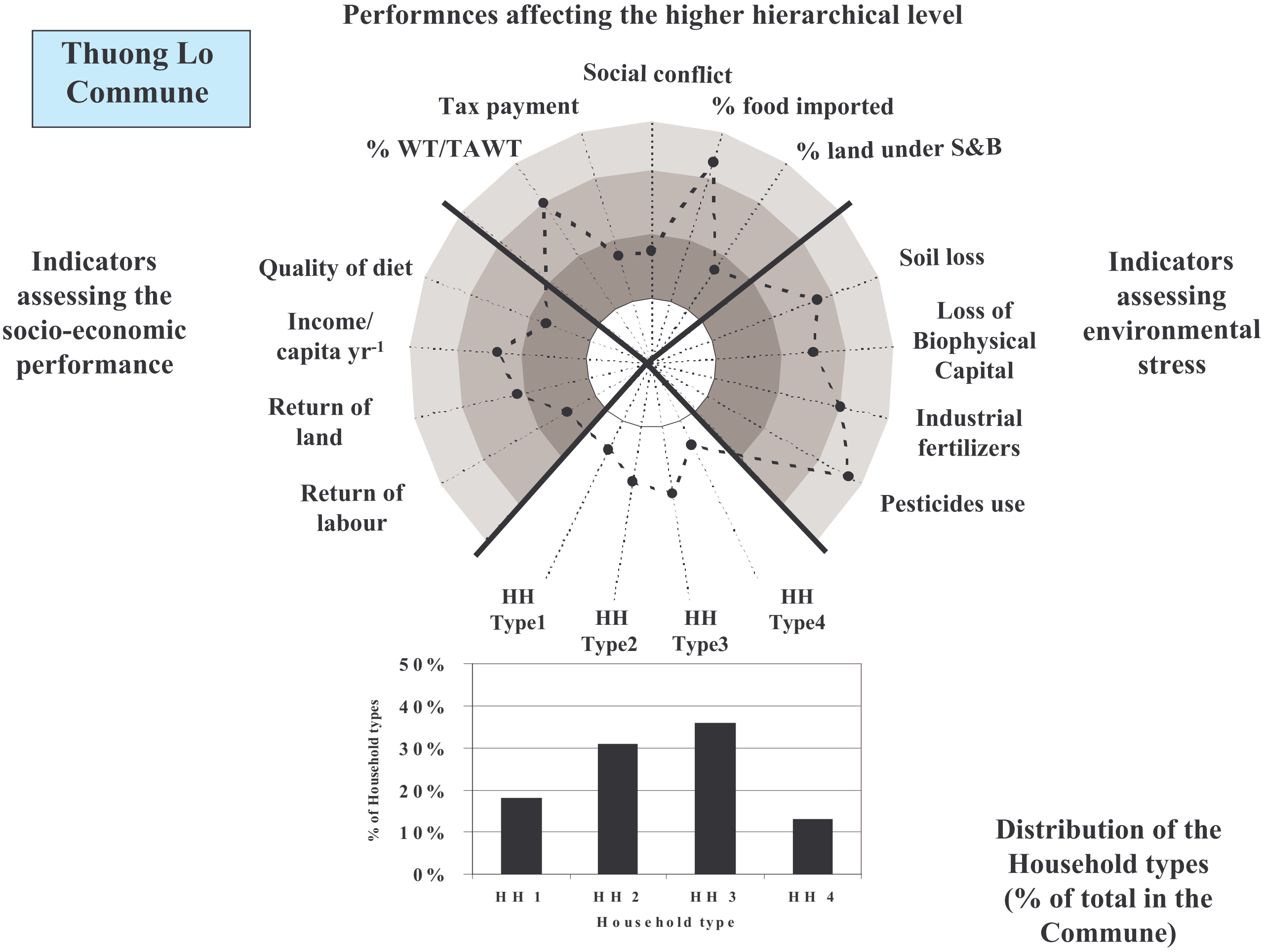


***Figure 7.10d** Hierarchical representation using St Andrew's Cross for Thuong Lo commune*

Figure 7.11 *(see p. 151a) Overview of the nested hierarchical nature of the integrated representation of Thuong Lo farming system*

This representation is based on the definition of "the household level" as "the level ***n***".

- ***Level n-1*** refers to the characterization of the various activities determining the farming system. "Activity mixes" are the relevant elements used to describe the typology of farming households. The characterization of the level n-1 is based on agronomic technical coefficients, economic variables, and characteristics of the natural resources available and their quality (linked to the typology of the exploited ecosystem). In this study, 7 basic relevant activities were identified and included in the various mixes.
- ***Level n*** refers to the household. As discussed before 4 household types were identified according to the profile of investments of working time, and considered as the relevant elements for such a characterization.
- ***Level n+1*** refers to the village to which the households belong. In this case, the 4 household types have been considered as relevant elements to characterize the 3 villages.
- ***Level n+2*** refers to the Thuong Lo commune, characterized by using the villages as relevant elements.
- Depending on the circumstances an additional level "**n+3**" can be used to put our assessments in perspective. For example, how the values found at the level of the commune (in this case n+2) compare with average values in Vietnam (are they above or below the rest of the country? How large is the distance? What about a comparison with the rest of the world?).

At this point it is possible to go through an overview of the various steps described in the previous sections, moving from the bottom of **Figure 7.5** toward the top, trying to establish a relation among all the tables and figures presented up to now.

First step is the definition of technical coefficients, economic variables and the effect of availability and quality of natural resources in this farming system in relation to the 7 activities selected to characterize the farming system (characterization of technical coefficients and their effect on labor and land economic productivity per activity - **Table 7.1**).

By analyzing the land-time budget of each household (**Table 7.2**) and the characteristics of the available activities (from **Table 7.1**), it is possible to look for typologies and their characterization (**Table 7.4**) according to a set of indicators reflecting relevant criteria (**Table 7.3**). This implies moving from level n-1 to level n (the household).

At the household level, it is possible to provide, per each household type, a multi-objective representation of its performance (based on data from **Table 7.4**) - example of this is given in **Figures 7.1** - and a relative map of land use (combining data from **Table 7.1** and **Table 7.4**) as in **Figures 7.2** discussed before. It should be noted that the various objectives (relevant criteria considered) are the same for the various households belonging to this farming system.

Two observations: (A) a spatial representation of land use per each household type is needed, since the indicators of environmental impact presented in the right side of the radar diagram can be applied only to the limited scale of activity of an individual household. To be

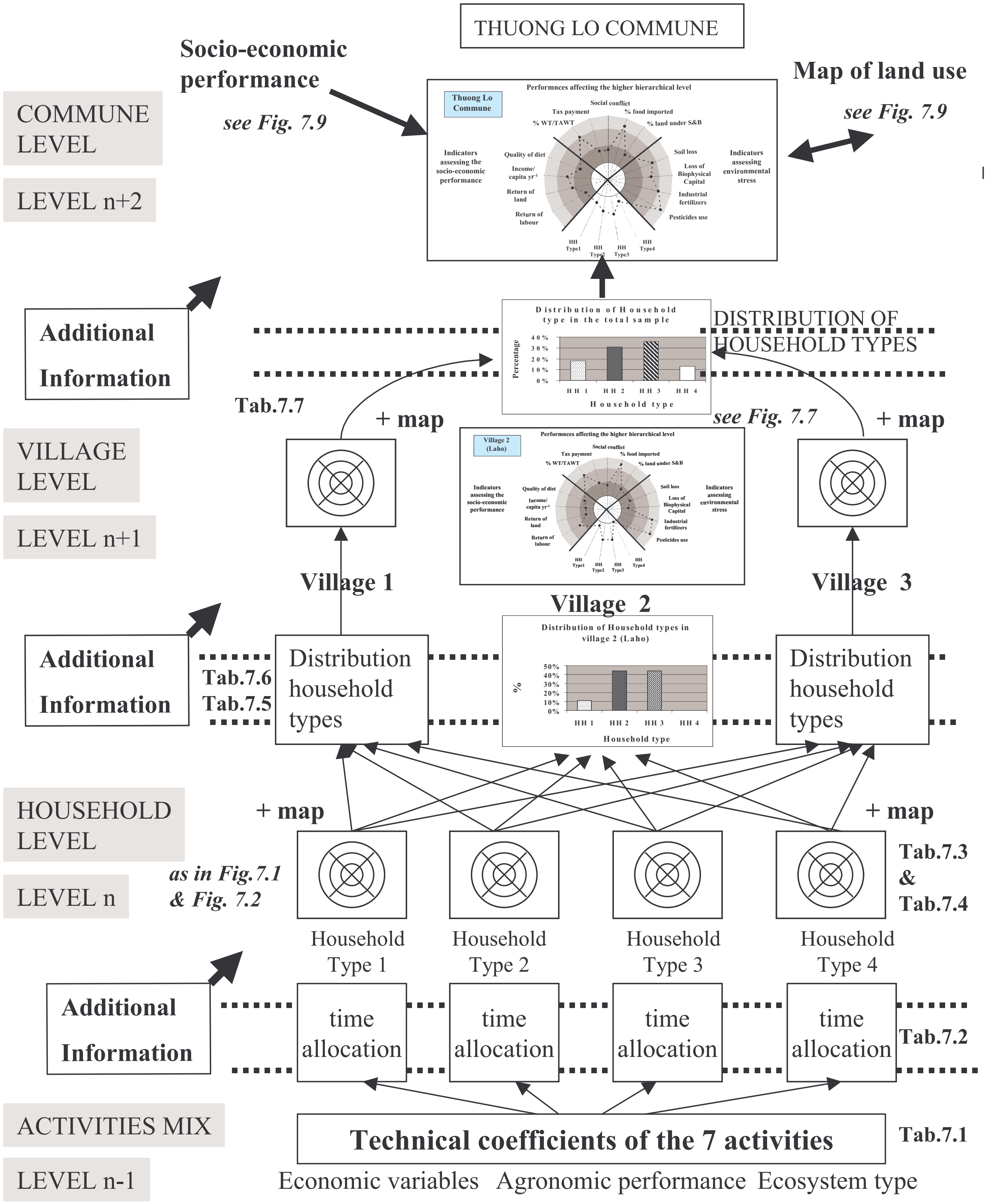


Figure 7.11 *Overview of the nested hierarchical nature of the integrated representation of Thuong Lo farming system*

scaled up, they have to be referred to a geographic analysis of land use. (B) in **Figure 7.12** on the top of the two boxes representing the radar diagram for household type 2 and 3 the indication of "+ ***map***" is missing, but this is due to reason of space – e.g. the map of the household type 3 is given in **Figure 7.2**).

By using the profile of distribution of household types within the 3 villages it is possible now to move from level n to level n+1. That is, it is possible to characterize the 3 villages using the same multi-objective integrate representation used for household - but this time - referred to a larger scale. Obviously, this requires, in relation to the map of land use at the village level, to integrate the information coming from lower level (the amount of land used by each household type and the relative mix of uses – as in **Figure 7.2**) with the view obtained at the village level (where this land is located and what type of additional uses are present in the village, which are out of the handling of individual households).

Following the same logic it is possible to move from level n+1 to the level n+2, and I hope that at this point **Figure 7.5** became self-explanatory for the reader. At the level of the Commune, we can have reached a scale large enough to operationalize some of the indicators of environmental impact that could not be significant at a smaller scale. That is, whether indicators of stress on the soil can be usefully assessed also at the level n, there are other indicators (e.g. nitrogen leakage at the watershed level or loss of habitat for biodiversity) that can be applied only at a larger scale. Depending on the selected indicator – e.g. preservation of biodiversity - even the level n+2 can result too small (in that case we have to organize the information coming from lower levels into a larger scale non-equivalent descriptive domain).

A last observation about the particular configuration taken by the radar diagram used in this application. The radar diagram is based on the St Andrew's cross type:

(1) On the left side we have a set of indicators of socio-economic performance such as: quality of the diet (in kcal/day/capita), income per capita, economic return of land, economic return of labor.

(2) On the right side we have a set of indicators related to environmental stress caused by land uses such as: soil loss, loss of biophysical capital, kg/ha of industrial fertilizers, kg/ha of pesticide.

(3) In the upper side we have a set of indicators that can be use to translate the performance of a given level (let's say ***level k***) to the higher hierarchical level (***level k+1***). That is how the characteristics of lower level elements will affect the characteristics of higher level in relation to the selected set of indicators, per unit of human activity.

(4) In the lower side of the graph, **there are not indicators**. This section is reserved to record the profile of distribution of lower level elements characterized in the level k-1.

7.3 Analysis of the case study using the insight provided by MOIR

The situation of Thuong Lo commune could be easily described as that of a very poor and marginal mountainous area in need for help. A quite common situation found in Vietnamese uplands. In such a context, the forest allocation program implemented by the government seems to not have changed existing trends. In this section, I provide some comments on this failure, as resulting from the integrated analysis presented so far.

7.3.1 Ignoring the co-existence of many different realities (non-equivalent observers)

In ecology it is known that interacting species tend, whenever possible to avoid direct competition for the same resources (diversification of niches). In the same way, in pre-industrial societies, very often, human groups tend to avoid direct competition for the same resource.

Thuong Lo commune may, at first glance, appear as a homogeneous (poor and marginal) reality. However, the picture that emerges when assessing the various farming system strategies at the household level is quite different (of course when the comparison is carried out within its local context). That is, the households there can seem all very similar when assessed against Western standards (e.g. in terms of a range of income compared with international standards). On the contrary, when assessed within their local context they use a large variety of strategies and different mixes of natural resources to survive (to guarantee their own food supply and minimization of risk). That is, although living in the same area, different groups have developed different strategies in the use of the territory along with a different perception of what should be considered as a "resource" or a "threat". Household size, age structure, historical and cultural background (farmers who settled early and farmers who settled later on, farmers who learned how to work with Kinh – the Vietnamese ethnic majority- and farmers who did not) are all factors that can affect: (1) the characteristics of existing household types and (2) the curve of distribution of the population of households over the accessible set of types.

For example, in Thuong Lo commune pasturing animals is a key "resource" for some households and "threat" for others, the latter having their home-gardens or crop land plots destroyed at time by cows, the former having spare working time of children and elderly at zero opportunity cost. Different perceptions generate frictions as well opens conflicts among farmers. In the same way the "allocated land within the new program" is considered a possible "resource" by the government while for local people it is better perceived as a "threat". Most of the farmers have not time or capital to invest in risky activities such as plantation of fruit trees on land far away from home, especially when contracts with the local institutions are not clearly defined and the return on the investment is quite away in time.

In particular the 4 household types found in this analysis can be characterised as having quite different (and non-equivalent) strategies of farming system. That is to say:

(1) For ***household type one*** the most important resource is represented by the off-farm work (generally a job in the public sector). The secure wage guarantees to the household adequate food supply (with rice as staple food) during the entire year, as well as some capital that can be invested in cash crop activities, education for the children, house improvements. People with off farm job are socially better off because they speak good Vietnamese and are well connected inside and outside the commune. These are the farmers that can take part in extension programs and related activities. For them it is also much easier to get credit. Therefore the certainty of wage represents a sort of "social bifurcation" since it shelters these households from the uncertainties characteristics of subsistence agriculture. This provides this group with a major comparative advantage (the possibility of getting positive feed-back from the interaction with the market and central government).

(2) For ***household type two*** cows represent the main source of cash, even though cows are a capital at risk. Cows quite easily can get disease and die. In this case, the problem is how to pay back the credit used to start the activity (or in alternative how to obtain money to pay for the treatments). Generally only farmers who can take the risk (who have a minimum capital available) get in such an activity. Another key factor is the availability of working time to invest in such an activity at low economic return per hour. Therefore, households having available children or elderly, able to take care of cows and that cannot be employed in other more remunerative activities, are more likely to belong in this type. Also for this household type paddy rice and cropland provide the main food supply. Home gardens are also planted with cash crop: fruit trees (oranges, lemon), pepper, banana, pineapple, using a limited quantity of inputs (manure and limited amounts of industrial fertilizers). Diet is maintained around "minimum acceptable standards" and food is purchased when needed (rice and cassava as staple food, with prevalence of rice).

(3) For ***household type three*** slash-and-burn activity is the main source of food supply (with upland rice and cassava). Paddy fields in the commune provide also some basic rice supply for the family. Cropland and home garden are planted with cassava, taro, and dry rice to provide additional food supply (rice and cassava are the staple food, with prevalence of cassava). In the home garden fruit trees (oranges, lemon), bananas, pineapple, are planted as cash crop. However no inputs are used here, and the production is limited (also because of pests). These households are chronically in need of money to buy food (mainly rice). Because of that, the products are sold at low price generally much early than harvest time. Katu farmers, both men and women, are quite shy, so that they dare not to bargain over the price when trying to sell the products on their own in the local market. This is one additional reason explaining their lower return on labour. Their products sold necessarily to middle women are paid less. Social discrimination is also evident in the implementation of extension programs, from which these farmers are generally cut off.

(4) For the ***household type four*** collecting Non Timber Forest Products represents a key resource to get cash in order to buy food supplements. Due to scarcity of cropland, this type is not able to produce sufficient food supply. They cannot afford slash-and-burn activity because they do not have enough work supply to invest in it. Women are caring for small children and men are often alone with the only suitable accessible land located very far away from the house (more then 10 km). They cannot afford to get credit because of lack of resources to cover the risk. Lack of capital and know-how prevent them from investing in cash crop even when they are located in very favourable geographical locations (for example, those living in “village one”, the closest to the district centre). Because of their marginal status, farmers belonging to this type have been cut off in the extension and training exercises. We can say that household type four is the one in the worst situation (lack of work supply, land, capital, know-how, social relations, and more discriminated in the implementation of development programs). Their dramatic situation is reflected in the chronic food shortage that affects this household typology, for which cassava represents the main staple food.

7.3.2 Underestimating the role of resources constraints

Very often experts in cooperation seem to believe that by giving a few seeds and advice to rural populations it is possible to dramatically change their situation. Ecological principles, on the other hand, clearly indicate that if you want to take out from a terrestrial ecosystems much more biomass than before – when introducing new agronomic techniques - you have to return much more nutrients to the soil (to replace those harvested away). That is, beyond a certain limit, intensification of agriculture requires an increased use of inputs. This is turn requires the possibility of purchasing these productive inputs on the market. Such a purchasing, obviously, is possible only if the products can then be sold by the farmers at an adequate economic return. The last assumption, relies on the existence of consumers in the area with a certain purchasing power. If these conditions are not fulfilled, seeds, advice and good intentions have little probability to succeed in boosting either the economic and the biophysical performance of the farming system considered.

From these obvious considerations we can make the following points about our case study:

A. The saturation of the existing resource basis implies that intensification can only be obtained by increasing the inflow of inputs

Agricultural land of the commune accounts for 80 ha or 0.08 ha per capita; forest land accounts for 839 ha or 0.9 ha per capita. When considering a rate of population growth (in 1997), of 3%, it is easy to arrive at the conclusion that the system is already beyond existing carrying capacity with a scaring future ahead. The very fact that already about 60% of food supply came from slash-and-burn agriculture, which is performed outside the boundaries of the commune, says it all. In addition to that, the reduction of the fallow period to just 4-5 years (by farmers that know very well how to manage such a farming system and how unsustainable is this practice) indicates that also this emergency resource has been saturated years ago. A collapse of this farming system can be expected quite soon.

The collection of Non Timber Forest Products, such as rattan and honey (the most profitable activities although very harsh and risky) is also experiencing a decreasing marginal return and, at the moment is carried on only by the poorest farmers.

In conclusion, it is not to exclude that in this system there is room for some technical improvements. Better techniques of rotation can be experimented, some hectares of bottom hill land can be converted from the present poorly growing Eucalyptus plantations into better agro-forestry practices. However, our point is that the big picture cannot remain but critical.

B. The land allocated in this project did not represent a resource for local people

The land “allocated” by the program (269 ha, 28% of the commune area, 0.3 ha per capita) does not represent a change in the set of possible “activity mixes” available right now to the households in this area. According to the government such land should be reforested by the new owners with plantations or used for agroforestry. However, several factors made this “perspective” of the government dramatically different from the perspective of local farmers: (1) the amount of land allocated per farmer is small and split in two or three plots. This implies a huge demand of working time (just to move from one plot to another); (2) the quality of the land allocated is very poor (mostly degraded, bare land); (3) the required economic investment to start an exploitation of this land represents an unbearable burden for most of the farmers. Therefore, the option of taking care of these allocated plots, basically has not been included in the “activity mix” of the various household types (among the set of viable activities that can be adopted to stabilize the societal metabolism of this community).

Obviously, this allocated land may represent a resource for the fact that it is possible to sell the allocation contract, or to use the contract to get credit from the bank. However, only few farmers are willing to face the heavy commitments required when enrolling into the program to take advantage of this opportunity.

7.4 Conclusion

The cases study illustrated in this chapter indicates that the conceptual approach of MOIR makes it possible to better deal with the following crucial points:

(1) Large scale generalizations can miss important “location specific” characteristics. In the same way, focusing on “location specific” issues carries the risk of loosing the “big picture”. This implies that, even when remaining in the same country – in this case Vietnam - policies valid in one area must be checked, at the local level, to know whether or not they hold their validity in a different area. On the other hand, coming to the “big picture”, when comparing the characterization of local communities – in socioeconomic terms - with average values registered at the country level and/or to international standards we are forced to observe that traditional farming systems of slash and burn have very little chances to be economically sustainable in the future if forced to interact without protection with socio-economic systems operating at a much higher speed.

(2) Understanding farming system as nested hierarchical systems forces us to deal with the concept of multiple-scale, meaning that there are relevant different dimensions and spatio-temporal scales at which events are occurring. Differences in the representation of elements on different levels can be so large that it is often necessary to change descriptive domain to “see” what is going on at different levels. Even when operating at the level of a given province or village, we can face a situation in which different households (with a different culture and history), can have a very different perception of risks and opportunities, or different access to technology and resources, or even different goals. Especially when dealing with ethnic minorities, it is crucial to understand “what” each of the individual household types actually “sees” (their “emic” perspective), because their perceptions of their context can be quite different, even if – when from the outside by adopting an “etic” perspective - they seem all be operating in the same context.

Technical Annex Chapter 7: Assumptions and assessments

This annex provides:

- ***(A) Assumptions and assessments for time allocation in the activities performed by the households;***
- ***(B) Assumptions and assessments used for the indicators of performance.***

(A) Assumptions and assessments for time allocation in the activities performed by the households

I wish to point out that the following assumptions have been made according to the information collected by interviews, as well as confronting data from literature for similar contexts. Assumtion then have been cross-checked with a Vietnamese collegue.

- **Working time allocated to the characteristic mix of productive activities**

Home garden

For the activities concerning the management of the home garden I estimated a requirement of household working time of 1-2 hours days, averaged out on every day of the year (it is to say 360-720 hours/years). The time allocated depending on: the area, structure, and number of species in the homegarden (market oriented home garden requires more time then homegarden for self-consumption). Activities carried on in the home garden are: planting, tinning, pruning, fertilizing (collecting green manure and preparing compost), fencing, harvesting, weeding, killing plants pest etc. Generally adult males carry on heavy activities (e.g. planting, fencing), while adult female and children are in charge of lighter activities (e.g. weeding, harvesting).

Paddy field

A plot of paddy field of 1000 m^2 requires about 2 full weeks (14 days) of work per rice crop: ploughing, planting rice seed, transplanting, water etc. (14 days per 8 working hours per day per crop). Then I added 3 days per crop for related activities such as cleaning and drying the rice). So I estimated that a plot of 1000 m^2 (one crop), requires 14+3=17 working days/man. For 2 crops I estimated 34 working days. In this activity the division of the labour is quite clear with males in charge of the ploughing and fertilizing, and females taking care for planting and transplanting seedling. Harvest (to be completed as fast as possible), see involved all the members of the household able to work.

Crop land (in the commune)

A plot of 1000 m^2 requires about 60-70 working days per years (1 working day per person, 8 hours/day). In the work I used an estimate of 70 days per year per 1000 m^2. In the crop land usually farmers integrate beans, corn, cassava and other starchy roots, vegetable, etc. (sometime dry rice). A part from some heavy task (ploughing when needed) females are those in the household who take care to manage such a plots. Generally women and youngsters are in charge of the weeding.

Allocated land

According to the interviews I estimated as amounting at 5 days per year the time allocated in the allocated plots (only a time to time survey, and a rough weeding). Allocated land are generally degraded or bare land located on the sloping land surrounding the commune. Activities on the allocated plots are carried on only by adult males.

Husbandry

I estimated a time allocation of 6 hours per day per 365 days/yr to take cows to pasture land and tending them. Due to the relative easy task this activity is carried on generally by children and elderly who cannot supply work for other, more productive, household activities. Households with only one cow could feed it, at least in part, in cowshed in the home garden. However because of collecting the necessary amount of feed requires investing both time and physical effort, cows are leaded to graze in the surrounding plantations, and marginal land of the commune. Having more then a cow requires necessarily to take them grazing, and it makes necessary to employ a person full time. Cow grazing in the commune land are often reason of conflicts among farmers because of the damages cause by cows pasturing on the neighbour plots (sometime even in the homegardens).

Off farm

I considered as 300 working days/year (with a working day of 8 hours) the time allocated to off farm activities. It is to say 365 day minus 48 Sundays (Saturday is a woking day) minus 15 days/year of national hollidays. (For other special employs, such as teaching, medleman, I considered time allocation otherwise according to the information suppled during the interviews. In Thuong Lo commune, apart from a few rare exceptions, only men have off farm employ.

Non Timber Forest Products (collection of)

I estimated that a working day of such an activity consists of 10 working hours. Each trip to the forest usually means for farmers to spend a week (6-7 days) there, trying to collect as much products as possible. Because of the very harsh and risky working conditions it seems that for this activity generally no more then a month per year can be affrodable. This activity is strictly a man work, from the age 13-15 boys may sometimes go to the forest for a couple of days to collect grasses and mushrooms (easy to get and carry home).

Slash-and-burn

I estimated that 1 ha of slash-and-burn field requires about 240 working days per year (slashing, burning, sowing, weeding, tending, harvesting). I included 5-6 days per year per capita spent to go backwards and forwards from the commune to the slash-and-burn area (there are four slash-and-burn settlements in the forest which distance form the commune range from about 7-8 to about 15-18 km). The fact that part of the family may spend long time in the forest settelments has impornat implication when assessing time allocation in the household chores. In the slash-and-burn activity adult males carry on the shalshing, burning and along with female planting, harvesting, tending and weeding (youngsters also take part in the latter three activities) (**Table 7.10**).

Table 7.10 *(see p. 159a) Time allocation in slash-and-burn activities*

Chores

I estimated households allocating on average about 700 hours per capita per year on chores activities - the time spent on activities for the household self maintenance - such as fetching water, collecting fuel wood, preparing and cooking food, market, house maintenance etc. (see **Table 7.11**).

Table 7.11 *(see p. 159b) Assessment of the time allocated to chore activities*

The "double residence" issue

As mentioned elsewhere the reality of the farming system in Thuong Lo is very complex (as it is always in the subsistence rural world). Households cultivating plots in Chamong have a "double residence", it is to say that the working force lives for long period of time in a camp in the slash-and-burn area, and the young children are looked after by older sisters or brothers who stay at home in the village. The time spent in Chamong for the working force of a family can ammount to 4-5 months per year to carry on the cultivation of the fields and tending the crops. Some families are spending there most of their time. This has important implication when estimating time allocation in chores because of this time results doubled. Although I made the attempt to assess the time allocated by the families in displacement from the commune to the slash-and-burn settlements, I have to point out about the difficulties that such an estimate has to face with.

How feeding strategies for pig raising does affect overall time allocation of the household.

Pigs kept feeding in the pigsty drammatically increase the working time allocated to fuelwod collection, meal preparation and cooking. A 5 people family rearing a couple of pigs can double the time allocated to these activities. Generally only household who can afford to buy feeds and have a surplus of work can "afford" to rear pigs in pigsty, or simply are the only one who can keep pigs.

Table 7.10 Time allocation in slash-and-burn activities

Activity	For 1.0 ha (day/man)
Rice	
Planting [a]	30-40
Ssowing	8
Weeding[b]	20 per 2 times= 40
Harvesting	10
Tot. rice	86-96
Corn*	15
Cassava	
Planting	8
Weeding[c]	15-20 per 2 times= 30-40
Harvesting	20
Tot. cassava	53-63
Tending[&]	20
Time backward and forward to the plots[d]	20
Time backward and forward to the camp[e]	20
TOT	**≈240**

(a): Not all the trees in the plot and cut, care is due in clearing the plots' borders to halt the fire from extending to the next vegetation (possibly to plots belonging to other families)

(b): Plots have to be kept cleaned from weeds because of the high competition for both soil nutrients.

(c): Cassava needs weeding during the first couple of months, then the dense leaves cover provides shadow that limits the growth of wild grasses.

(d): It has to be noted that slash-and-burn plots are located on the smooth sloping land of the valleys surrounding the farmer settlements. It means that to reach the plots under cultivation, farmers have to walk for a few kilometres into the forest or along the river branches. The nature of the access to the plots also affects the time allocated to harvest. Farmers in fact, have to carry home on their back the crops (15-20 kg per time). At first to the hut of the forest settlement, and then to their home in the commune, a very tiresome and exhausting activities in which also women take part in (taking into accounts also the local climatic condition).

(e): I estimated that forward and backward from the commune requires 6-7 days per year. Assuming that 3-4 people per household are fully involved in the activity it means that the time allocated to the trips amounts to about 20 day per year).

(*): Corn is planted along with rice (at low density) but harvested later in the season.

(&): Tending is an important activity for sparing the plots from wild pigs that use to feed on the crops. Farmers search for signs of wild pigs intrusion and cast traps along the field margins as countermeasure. The presence of traps along the field margins makes dangerous walking around the fields, and times to time accidents (as well pig captures) are reported to happen. In some years mouse represents a plague and can reduce to less then 50% the yield. Although farmers cast traps and hunt them this does not seems help very much to save the crops.

Table 7.11 Assessment of the time allocated to chore activities

Activity (average hours per day)	**Household dimension**	
	5-6 people	9-10 people
Household management		
Fetching water [a]	1	2
Collecting fuelwood	2	4
Collecting food[b]	3	8
Preparing food	1	3
Cooking	2	4
Market	1	1
Other activities		
House maintenence	40 (5days/yr)	40 (5days/yr)
Preparing green manure and fertilizing	32 (4days/yr)	32 (4days/yr)
TOTAL	72 (hours/yr)	72 (hours/yr)
TOT hr/day	10	22
TOT hr/year (hr/day +hr/yr)	3720	8100
TOT hr/capita/yr	700-600	800-900

(a): In the commune there are 7 wells from where inhabitants can fetch wather, this is a task for the grow up children female (10-18). In the slash and burn area the camps are located along the stream so that getting water is quite easy.

(b): Most of the household energy supply comes from cassava. Because of about 1/3, 1/4 of the cassava roots are discarded an increasing number of people in the household means a more then proportional effort in collecting, carry home and preparing the tubers.

(*): Double residence:å from interviews we estimated that farmers who have this double residence spend about 3 months living in it. So the calculus is made based on 90 days of permanence.

(B) Assumption and assessments used for indicators of performance

In this annex I present the assumptions made for assessing of the indicators of performance used in this work (**Table 7.4** and **Table 7.6)**. Data, when possible, come from both interviews, and literature (for similar contexts). In the latter case I tried to use sensible values similar to those that are possible for a reality like that of Thuong Lo commune. I do not pretend data to be precise and because of the different scope of the original study, neither they could. Anyway they can be useful as indicators of performance in this methodological exercise.

Other possible indicators of farming system performance are shown in the following tables. However both because of some redundancy (e.g. soil loss and water run off, poverty assessed in kcal/capita/day and in monetary terms), and to keep things simple they have not be used in the present work.

The annex is divided according to the order used for the different set of indicators used in **Table 7.4** and **Table 7.6**.

I) Indicators assessing environmental performance of the farming system.

1) Soil loss by the different agricultural activities

The particularity of the tropical climate makes the soil in the tropics to be generally very sensitive to the presence of the vegetation cover (Whitemore, 1998). Its absence leading to a quick loss of the upper layers and surfacing bedrock, and/or the formation of an aluminium-iron hard crust. Soil loss-tolerance level for tropical areas have been suggested by Hudson (in Clark and Morrison, 1987), to be around 13-14 ton/ha/yr.

- ***Slash-and-burn***: Studies on soil erosion for slash-and-burn areas (Do Dinh Sam, 1994), indicate that with 15-25º slopes the soil loss ranges from 115 to 130 ton/ha/yr. Vu and Nguyen (1995) for central highlands give values ranging from 100 up to 150 ton/ha/yr. A very large amount indeed.
- ***Paddy, and crop land***: For tropical lowlands Beets, (1990, pp. 461) reports a soil loss of about 1 ton/ha/year.
- ***Cows pasturing on sloping land***: According to the soil type, slope, and vegetation cover (grassland and Eucalyptus plantations) over which cows are kept grazing, I estimated a soil loss of 20-40 tons/ha/year.

2) Biophysical capital

Biophysical capital (BC) has been defined as "*the ability of an ecosystem to use solar energy for generating biophysical process that stabilise the biosphere structure/function*" (Giampietro *et al*., 1992, p. 222). It is a measure of the plant water flow (**Table 7.12**). By BC it is possible take into account both the quantity of biomass present in the surface area (kg m^{-2}) and its level of complexity, measured in W/kg, the rate of energy dissipation per kg of biomass (Giampietro *et al*., 1992). Its unit of measure then takes the form of W m^{-2} (W/kg x kg m^{-2}). **Table 7.12** presents a comparison of productivity measures among different ecosystems.

Possible use: Ratio of water consumption per unit of primary production can represent an underestimation of biophysical activity induced by biomass in relation to water cycle (Giampietro *et al.*, 1992).

Table 7.12 *(see p. 161a) Calculation of gross productivity from NPP and standing biomass for some terrestrial ecosystems (from Giampietro et al., 1992, modified)*

- For home garden with fruit trees, plantation and young secondary forest, I refer to Biophysical Capital as for Wood land.
- For paddy field, crop land, rice field in the slash-and-burn area, and grazing grassland I refer to Biophysical Capital as for tropical grassland.

3) Pesticide use

Nguyen and Dung, (1998) report for paddy fields in the Mekong delta, farmers using as much as 1,000 g/ha/yr of active ingredient of pesticide. According to the author this is very much over the environment carrying capacity as well as a threat for farmers health (and more a waste of money). (For central China, Pastore *et al.*, 1999 report farmers using an average of 3.3 kg/ha/yr of pesticide - gross figure). In Thuong Lo commune pesticides are used only in the paddy field.

In **Table 7.13** are presented some useful indicators to assess environmental stress cause by agricultural activities.

Table 10.13 *(see p. 161b) Some useful indicators assessing environmental stress*

- ***Population density:*** With 235 inhabitants per km^2, Vietnam has one of the highest density in Southeast Asia. This is mostly concentrated in the two deltas. Considering the nature of the environment also the up lands reached a high population density: 75 people per km2 in the northern region, and 47 people km^2 in the central region. It has to be underlined that the threshold for sustainable shifting cultivation if often put at 30 people per km^2 (HPP-UNDP, 1997). Coming to the commune, when considering the area under the commune management, 968 ha (9.68 km^2), we have a density of 95 people per km^2, double of the average for the central uplands.

- ***Land saturation index:*** When considering the ration of land in use per capita (0.09 ha) and the agricultural land available in the commune per capita (0.09 ha) we have that 100% of the land available is actually under use.

- ***Length of the fallow period for slash-and-burn activity***: Fallow in shifting cultivation is the methods of restoring soil fertility. With increasing population pressure fallow tends to became shorter and soil less fertile. The number of the years of cultivation as percentage of

Table 7.12 *Calculation of gross productivity from NPP and standing biomass for some terrestrial ecosystems (from Giampietro et al., 1992, modified)*

Vegetation unit	NPP (g m^{-2} year $^{-1}$)	SB (kg m^{-2})	RR	GPP (g m^{-2} year $^{-1}$)	BC W m^{-2}
Tropical rain forest	2000	60.0	75	8000	54.7
Boreal forest	500	35.0	65	1400	9.8
Wood land	600	11.0	55	1300	9.0
Tundra	140	1.5	50	280	1.9
Desert scrub	70	2.0	60	180	1.2
Tropical grass land	700	2.5	60	1750	11.9
Temperate grass land	500	1.5	45	909	6.1
Icy desert	-	-	-	-	≈ 0

(NPP): Net Primary Productivity; (SB): Standing Biomass; (RR): Respiratory Ratio. From BAR values by interpolation using the graph BAR-RR (see Giampietro *et al.*, 1992 for details); (GPP): Gross Primary Productivity; (BC): Biophysical Capital.

Table 7.13 *Some useful indicators assessing environmental stress*

Indicator	Forest cover	Slash-and-burn (15-25 slope)	Paddy-cropland	Pasture (on sloping land)
Soil loss (tons/ha/yr)	min 0.03-max 6.2[w]	100-150[d,v]	1[B]	20-40
Water run off (m^3/ha/yr)	270-330[b]	680-850[b]	10[B]	400-500
Above-ground inputs (t/ha/yr)[p]	8.8-10.5	3.2	-	3-5
NPP t/ha/yr [p]	20	10-20	15-30	10-20
NPP/SB	1:15-1:20	1:1-1:2	1:1-1:2	1:1-1:2
Fine Root Biomass [pp]	20	1	4-5	4-5
BC (W m^{-2}) [g]	55	12[f]	12[ff]	12[ff]

(NPP): Net Primary Productivity; (SB): Standing Biomass; (BC): Biophysical capital; (B): from Beets, (1990);

(d): Do Dinh San, (1994); (v): Vu and Nguyen, (1995)(considering natural forest and cassava culture); (w): Wiersum, (1996 - in Brady, 1996); (p): Palm, (1996) (Aboveground input as litterfall); (pp): Palm, (1996). The indicator is defined as “times more then the slash-and-burn case” and assuming 1 the value for slash-and-burn. Fine Roots Biomass is a key element in process of nutrient cycling in the ecosystem as well as of the regrowth process; (f): land under cultivation and fallow (as for tropical grass land in Giampietro, *et al.* 1992); (ff): paddy rice and cropland (as for tropical grass land in Giampietro, *et al.* 1992); (g): from Giampietro *et.al*., (1992) total rotation is defined as the Cultivation Coefficient (R) , being total rotation the sum of years of cultivation and years of fallow (MARD, 1996).

R% = (Years of cultivation) / (Years of cultivation + Years of fallow) x 100

To maintain fertility in a shifting cultivation system in tropical climates, R should be kept at least in a range of 17-33%. It is to say 2 years of cultivation and 7-8 years of fallow, or 4 years cultivation (rice, rice maize, and then cassava) and 12-16 years fallow. In the Katu case we have 1-2 years of cultivation and 3-4 years fallow for an R% = 33-50%.

- ***% land demanded by shifting cultivation:*** About 250 ha, located outside the commune boundaries, are under slash-and-burn. It means 3 times more then the total agricultural land in the commune (80 ha), or ¼ of the total commune land.

II) Indicators assessing the dependence from external inputs

The indicator that have been used in this case are (Table 7.14): (1) the % food (as energy) imported by the household, it is to say that that is not produced within the household farming system, (2) Nitrogen flow, it is to say the amount of industrial fertilizers used by the household in its farming activity.

Table 7.14 *Some useful indicators assessing external dependence*

Indicators	Total sample	Type 1 Off farm Crop.$_{mix}$	Type 2 Husbandry Crop.$_{mix}$	Type 3 S&B Crop.$_{mix}$	Type 4 NTFP Crop.$_{mix}$
% food energy from outside	20	>50	>10	>10	>30
Nitrogen flow(kg/ha) (% of the saturation limits, 200kg)	25 (12.5)	>50 (25)	25-50 (12.5-25)	20-30 (25)	20-30 (25)

1) % of food imported

Food is mostly locally produced. Staple food is mainly cassava, rice. Corn, taro, sweet potatoes, and legumes are also part of the diet). However better-off by a part of their food supply in the market (rice and other products). Also the poorest farmers who do not have enough land and labour invest the money from collecting NTFP to buy, a limited amount of, food in the market (mostly rice).

2) Nitrogen flow

Nitrogen fertilizer is mostly used in the paddy field. Nitrogen saturation level has been reported ranging from 170-230 kg per ha (Smil, 1987, p. 287)

- ***Paddy:*** For paddy rice the use of industrial fertilizers ranges from 50 to 100 kg N per ha per year (according to the capital available to farmers). Manure and green manure are the main fertilizers employed by local farmers. However little manure is used in general in Thuong Lo commune because its use is not part of the traditional farming culture.

- ***Total land:*** When estimating the nitrogen flow for the household type land I divided this amount for the total land under cultivation for the household type. The total amount ranges from 0 to 50 kg per ha per year according the household typology.

III) Indicators assessing the farming system performance according to the socio-economic benefits

(1) Quality of diet

The quality of the diet has been estimated using both the Monthly income per capita and Food supply purchasing power

- **Monthly income per capita**

According to concepts used by the World Bank and the Environmental and Social Commission for Asia and the Pacific (ESCAP) since 1980s, the poverty line of the developing countries has been determined by the cost of foodstuffs essential to preserve life at an average level of calories intake around 2,100-2,300 kcal per day per capita (Nam, *et al*., 2000). In 1993, the Vietnam General Department of Statistics (VGDS) set the food poverty line at a level of calories intake of 2,100 kcal per day per capita. Considering cost in different regions for the consumption of basic foods, monthly per capita income to meet this standard should be 50,000 VND in rural areas, and 70,000 VND in urban areas. In this way, rural households were classified by VGDS by average monthly per capita income as follows (Nam, *et al*., 2000):

(1) under 50,000 VND for "poor" households (under 30,000 VND for "very poor");

(2) 50,000-70,000 VND for "lower middle";

(3) 70,000-125,000 VND for "middle";

(4) 125,000-250,000 VND for "upper middle**";**

(5) from 250,000 VND upwards for "getting rich".

- ***Food supply purchasing power***

Using this frame the Vietnamese Ministry of Soldier Invalid and Social Affairs (VMSISA) gives the following households classification for the rural areas (Do, 1994):

- Hungry: average per capita income equivalent to 8 kg of rice/month (96 kg/cap/yr)
- Poor: average per capita income equivalent to 15-20 kg of rice/month (180-240 kg/cap/yr)

Given a market price for rice around 3,000 VND per kg we have that average per capita income equivalent to 15-20 kg of rice/month means an income of 45-60,000 VND. I use this description to assess the poverty level of the sample (**Table 7.15**).

Comments: according to the definition provided by the Ministry of Soldier Invalid and Social Affairs (Do, 1994), 51% of the sample can be defined "hungry" and 31% "poor". Do Dinh Sam (1994), considering "poor" households with an average per capita income equivalent to 20 kg of rice/month, states that about 34% of the households in the central highlands are ranked as "poor". According to this analysis the sample (25% of Thuong Lo households) gives a picture of the situation far worst of the average for central highlands. From the field work it emerged that poor households face food shortage from 4 to 7 months per year. Cassava is the main staple food, integrated with sweet potatoes, taro and corn. Food shortage means, a part from shifting from rice to cassava, also reducing the meals per day, from 3 to 2 and for some families to 1 during the winter season.

Table 7.15 *(see p. 164a) Poverty line according to different indicators*

(*2) Food energy intake (Table 7.16)*

According to National Institute of Nutrition, (1995, in FAO, 1999c) average energy intake in Vietnam is 1,925 kcal/person/day, (below the poverty line of 2,100 kcal/day per capita). Of this, cereals (mainly rice) make up 78.0% and tubers 3.4% (remain from pulses, oil, meat etc.). Poverty studies based on data from the Vietnam Living Standard Survey (AAVV, 1999; HPP–UNDP, 1997), using a poverty line equivalent to 2,100 calories per day per capita, indicate a high rate of poverty in the two mountainous areas: 59% in the Northern Mountains and 50% in the Central Highlands, which rank these areas among the poorest three areas of the country (AAVV, 1999; HPP–UNDP, 1997).

Indicators of quality of diet such as energy intake per cap per day, and the percentage of it supplied by cereal and tubers have been estimated according to the information about daily meals, supplied by some farmers belonging to different household typologies during the field interviews.

Type 1: Households of type 1 do not own paddy fields, they relay mostly on the home garden for cash crop production. Good income from off farm or cash crops allows covering food needs. Rice is the main staple food in the three meals per day.

Energy food intake is more then 2,100 kcal per capita per day.

Type 2**:** Households of type 2 get rice supply from paddy fields, crop land and in some cases from slash-and-burn plots. They can afford to buy rice during months of rice shortage. Starchy roots (mainly cassava) are also part of the staple food for a 20-30%.

Energy food intake is more then 2,100 kcal per capita per day.

Table 7.15 Poverty line according to different indicators

		Household Types		
Indicator	Type 1 Off farm Crop.$_{\text{mix}}$	Type 2 Husbandry Crop.$_{\text{mix}}$	Type 3 S&B Crop.$_{\text{mix}}$	Type 4 NTFP Crop.$_{\text{mix}}$
Average nº people per household	5.0	7.7	6.9	4.8
HH av. Income (1,000VND/yr)	6,108	3,541	2,077	1,418
Average per capita (1,000VND/yr)	1,221	499	301	295
Av. Per capita (1,000 VND/month)	101	38	25	25
Kg/month per capita of rice equivalent	34-36	13-14	8-9	8-9
Definition according to VMSISA	middle	poor	hungry	hungry
Definition according to VGDS	middle	poor	very poor	very poor

Note: rice price in Thuong Lo ranges from 2,800 to 3,000 VND/kg (1996 price)

Type 3 and 4: Households of type 3 and 4 get most of the energy intake, 70-80% from starchy roots. Meals per day are reduced to two, in some cases just to one single meal per day during January to April, when winter-dry season occurs and food shortage is severe. Energy food intake ranges from 1,600-2,000 kcal per capita per day.

Table 7.16 *Some indicators of energy intake and quality of diet*

		Household Types			
Energy intake	Country average	Type 1 Off farm Crop.$_{mix}$	Type 2 Husbandry Crop.$_{mix}$	Type 3 S&B Crop.$_{mix}$	Type 4 NTFP Crop.$_{mix}$
kcal/cap/day	1,925	>2,100	>2,100	1,700-1,900	1,700-1,900
% supplied by cereals	78	90-100	70-90	20-30	20-30
% supplied by tubers	3.4	0-10	10-30	70-80	70-80

Note: Rice: 3,620 kcal/kg; Cassava: 1,200 kcal/kg; Energetic need for a 65 kg weigh man is about 2,700-2,800 kcal/day for moderate work and 3200-3300 kcal/day for intense work.

IV) Indicators assessing the farming system performance of productivity

1. Economic returns of labour and land (data summarised in Table 7.17)

I try to estimate the return of the labour and of the land integration the income from the products sold in the market and the value (at market price) of the products used for self-consumption. Because of the complexity of the farming system it is difficult to have precise data. While for instance all the households manage paddy fields in the same way, home gardens and crop lands present a wide range of pattern. These patterns have to be understood within the wider farming system strategy, that means including slash-and-burn, husbandry activities as well as family structure etc.

Yield from paddy field, slash-and-burn, and most of the cropland are used for self-consumption. Husbandry represents a sort of bank as it "stores" a great deal of money promptly used when need may be. NTFP are an ultimate resource as the scarcity of the products (e.g. rattan), make this risky activity a very harsh job (no more then 30 days per year).

Crop land: Crop land is an important source of vegetable protein as legumes (mainly beans) vegetables, tubers (cassava, taro, sweet potatoes), corn and sometime dry rice. In 1,000 m2 crop land we can have: 20 kg of beans (dry weight), 400 kg cassava, 40 kg corn and more other green vegetables (a few species for home consumption such as chilly pepper, and some varieties of pumpkin). Beans have a high market price about 10,000 VND/kg (dry weight). Cassava is worth 300 VND/kg, corn about 2,000 VND/kg. A 1,000 m2 of crop land generally takes about 70 working days per year, it means about 480 hours.

Return per hour: it can range around 800 to 1,000 VND depending on the species planted (farmers with food shortage plant more cassava then others).

Return per ha: according to the species ratio (as more or less the management: weeding, fertilizers etc. is the same for all the farmers) 4-5 million VND/ha per year.

Home garden: The high variability of the land (in quality and area), and inputs (knowledge, species planted, fertilisers, pest attack etc.) as well as household structure and primary needs, make it difficult to deal with this unit. Return per hour and per hectare are then highly variable.

Return per hour: it can range from some hundred VND/hr up to 3-4,000 VND/hr in cash oriented well managed home gardens.

Return per ha: from 1 million up to 9-10 millions VND/ha.

Paddy field: Yield (max) 2 crop 1,200 first crop, 1,000 second crop)

Return per hour (Productivity of time): 0.1 ha require 34 working days (for 2 crops); 1 ha needs 340 working days (assuming 8 working hr/day), it is to say 2,720 hr, it means a productivity of 0.8 kg/hr, or in economic terms of 2,430 VND/hr.

Return per ha (Productivity of land): 2,200 kg/ha/ yr per 3,000 VND equals to 6,600,000 VND/ha.

Slash-and-burn: We consider that for 1 ha under cultivation 3 are under fallow.

We estimate and average of 240 working days per ha of area cultivated (1920 hr). With a productivity of 1,000 kg rice/ha per year (4.2 kg per working day or 0.53 kg/hr).

Rice: Assuming 3,000 VND per kg rice (rice market price in Thuong Lo commune ranged 2,800-3,000 d/kg) it means a total 3 millions VND/yr, it is to say 240 working days.

Cassava: The price of cassava in Thuong Lo market is about 300 VND/kg (fresh roots).

Average yield range from 3-4 tons/ha per year (poor soil). It means a market value of 900,000-1 million VND/ha.

Return of labour: 4 million/240 days /8 hr = 2083 VND/hr

Return of land: The sum of 4 millions VND/ha has to be divided by the 4 ha under turning (the 3 ha in fallow needed to re-establish soil nutrients). It is to say 1 million VND/ha per year.

NTFP: As people generally spend a full week each timer they go for collecting NTFP in the forest, we can assume 10 working hours. The productivity of the labour range then from 15-20,000 VND/day, it is to say 1,500-2,000 VND/hr.

Return of Labour: say 1,500-2,000 VND/hr

Return of land: 500-1,000 ha may have to be explored by a man per year (not more then 30 days of work per year). Being around 450,000-600,000 VND the income for the yearly activity, it means an estimated income per ha of about 600-1,200 VND/ha.

Note: The area of forest explored depend also on the chance to find the right spot with good density of rattan, a climbing palm which take advantage from the light spot in the forest.

Husbandry: Usually the market price of a cow after a year is about 1 million VND. Assuming the 2,200 hours per year invested in the activity the return per hour is then of 455 VND/hr. It has to be pointed out that the activity is carried on by children or elderly who could not be employed in other household's activities.

Return of labour: 455 VND/hr. Of course the return of labour increase proportionally according to cow heads as the time spent for tending is the same. It means that is convenient for farmers to invest in such an activity as it employ household time otherwise not useful and take advantage from free grazing land in the county area.

Return of land: an average of 8 ha (7-9 ha depending on the pasture quality), per year are required to feed a cow (sold for 1 million VND), it means about 125,000 VND per ha of pasture.

Off farm: The return of work has a wide range according to the kind of employment (low–high level of public employ, company employ etc.). Wages from local public services can range from 1,500 up to 3,500 VND/hr (from 200,000 to 500,000 VND/month (300 working days/yr).

Return of work: 1,500 up to 3,500 VND/hr

Table 7.17 *Economic return per hour and per ha of the main productive activities*

Activity	Productivity	
	Of work (VND/hr)	Of land (VND/ ha/yr)
Home garden*	500-4,000	1-10 millions
Paddy field*	2,400	6-7 millions
Crop land	800-1,000	4-5 millions
Husbandry (7-9 ha/cow)	400-500 (per cow)	125,000
Slash-and-burn	2,000-2,100	≈1 million
NTFP	1,500-2,000	600-1,200
Off farm	1,500-3,500	-

(*) Gross Returns as we should subtract the cost of seed and inputs (although of little amount can be significant in the poor farmers economy).

Chapter 8

Conclusions

> *The "manager" tries to "improve" situations which are seen as problematical – or at least as less than perfect – and the job is never done (ask the single parent!) because as the situation evolves new aspects calling for attention emerge, and yesterday's "solutions" may now be seen as today's "problems".*
> Checkland and Scholes[15]

> *Whose reality counts?*
> Robert Chambers[16]

Summary

This chapter summarizes the main issues raised in the thesis: the need for a new approach to farming system analysis, the meaning of multifunctionality in agriculture, new tools for thinking provided by the complex system theory, the importance of being aware of the incommensurability trade-offs, and the concept of "sustainability dialectics". Then, it is discussed about the usefulness of the MOIR approach here presented, as a new tool for farming system analysis.

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[15] Checkland and Scholes (1990, p. 1).

[16] Chambers (1997), The quote refers to the book's title.

8.1 Recognizing the problems, the multifunctional role and the complex meaning of agriculture

When looking at the whole picture of agriculture we are confronted with a situation of critical, and generalized crisis. One evident sign of its dimension is the fact that the crisis does not only concern developing countries: the poor, and the hungry, as we may expect. It exploded also in developed, wealthier and richer countries such as EU and USA. In the case of EU, for instance, agriculture and agro-food system are experiencing a dramatic turmoil: public protests are taking place against the adoption of new (and untested) technologies, a number of scandals led consumers to ask for better food quality, citizens began pressuring national governments to take action to stop pollution and environment degradation, farmers are lobbying for maintaining a reasonable income, agro-food corporations are lobbying to gain the complete control on the agro-food system. As a result policy makers are facing serious problems of governance.

It is difficult to see what benefits, if any, a “traditional” approach, based on increasing economic efficiency, can bring to an effective analysis of farming system. Probably the answer cannot be found in any scientific or technical analysis, but in the political dimension, and lobby power that characterise human societies (see for instance the account given by Wallach and Sforza, 1999; Myers and Kent, 2001; Doyle, 2002; Pye-Smith, 2002).

The size of the problems are of such an entity, and the threat so high, that a complete beliefs rethinking of the foundations and system is urgently required: it is urgent to recognize the multifunctional role and the complex meaning of agriculture systems.

The major step forward is recognizing that agro-food systems are complex systems made up by many different components (e.g. biophysical, ecological, social, economic, historical), operating at different scales (from the local plot or household up to the global climate and market systems). Components and scales, we have to note, that do not exist as independent units but have life as an whole. An adequate representation of a productive system requires then a *multidimensional*, or *multicriterial*, approach, where many perspectives and levels of analysis have to be taken into account (e.g. economic, environmental, social, cultural), and many stakeholders (e.g. farmers, consumers, citizens) have to be involved in the decisional process.

8.2 The rationale of this work: adopting a complex perspective

In his paper “*The historical roots of our ecological crisis*” the anthropologist Lynn White (1967, p. 1204), states: “*What shall we do*? *No one yet knows. Unless we think about fundamentals, our specific measures may produce new backlashes more serious than those they are design to remedy*.”. And he follows: “*I personally doubt that disastrous ecologic backlash can be avoided simply by applying to our problems more science and more technology*.”, (White, 1967, p. 1206). This is a call for re-thinking about fundations dismissing the search for technological “silver bullets”, thinking they would solve problems like magic. Of course technology and specialist research are without doubt important, but we cannot loose sights of the context and the complexity of the problems we are facing.

This work does not intend to offer “the solution” to the problems concerning the management of agro-ecosystem and rural development in view of sustainability. The goal of this work is, rather, that to present a new way to address the complex agro-environmental problems and a new tools for analysis.

This requires first of all to recognise that sustainability problems are complex, and in particular that such complexity derives from the fact that when we look at a system, the system emerges as a matter of relation between the observer and the observed system (complexity "à la Rosen" as described in Part 1).

In order to improve our ability to face new challenges, we should first of all recognize the adaptive nature of living systems, the hierarchical structure of relation, the fact that those systems have the property to spontaneously self-organize independently of our will and wishes, and to be willing to take eventually into account the role of the observer in the study of nature and social systems. These points may appear quite obvious, but when we look at the body of literature which pretends to account for the true functioning of the living systems (being ecosystems or social systems) and to objectively predict their behaviors, this seems be far away from the theoretical foundations adopted in the building of disciplinary knowledge.

Such characteristics have been recognised long ago in biology and social sciences (see for instance the fundamental work of Korzybski (1933) on the role of language in contructing the reality), but still did not spread into the other sciences, especially those that pretend to be "hard sciences". Arthur Koestler in 1967, quoting the words of Needham (1936), complained that: "*More then thirty years ago Needham wrote: "Whatever the nature of organism may be, they form the central problem of biology, and biology will be fruitful in the future only if this is recognized. The hierarchy of relations, from molecular structure of carbon coumpounds to the equilibrium of species and ecological wholes, will perhaps be the leading idea of the future." Yet the word "hierarchy" does not even appear in the index of most modern textbooks of psychology or biology*." (Koestler, 1967, p. 45). It is embarrassing to note that 35 years after Koestler (and nearly 60 after Needham) wrote these ideas, still hierarchy theory and the related theories of complexity seem unable to move from specialist publications into modern textbooks.

This impasse is impressive when considering the work which has been done in the field of hierarchy theory and complex system, and the number of scholars embracing this approach that have been awarded Nobel prices (e.g. Herbert Simon, Kenneth Arrow in economics, Gerald Edelman in medicine, Ilya Prigogine, Gregory Chaitin, Philip Anderson, Murray Gell-Mann in physics). University students are rarely aware of these "new" ideas. A possible explanation of this fact may lay in the fact that embracing hierarchy theory means challenging the "holy assumption" of the existence of a single truth, which can be known by humans. This would imply that what science sees and studies in reality depends on how scientists decided to look at the world. The bitter and long struggle to gain the control over the calendar (who has the authority of deciding what day is today?) that generated many religious schisms in western churches clearly shows that any social system of power is strictly associated to the enforcement of a single representation of the reality (Duncan, 1999). Power means controlling the "etic" representation of the reality, against competing "emic" representations. As stated by Doroty Rower (quoted in Chambers, 1997, p. 76): "*In the final analysis, power is the right to have your definition of reality prevailing over other people's definition of reality*.". Hierarchy theory implies acknowledging that science cannot be neutral, when dealing with deciding a problem structuring in the field of sustainability.

Many scientists seem to believe that those performing a critical analysis of the foundations of the various scientific disciplines (e.g. the existence of starting assumptions, logical problems, as well as the existence of different values of judgment at different scale of analysis) are not doing real science. They seem to believe that in a moment of serious crisis scientists must invest their time only into solving "true and serious" scientific problems, rather than wasting their time on epistemological issues. This fracture went on for so long, that today is almost impossible to convince a famous nuclear physicist to try to understand the reasons of people protesting against the stock of nuclear wastes in their village (personal experience). The famous physicist I know, which seems convinced to know the best course of action for everybody on this planet, tends to consider the protesters, as people which are rebelling against the laws of nature.

8.3 Complexity "à la Rosen" or "dialectic complexity"

In chapter 2 I made the point that there a number of different ways to understand complexity (and a large number of labels to name complex systems). They can be resumed as: (1) Complexity as synonymous of complicatedness (the mutual interaction of many parts); (2) Complexity as a whole that is more than the sum of the parts (emergent properties meaning new behaviours); (3) Complexity as the properties of a system to self-organize and change in time its essence, identity and behaviour (emergence meaning new relevant attributes for the observer); (4) Complexity as "dialectic process": The interaction between observer and the observed system (complexity à la Rosen), that I would named also "dialectic complexity".

Apart from the definition in (1) which refers to a rather mechanicistic approach, the other three interpretations of complex systems stress the notion of complex systems which: (i) express different meanings at different level of analysis (scale issue), (ii) change in time to adapt to the environment by expressing novel behaviors. This is already much ahead of the classic reductionist apporch. The novelty in the approach proposed by Rosen is that his definition of complexity refers to the continuous contextualization process between the observed system and observer (system), both changing in time their properties: the observed system modifying itself by evolving novel characteristics and behaviors by a process of self-organization, as well as it does the observer along with its way to look at the observed system.

The dialectic relation between the observed system and the observer implies that a given entity can be perceived and represented according to an open - virtually infinite – number of different ways. However, because any individual observer/agent has finite goals and limited means of perception it will adopt only a bound and finite subset of them.

I can guess that the Rosen approach will not find an easy acceptance. In fact, it challenges the existing power relations both in society and in science. Power structure always tends to justify itself as the being in possession of the true meanings, the true values. In this way, those in power justify their legitimacy. Since, if this is true, they are those able of performing the best actions to achieve the maximum benefits for the management of human affairs.

8.4 Strategic implications of complexity for policy: "Sustainability dialectics"

The points made in the previous section have very important implications for policy. They imply that:

- real-world systems are not steady-state systems but highly dynamic and evolving systems, (ceteris are not paribus). Any representation of these systems depends on the observer frame,
- we can no longer search for the "optimal", or "best" solution (optimal for who and in which sense?), as there is no solution optimizing all the criteria at the same time for all the actors,
- any definition of a solution as "good" or "bad" has to be associated to the definition of "good" or "bad" for whom, in which sense, for how long, and at which cost.

Procedures for decision making, therefore, should permit:

- a clear and transparent formulation of the questions, and structuring of the problem,
- a search for compromise solutions and an explicit acknowledgment of the existence of **incommensurable trade-offs** inherent in alternative policies,
- an explicit definition of the stakeholders that should be involved in the process as well as a specification of the role and timing of their involvement in the decisional process
- policy-makers and institutions to operate fairly in face of unavoidable conflicts.

Using dialectics complexity as an epistemological tool lead us to move from the concept of "*sustainability*" to that of "*sustainability dialectics*". While the former relies on a rather vague concept of multiple optimization over a number of criteria (e.g. social, economic, environmental, intergenerational), the latter addresses the deep meanings and issues involved in the development process, mainly that: i) different stakeholders have different perspectives (that can change in time), ii) meanings and behaviours expressed by a system are perceived differently according to the scale of analysis (both in space and in time), iii) unpredictable novelties have to be expected and we must deal with the concepts of risk, uncentainty and ignorance.

The idea of sustainable dialectics fits in with what was proposed by Herbert Simon in the late 1940s, that is to say to move from a concept of "*substantive rationality*", the extent to which appropriate courses of action are chosen, to that of "*procedural rationality*", the effectiveness, in the light of human cognitive power and limitation, of the procedure used to chose actions.

8.5 Incommesurable trade-offs and the multicriteria approach

For trade-off the Merriam-Webster dictionary (available online) provides two definitions: (1) a balancing of factors all of which are not attainable at the same time, and (2) a giving up of one thing in return for another. In the first instance the term "*Incommensurable trade-offs*" may seem conterintuitive because of the items traded should be commensurable, that is to say "having a common measure" (Merriam-Webster dictionary). The common measure is usually provided by a third item usually called money (but it can also be represented by shells or anything else recognised by the society apt to the pourpose).

This is of course an act of strong abstraction useful to facilitate transactions. In reality when I give up somethig in return for somethig else rarely the two things have something in common. Exchanging a book for another can be comparable in terms of weight (useful to know if I have to carry it a long way), but what about the subjects, the content of information (imagine the titles being "The beauty of gardening" and "Make your own bomb")? Of course comparison is made somehow to exchange things. However this is generally a very complex process which involves considering at the same time a number of different criteria (e.g. to get a new house, but high difficulties can be met also in choosing a simple present). It has to be noted for instance, that in many sorts of decisions, money, although important, is not the main issue (there are issues on which most of the people would not discuss about possible trade-offs at all, or in case just when forced and against their will). I would say that trade-offs are always incommensurable, commensurability being an useful artifact and just that.

It is also to note that measures (as attitudes) change very easily according to the context and perception of it, and that many decisional processes are hidden to the conscious mind or are anyway much more complex of what is predicted by the economic models [e.g. "*prospect theory*" (Kahneman and Tversky, 1971; Tversky and Kahenman, 1981; "*cognitive dissonance*" (Festinger, 1962; Aronson, 1999)]. According to the psychologist and Nobel laureate in Economics Daniel Kanheman (2000, p. xvii) "…, *the standard assumption that people maximize utility function is not tautological but false*."

The current way to deal with these issues, is however that proposed by the neo-classical economy, to force whatever items to take an economic-crematistic value (being the item of inorganic, biological, spiritual nature and having a temporal dimention as wide as seconds to millions years). Once everything has been reduced to one commensurable value then trade-offs analysis can be made.

This approach is strongly criticised by ecological economists who maintain that incomparability and incommensurability issues must be taken into account and others methodologies have to be employed (e.g. Funtowicz and and Ravetz, 1994a; Munda *et al*., 1994; Munda, 1997; 2004; Martinez-Alier *et al*., 1998; Giampietro, 2004).

Of course, eventually decisions have to be made, but what matters is the process by which problems are structured, conflicts managed and solutions agreeded upon. To dealt with these issues scholars in the field of ecological economics are proposing new tools able to take into consideration these issues such as multicriteria approches. Indicators used in economy and ecology are both qualitative and quantitative and then multicriteria methods able to deal with mixed information are considered very useful such as NAIADE, REGIME, ELECTRE (for details see for instance Keeney and Raiffa, 1976; Bana e Costa, 1990; Munda *et al*., 1994; Beinat and Nijkamp, 1998; Janssen and Munda, 1999; Janssen, 2001; NERA, 2002). According to Munda (1993; 1995; 2004), multicriteria methods that try to take mixed information (qualitative and quantitative) into account face with two main problems: (1) the problem of equivalence of the procedures used in standardising the various evaluations of the performance of alternatives according to different criteria; and (2) the problem related to the available information as it concerns the uncertainty (stochastic and/or fuzzy) contained in this information. Therefore, the combination of different levels of measurement with different types of uncertainty has to be considered as an important research issue in multicriteria evaluation.

However as Quade (1970, quoted in Smil, 1993, pp. 25-26) argues: "*The point is that every quantitative analysis, no matter how innocuous it appears, eventually passes into an area where pure analysis fails, and subjective judgment enter... judgment and intuition permeate every aspect of analysis: in limiting its extent, in deciding what hypotheses and approaches are likely to be more fruitful, in determining what the "facts" are and what numerical values to use, and in finding the logical sequence of steps from assumption conditions*.".

8.6 The usefulness of the MOIR approach

I believe that MOIR can be an useful tool when evaluating possible scenarios and possible policies. The MOIR approach, in fact, makes it possible to:

- characterise the performance of a given rural system in relation to a selected family of indicators (social, economic, and environmental), reflecting non-equivalent view of its performance.
- force the analyst to put in perspective local characteristics with the larger socio-economic and ecological context (or smaller if need may be).
- establish links among the values taken by different indicators, in order to be able to discuss of sustainability trade-offs associated to different scenarios.

The quality of this analytical tool therefore depends on: (1) an adequate choice of the set of relevant criteria (reflected by the selection of indicators included in the MOIR performance space), (2) the ability of gathering the required data in relation to the selected set of indicators of performance, and (3) an adequate understanding of the existing relations among them (the ability of forecasting how changes in the value of an indicator will be reflected into changes in the values taken by other indicators).

Other crucial aspects are: (1) the ability to perform a check on the robustness of the scenarios (a check on the viability of the proposed solutions), and (2) the ability to interface this information with the issue of governance (the feasibility of the proposed changes and proposed policy in the given social and institutional context). This goal introduces an additional dimensions of quality for the analysis. Any process of societal multicriteria evaluation based on MOIR requires considering always (i) the technical dimension that deals with how to represent the problem, options and scenarios, and (ii) the social dimension that deal with governance, how to involve in the discussion of the definition and selection of alternative policies relevant stakeholders.

(i) The technical challenge *(dealing with representation)*: a discussion on sustainability trade-offs, has to be based on the ability of "scaling up and down". This requires the ability of linking models used to describe events on different levels and descriptive domains. For example, using a model based on a scale, which makes possible to assess loss of biodiversity means the impossibility of representing events at the household level. This implies also that the decision of a single farmer can be totally negligible for biodiversity preservation. However, when such a decision can be amplified by an attractor solution (that is to say when a large quantity of farmers decide to join the same household type), we deal with a "typology" which can generate important environmental impact.

(ii) The social challenge *(dealing with governance)*: even if it is easy to agree on general formulation of goals ("peace", "freedom", "fight against poverty", "respect and protection of the environment"), when they are translated into objectives and criteria within a given context, and for incommensurable sustainability trade-off analysis, things change dramatically. The "application" of these general goals to a specific situation requires a lot of care. For example, when analyzing the implementation of a specific policy using a MOIR analysis, we can characterize in practical terms the difference in "meaning" given to generic goals, within the same specific context, by different stakeholders. In this way it becomes easy to realize that the implementation of any policy must be always related to the characterization of these generic goals made by local stakeholders.

I believe that the MOIR approach makes it easier to use in combination "hard" and "soft" information to analyze problems and to discuss about incommensurable sustainability trade-offs. When organizing the scientific information in this way, it becomes also easier to involve the various stakeholders, carrying legitimate but contrasting views, into a common discussion. In fact, the very concept of MOIR implies acknowledging: (A) the existence of legitimate but non-equivalent perceptions and characterizations of a given problem found among the stakeholders: (B) that the legitimate but non-equivalent perceptions and characterizations of relevant social actors have to be considered in the discussion. Put in another way, MOIR can be a method that helps the stakeholders to better understand the perceptions and the constraints affecting the option space of the others.

The MOIR approach is therefore one of the many tools required for a procedure of *conflict analysis* (see later on for more details). A procedure characterized by technical, socio-economic, environmental and political value judgments aiming MOIR to be an useful approach for the involvement of the stakeholders in the process. MOIR is intended to help the discussion over relevant criteria, validity of the models used in the analysis, and the characterization of scenarios in terms of relevant pros and cons.

8.7 MOIR cannot be used as an overall assessments

This is a important point that needs to be stressed: the total area included inside the profile of performance should be NOT considered as an index of overall quality for the system. This is because of:

(1) the various indicators (that can be both quantitative and qualitative) refer to ***non-commensurable criteria*** and therefore the process of normalization does not imply that they have been weighted in relation to their relative importance in determining the overall performance of the system. The final profile of weighting factors that will be adopted in the decision is the result of a negotiation (power relation) among the different perspectives, and therefore has nothing to do with an objective assessment of the overall quality for the system,

(b) the profile of weighting factors used to compare the indications provided by the set of indicators used for the integrated representation is location and time specific (e.g. the attitue of the stakeholders can easily change according with the changes of the context of reference, prospect theory is a well studied example),

(c) the profile of performance resulting from the integrated representation on a multicriteria space is referring to just one of the possible integrated representations of the system.

(d) eventually the aggregation procedure aiming at getting a final index of performance makes the reader loose track of the heterogeneous characteristics of the systems. Therefore an area smaller or larger than another (e.g. 5.42 $cm^2 > 3.56$ cm^2) does say precisely nothing about the systems performances (even if a system performs better then another for all the indicators), because we do not know the relative performances of the indicators (just one indicator can account for all the difference) and because of the point (a).

8.8 Pros and cons of MOIR Graphical Integrated Representations

Graphical representations help the stakeholders in visualizing the implications of sustainability dialectics, they make explicit the consequences (both in positive and negative) implied by an alternative (or differences found in systems compared in the analysis). As all the other graphical methods also MOIR has its own pros and cons that are similar to other graphical representation.

Pros: (i) conveys relevant information in a form easily comprehensible to the stakeholders; (ii) makes detectable some properties of the whole not easy to detect for non-experts (a sort of "map" of the system performance); (iii) generates a dynamic graphical representation of changes in indicators when discussing scenarios; iv) facilitate the discussion on incommensurable trade-offs (effects of sustainability dialectics)

Cons: (i) can lead to an oversimplification of the reality (but this problem is common to all types of representation and all types of models); (ii) can be used to mislead the perception of a given situation: different choices of observable qualities and then of encoding variables lead to different representations of system's profile (this is also true for all models, see for instance the case discussed for composite indicators in chapter 3);

8.9 Conclusion

I wish to conclude quoting again the statement by W.I. Thomas: "*If men define situations as real, they are real in their consequences*.", (quoted in Merton, 1948, p. 193). What we believe in, makes us to act accordingly. So to me exploring the epistemological issues in farming system modelling (and modelling in general) is an important step forward in order to produce changes in science and in society.

I hope that this work can somehow to contribute in the field of farming system analsysis and rural development. In particular in providing a new way of reading and constructing narratives in the ambit of sustainable dialectics. I believe that this approach allows to create more useful models accounting for the complexity of the real world (the continuos effort to outlast life continuous becoming).

REFERENCES

AAVV, 1999. *Vietnam Development Report- Attacking Poverty.* Joint Report of the Government-Donor-NGO Working Group. Consultative Group Meeting for Vietnam, 168 pp. Available on internet at URL: <http://www.worldbank.org.vn/rep3/attpov.pdf>

Adger, N.W., 1999. Social vulnerability to climate change and extremes in coastal Vietnam. *World Development*, 27(2): 249-269.

Ahl, V., and Allen, T. F.H., 1996. *Hierarchy Theory*. Columbia University Press, New York, 205 pp.

Alestrøm, P., 1995. *Genetic engineering in aquaculture*. In Reinertsen, H., and Halland, H., (Eds.) *Sustainable fish farming*. pp. 125-130. "Proceeding of the first international symposium on sustainable fish farming". Oslo, Norway - 28-31 August 1994. A.A.Balkema, Rotterdam - Brookfield, The Netherlands.

Alexandratos, N., 1995. *World agriculture towards 2100, a FAO study.* FAO, Rome/John Wiley & Sons, New York, 488 pp.

Allen, T.F.H., and Hoekstra, T.W., 1992. *Towards a unified ecology*. Columbia University Press, New York, 384 pp.

Allen, T.F.H., and Starr, T.B., 1982. *Hierarchy - Perspectives for ecological complexity.* University of Chicago Press, Chicago. 310 pp.

Allen, T.F.H., Tainter, J.A. and Hoekstra, T.W., 2003. *Supply-Side Sustainability*. Columbia University Press, New York, 440 pp.

Altieri, M., 2002. Agroecology: the science of natural resource management for poor farmers in marginal environments. *Agriculture, Ecosystems and Environment*, 93: 1-24.

Altieri, M., 1987. *Agroecology: The science of sustainable agriculture*. Westview Press, Boulder, 187 pp. An edition in Spanish (1999) titled *Agroecologia:Bases científicas para una agricultura sustentable* is freely available in internet at URL <http://www.uady.mx/sitios/veterina/ofacad/curso_protropico/material/libros/agroecologia/agroecologia.pdf>

Altieri, M.A., and Rosset, P., 1999. Ten reasons why biotechnology will not ensure food security, protect the environment and reduce poverty in the developing world. *AgBioForum, 2 (3-4): 155-162.*

Altieri, M.A., and Masera, O., 1993. Sustainable rural development in Latin America: Building from the bottom-up. *Ecological Economics*, 7: 93-121.

Anderson, P.W., 1969. New Scientist 25 Sept, p. 638.

Anderson, P.W., 1972. More is different. *Science*, 177: 393-396.

Arker, H.R., and Ayton, P., 1999. The sunk cost and Concorde effects: Are humans less rational than lower animals? *Psychological Bulletin*, 125(5): 591-600.

Aronson, E., 1999. *The social animal*. (8th ed), Worth Publishers, New York, 548 pp.

Aronson, E., Wilson, T.D., Akert, R.M., 2002. *Social psychology*. Prentice Hall Inc., New Jersey, 677 pp.

Asch, S.E., 1968. *Gestalt theory*. In: Sills, D.L., (Ed.), *International encyclopedia of the social sciences*. Macmillan company & The Free Press, New York, Vol. 6, pp. 158-175.

Ashby, R. 1956 *An Introduction to Cybernetics*. Chapman & Hall, London, 295 pp. The book is available in internet at URL: <http://pespmc1.vub.ac.be/books/IntroCyb.pdf>

Bailey, C., 1997. Aquaculture and basic human needs. *World Aquaculture*, September, pp. 28-31.

Bailey, P., Gough, C., Chadwich, M., McGranahan, G., 1996. *Methods for integrated environmental assessment: Research directions for the European Union*. European Commission/Stockholm Environment Institute. SEI, Stockholm, 120 pp.

Bak, P., 1996. *How nature works: The science of self-organization criticality*. Springer-Verlag, New York, 212 pp.

Bana e Costa, C.A., (Ed.), 1990. *Readings in Multiple Criteria Decision Aid*. Springer-Verlag, Berlin, 660 pp.

Bardach, J.E., 1986. Constraints to polyculture. *Aquaculture Engineering* 5: 287-300.

Barnabé, G. (Ed.), 1990. *Aquaculture (Vol. 2).* Ellis Horwood Press, New York, 1104 pp.

Beets, W. C., 1990. *Raising and sustaining productivity of smallholder farming system in the tropics.* AgBe Publishing, Alkmaar, Holland, 738 pp.

Beinat, E., and Nijkamp, P., (Eds.), 1998. *Multicriteria analysis for land-use management.* Kluwer Academic Publisher, Dordrecht, The Netherlands, 372 pp.

Bell, S., Morse, S., 1999. *Sustainability indicators: Measuring the immeasurable*. Earthscan, London, 175 pp.

Bertalanffy, L., von, 1968. *General system theory: Foundation, development, applications*. (Revised edition), George Braziller, New York, 295 pp.

Beveridge, M.C., Ross, L.G., Kelly, L.A., 1994. Aquaculture and biodiversity. *Ambio*, 23(8):497-502.

Birò, P., 1995. Management of pond ecosystem and trophic webs. *Aquaculture* 129: 373-386.

Bland, W.L., 1999. Toward integrated assessment in agriculture. *Agricultural Systems*, 60(3): 157-167.

Bockstaler, C., and Girardin, P., 2000. *Agro-ecological indicators – instruments to assess sustainability in agriculture*. In: Härdtlein, M., Kaltschmitt, M., Lewandowski, I., Wurl, H.N., (Eds.), *Nachhaltigkeit in der Landwirtschaft*. Eric Schimdt Verlag GmbH & Co., Berlin, pp. 69-83.

Bockstaller, C.H., Girardin, P.H, Van Der Werf, H.M.G., 1997. Use of agro-ecological indicators for the evaluation of farming systems. *European Journal of Agronomy*, 7: 261-270.

Borgese, E.M., 1980. *Seafarm: The Story of Aquaculture.* Harry N. Abrams Publisher, New York, 236 pp.

Boserup, E., 1981. *Population and technological change*. The University of Chicago Press, Chicago, 255 pp.

Bossel, H., 1999. *Indicators for sustainable development: Theory, method, application.* International Institute for Sustainable Development publisher. Wipening-Manitoba, Canada. 123 pp. Available on internet at URL: <http://iisd.ca/pdf/balatonreport.pdf> and at URL: <http://www.iisd.org/publications/publication.asp?pno=275>

Boyd, C.E., 1999. Aquaculture sustainability and environmental issues. *World Aquaculture*, June, pp. 10-13.

Boyd, C.E., and Clay, J.W., 1998. Shrimp farming and the environment. *Scientific American*, June: 59-65.

Box, G. E. P., 1976. Science and statistics. *Journal of the American Statistical Association,* 71: 791-799.

Brady, N.C., 1996. Alternative to slash-and–burn: a global imperative. *Agriculture, Ecosystems and Environment,* 58: 3-11.

Brookfield, H., and Padoch, C., 1994. Appreciating agrodiversity: a look at the dynamism and diversity of indigenous farming practices. *Environment*, 36(5): 6-11.

Brouwer, F., and Crabtree, B., (Eds), 1999. *Environmental indicators and agricultural policy.* CABI Publishing, New York, 305 pp.

Brown, M.T., and Ulgiati, S., 1999. Emergy evaluation of natural capital and biosphere services. *Ambio*, 28(6): 486-493..

Brown, L.R., Kane, H., Roodman, D.M., 1994. *Vital signs 1994-1995*. Worldwatch Institute. Eartscan Pubication, London, 160 pp.

Burge, T., 1979. Semantical Paradox. *Journal of Philosophy*, 76: 169-198.

Burgers, J.M., 1975. Causality and anticipation. *Science*, 189: 194-198.

Carlson, R., 1962. *Silent spring*. Houghton Mifflin Company, Boston, 400 pp.

Carter, V.G., and Dale, T., 1974. *Topsoil and civilization*. (Revised edition). University of Oklahoma Press, Norman, 291 pp.

Casti, J.L., 1996. Confronting science's logical limits. *Scientific American*, October: 78-81.

CENASAC, 1987. *Situazione e Prospettive dell'Acquacultura in Italia.* CENASAC, Rome, 84 pp. (in Italian).

Chaitin, G.J., 2002. Computers, paradoxes and the foundations of mathematics. *American Scientist*, 90: 164-171.

Chaitin, J.G., 1975. Randomness and mathematical proof. *Scientific American*, 232 (5): 47-52. Available at URL: http://www.cs.auckland.ac.nz/CDMTCS/chaitin/sciamer.html

Chambers, R., 1997. *Whose reality counts? Putting the first last.* Intermediate Technology Publications, London, 248 pp.

Chambers, R., 1993. *Challenging the professions: Frontiers for rural development.* Intermediate Technology Publication, London, 143 pp.

Chambers, R., 1983. *Rural development: Putting the last first.* Intermediate Technology Publication, London, 246 pp.

Chapman, V.J. 1977. Introduction. In: *Ecosystems of the World*, *I. Wet Coastal Ecosystems*, 1-29 (Chapman, V.J. ed.). Elsevier, Amsterdam.

Checkland, P., and Scholes, J., 1990. *Soft systems: Methodology in action*. John Wiley & Sons, New York, 326 pp.

Chen, H.L., Charles, A.T., Hu, B.T., 1997. *Chinese integrated fish farming*. In: Mathias, J.A., Charles, A.T., Hu, B.T., (Eds.), *Integrated fish farming*. CRC Press Boca Raton, New York, pp. 97-109.

Chen, H.L., Hu, B.T., Charles A.T., 1995. Chinese integrated fish farming: a comparative bioeconomic analysis. *Aquaculture research*, 26: 81-94.

Cho, C. Y., Hynes, J.D., Wood, K.R., Yoshida, H.K., 1994. Development of high-nutrient-dense, low-pollution diets and prediction of aquaculture wasters using biological approaches. *Aquaculture* 124: 293-305.

Choudhury, K. and Jansen, L.J.M., 1999. *Terminology for Integrated Resources Planning and Management*. FAO, Rome, Italy, 69 pp.

Christensen, P., 1989. Historical roots for ecological economics – Biophysical versus allocative approaches. *Ecological Economics*, 1: 17-36.

Clark, N., Perez-Trejo, F., Allen, P., 1995. *Evolutionary dynamics and sustainable development, a system approach*. Edwar Elgar, Aldershot, UK, 175 pp.

Clark, W., and Morrison, J., 1994. *Land mismanagement and the development imperative in Fiji*. In: Blaikie, P., and Brookfiel, H., (Eds.) Land degradation and society. Routledge, London. pp. 176-185.

Clayton, A.M.H., and Radcliffe, N.J., 1996. *Sustainability - a systems approach.* Earthscan, London, 258 pp.

Cleveland, A.,D., Soleri, D., Smith, S.,E., 1994. Do folk crop varieties have a role in sustainable agriculture? *BioScience* , 44(1): 740-751.

Cleveland, W.S., 1985. *The elements of graphing data*. Hobart Press, Summit, NJ, 323 pp.

Cleveland, W.S., and McGill, R., 1985. Graphical perception and graphical methods for analyzing scientific data. *Science*, 229: 828-833.

Cohen, J., 1999. The march of paradigms. *Science*, 283: 1998-1999.

Cohen, J., and Steward, I., 1994. *The collapse of chaos: Discovering simplicity in a complex world*. Penguin books, New York, 495 pp.

Colombo, L., 1997. Professor Colombo is at the Department of Biology, Padova University , Italy.

Conelly, W.T., 1992. Agricultural intensification in a Philippine frontier community: Impact on labour efficiency and farm diversity. *Human Ecology*, 20(2): 203-223.

Conway, G.R. 1987. The properties of agroecosystems. *Agricultural Systems,* 24: 95-117.

Cook, A., Sinclair, A., Stefansson, G., 1997. Potential collapse of North Sea cod stocks. *Nature*, 385: 521-522.

Corral Quintana, S., 2001. *Una metodologia integrada de exploracion y comprension de los procesos de elaboracion de politicas publicas*. ISBN 84-688-4314-8, Universidad de la Laguna, Tenerife, 680 pp. (In Spanish).

Corral Quintana, S., Funtowicz, S., Guimarães Pereira, A., 2000. Exploring the quality of environmental decision-making processes. Available in internet at URL: http://alba.jrc.it/pedigree/pedigree.html

Cox, D., Fitzpatrick, R., Fletcher, A., Gore, S., Spiegelhalter, D. and Jones, D., 1992. Quality-of life assessment: can we keep it simple? *Journal of the Royal Statistical Society*, 155(3): 353-393.

Daily, H.E., 2000. When smart people make dumb mistakes. *Ecological Economics*, 34: 1-3.

Daily, H.E., and Cobb, J.B., 1989. *For the common good: Redirectioning economy toward community. the environment, and the sustainable future*. Beacon Press, Boston, 482 pp. (Revised edition 1994, Beacon Press, 534 pp.).

de Koning, G.H.J., Veldkamp, A., Fresco, L.O., 1998. Land use in Ecuador: a statistical analysis at different aggregation levels. *Agriculture, Ecosystems and Environment*, 70:231-247.

De Marchi, B., Pellizoni, L., Ungaro, D., 2001. *Il rischio ambientale*. Il Mulino, Bologna, 212 pp (in Italian).

De Murtas, I.D., 1993. *Aquacultura, una Ricognizione delle Attività Attraverso i Secoli.* ENEA, Rome 126 pp. (in Italian).

de Zwart, D., and Trivedi, R.C., 1995. *Manual on integrated water quality evaluation*. The manual has been prepared by order of the Netherlands Ministry of Foreign Affairs, Directorate General for International Cooperation. Copy can be requested at Drs. De Zwart, RIVM (Research for Man and Environment), National Institute of Public Health and the Environment, Bilthoven, The Netherlands, 318 pp.

Dewulf, J., and van Langenhove, H., 2001. Assessment of the sustainability of technology by means of a thermodynamically based life cycle analysis. *Environment and science pollution research*, 8:1-7. More information of the topic are available in internet at URL: http://www.pre.nl/eco-indicator99/triangle.htm

Diamond, J., 1997. *Guns, germs, and steel. The fates of human societies.* W.W. Norton & Company, New York, 480 pp.

Dierberg, F.E., and Kiattisimkul, W., 1996. Issues, impacts, and the implication of shrimp aquaculture in Thailand. *Environmental Management*, 20(5):649-666.

Dixon, J., and Gulliver, A., 2001. *Farming Systems and Poverty: Improving farmers' livelihoods in a changing world.* (with David Gibbon), FAO, World Bank, FAO-Rome, Document available at URL: http://www.fao.org/DOCREP/003/Y1860E/y1860e00.htm

Dixon, J., Gulliver, A., Gibbon, D., 2001. *Global farming system study: Challenge and priorities to 2030*. FAO, Rome, 90 pp. The document is available at URL: www.fao.org/ag/magazine/GFSS.pdf

Do Dinh Sam, 1994. *Shifting Cultivation in Vietnam: its Social, Economic and Environmental Values Relative to Alternative Land Use.* International Institute for Environment and Development, London, IIED Forestry and Land Use Series (3), 55 pp. + annexes.

Doyle, J., 1986. *Altered harvest: Agriculture, genetics, and the fate of the world's food supply.* Penguin Books, New York, 502 pp.

Dovers, S.R., e Handmer, J.W., 1995. Ignorance, the precautionary principle, and sustainability. *Ambio*, 24 (2):92-97.

Duncan, E.,D., 1999. *The calendar*. Fourth Estate, London, 360 pp.

Edelman, G.M., and Tononi, T., 2000. *A universe of consciousness. How matter become imagination.* Basic Books, New York, 288 pp.

Edwards, C.A., 1989. The importance of integration in sustainable agricultural systems. *Agriculture, Ecosystems and Environment*, 27: 25-35

Edwards, P., Do D.H., Pham, M.A., Mair, G., 2000. Traditional culture of indigenous common carp in rice field in northern Vietnam. *World Aquaculture*, December: 34-39.

Efdé, S., 1996. *Quantified and integrated crop and livestock production analysis at the farm level: exploring options for land use of mixed farms on heavy limestone soils south of Malang, East Java, Indonesia.* PhD thesis, Wageningen Agricultural University 230 pp.

Ellis, F., 1998. Household strategies and rural livelihood diversification. *The Journal of Development Studies*, 35(1): 1-38.

Ellis, F., 1996. *Peasant economics: Farm households and agrarian development*. Cambridge University Press, Cambridge, 309 pp.

European Operational Research Societies (EURO) Website at URL: http://www.euro-online.org

Eurostat, 2001. *Economy-wide material flow accounts and derived indicators. A methodological guide.* Office for Official Publications of the European Union, Luxembourg, 92 pp. The document is available at URL http://europa.eu.int/comm/eurostat/Public/datashop/print-product/EN?catalogue=Eurostat&product=KS-34-00-536-__-I-EN&mode=download

Faggi, P., Gomiero, T., Gribaldo, A., Palmieri, P., Paoletti, M., Pettenella, D., Vinceti, B., 1998. *Forest land Privatization in Vietnam: a sustainable process?* Final Report of the research on the Sustainability of the Forest Land Allocation Process. FAO-MARD Project: "Country capacity strengthening for National Forest Action Plan implementation in Vietnam" (FAO GCP/VIE/020/ITA). March 1998, Padova University, 113 pp. plus Annexes

FAO, 2000. *The state of the world fishery and aquaculture.* FAO Fishery Department, Rome, Italy, 142 pp.

FAO, 1999a. *Indicators for sustainable development of marine fisheries.* Technical guidelines for responsible fisheries 8, FAO, Rome, 68 pp. http://www.iim.csic.es/pesquerias/Pesca/FAO/codigo%20conducta/Indicators%20for%20sustainable%20development%20of%20marine%20capture%20fisheries.htm

FAO, 1999b. *Aquaculture Production Statistics. 1988-1997*. FAO, Rome, Italy, 120 pp.

FAO, 1999c. *ESN- Nutritional Countries Profile*- Vietnam. FAO, Roma. 24 pp.

FAO, 1997. *Land quality indicators and their use in sustainable agriculture and rural development*. FAO Land and Water Bulletin 5, 213 pp. From the Proceedings of the Workshop organized by the Land and Water Development Division FAO Agriculture Department and the Research, Extension and Training Division FAO Sustainable Development Department 25-26 January 1996.

FAO, 1996a. *Monitoring the ecological effects of coastal aquaculture wastes*. Report and Studied No. 57, FAO-Rome, 38 pp.

FAO, 1996b. *Food Balance Sheets.* FAO, Rome.

FAO, 1995. *Aquaculture production 1984-1993. FAO Fisheries Circular,* No. 815, FIDI/C 815 (Rev. 7). FAO, Rome.

FAO, 1993. Inland fisheries of Indo-Pacific countries. *FAO Fisheries Circular* No. 794, FIRI/C794 (Rev. 1). FAO, Rome.

FAO, 1992. Fishery management approaches in small reservoirs in China. *FAO Fisheries Circular,* No. 854, FIRI/C854. FAO, Rome.

FAO, 1989: Reform and development of China's fisheries. *FAO Fisheries Circular* No. 822, FIDI/C822. FAO, Rome.

FAO, 1980. Freshwater aquaculture development in China. *FAO Fisheries Tecnichal Paper* 215. FAO, Rome.

Festinger, L., 1962. *A Theory of Cognitive Dissonance*. Stanford University Press, Stanford, CA., 291 pp.

Fforde, A., 1988. *Specific aspects of the collectivization of wet-rice cultivation: Vietnamese experience.* pp. 298-309. In: Brada, J.C, and Wadekin, K-E., (Eds.), *Socialist agriculture in transition: Organizational response to failing performance*. Westview Press, London, 445 pp.

Folke, C., and Kautsky, N., 1992. Aquaculture with its environment: prospect for sustainability. *Ocean and Coastal Management*, 17: 5-24.

Folke, C., and Kautsky, N., 1989. The role of ecosystems for a sustainable development of Aquaculture. *Ambio*, 18:234-243.

Folke, C., Kautsky, N., Berg, H., Jansson, A., Troel, M., 1998. The ecological footprint concept for sustainable seafood production: a review. *Ecological Applications*, 8(1): Supplement: S63-S71.

Fortnow, L., and Homer, S., (In press). *History of Complexity.* In: van Dalen, D., Dawson, J., Kanamori, A., (Eds.). *History of logic.* Elsevier, 26 pp. The chapter is available at URL: http://people.cs.uchicago.edu/~fortnow/papers/history.pdf

Freudenberg, M., 2003. Composite indicators of country performance: A critical assessment. Sti working paper 2003/16 industry issues, OECD, Paris, France, 34 pp. The document is available in internet at URL: http://www.olis.oecd.org/olis/2003doc.nsf/43bb6130e5e86e5fc12569fa005d004c/8bb0f462911c2cc6c1256ddc00436279/$FILE/JT00153477.PDF

Funtowicz, S.O., and Ravetz, J.,R., 1994a. The worth of a songbird: ecological economics as a post-normal science. *Ecological Economics,* 10: 197-207.

Funtowicz, S.O., and Ravetz, J.R., 1994b. Emergent complex systems. *Futures*, 26(6): 568-582.

Funtowicz, S.O., and Ravetz, J.R., 1991. *A new scientific methodology for global environmental issues.* In: Costanza, R., (Ed.). *Ecological economics: The science and management of sustainability.* Columbia University Press, New York, pp. 137-152.

Funtowicz, S.O., and Ravetz, J.R., 1990. *Uncertainty and quality in science for policy.* Kluwer, Dordrecht, The Netherlands, 229 pp.

Funtowicz SO, Martinez-Alier J, Munda G, Ravetz J., 1999. *Information tools for environmental policy under conditions of complexity*. European Environmental Agency Experts' Corner, Environmental Issues Series; 1999: n. 9.

Futuyma. D.J., 1986. *Evolutionary biology*. Sinauer Associated publisher, Sunderland, Massachusetts, Second Edition, 600 pp.

Gallagher, R., and Appenzeller, T., 1999. Beyond reductionism. *Science*, 284:79.

Gallopin, G.C., 1996. Environmental and sustainability indicators and the concept of situational indicators. A system approach. *Environmental Modeling and Assessment*, 1:101-117.

Gandolfi, G., Zerunian, S., Torricelli, P., and Marconato, A., 1991. *I Pesci delle Acque Interne Italiane.* Istituto Poligrafico e Zecca dello Stato, Rome, 617 pp. (in Italian).

Garcia, S., 1997. *Indicators for sustainable development of fisheries.* In: FAO, 1997: Land quality indicators and their use in sustainable agriculture and rural development. FAO Land and Water Bulletin 5. 213 pp. From the Proceedings of the Workshop organized by the Land and Water Development Division FAO Agriculture Department and the Research, Extension and Training Division FAO Sustainable Development Department 25-26 January 1996. pp.131-155.

Garcia, S., and Staples, D.J., 2000. Sustainability reference systems and indicators for responsible marine capture fisheries: a review of concept and elements for a set of guidelines. *Mar. Freshwater Res*., 51:385-426.

Garcia, S., and Staples, D.J., Chesson, J., 2001. The FAO guidelines for the development and use for sustainable development of marine capture fisheries and an Australian example of their application. *Ocean & Coastal Management*, 43: 537-556.

Georgescu-Roegen, N., 1975. Energy and economic myths. *Southern Economic Journal*, 41(3). The paper is available in internet at URL: http://dieoff.org/page148.htm#28

Ghittino, P. 1983. *Tecnologia e Patologia in Acquacoltura, Vol. 1 Tecnologia.* Tipografia Emilio Bono, Torino, Italy, 532 pp. (in Italian).

Giampietro, M., 2004. *Multi-Scale Integrated Analysis of Agroecosystems: a complex system approach*. CRC press, Boca Raton, London, 437 pp.

Giampietro, M., 2002. The precautionary principle and ecological hazards of genetically modified organisms. *Ambio*, 31(6):466-470.

Giampietro, M., 1999. Economic growth, human disturbance to ecological systems and sustainability. In: Walker, L.R. (Ed.), *Ecosystems of Disturbed Grounds*. Elsevier, Amsterdam, pp. 741-763.

Giampietro, M., 1997a. Socioeconomic pressure, demographic pressure, environmental loading, and technological changes in agriculture. *Agriculture, Ecosystems, and Environment*, 65: 201-229.

Giampietro, M., 1997b. Socioeconomic constraints to farming with biodiversity, *Agriculture, Ecosystems, and Environment*, 62:145-167.

Giampietro, M., 1997c. *Exploring the link between technology, natural resources and socioeconomic structure of human society: a theoretical model.* In: Freese, L., (Ed.), *Advances in Human Ecology*, JAI Press 6: 73-128.

Giampietro, M., 1994a. Sustainability and technological development in agriculture: A critical appraisal of genetic engineering. *BioScience,* 44(10): 677-689.

Giampietro, M., 1994b. Using hierarchy theory to explore the concept of sustainable development. *Futures*, 26(6): 616-625.

Giampietro, M., and Pastore, G., 2001. *Operationalizing the concept of sustainable development in agriculture: Characterizing agroecosystems on a Multi-Criteria, Multiple scale Performances Space*. In: Gliessman S.R.(Ed.), *Agroecology and Sustainability*. CRC Boca Raton, London, pp. 177-202.

Giampietro, M., and Mayumi, K., 2000a. Multiple-scale integrated assessment of societal metabolism: introducing the approach, *Population and Environment*, 22(2): 109-154.

Giampietro, M., and Mayumi, K., 2000b. Multiple-scale integrated assessment of societal metabolism: integrating biophysical and economic representations across scales, *Population and Environment*, 22(2): 155-210.

Giampietro, M., and Pastore, G., 1999. Multidimensional reading of the dynamics of rural intensification in China: The Amoeba approach. *Critical Review in Plant Sciences*, 18(3): 299-329.

Giampietro, M., and Mayumi, K., 1997. A dynamic model of socioeconomic systems based on hierarchy theory and its application to sustainability. *Structural Change and Economic Dynamics,* 8(4): 453-470.

Giampietro, M. and Pimentel, D. 1994. Energy utilization in agriculture. In: Arntzen, C.J., and Ritter, E.M., (Eds.), *Encyclopedia of Agricultural Science*, Vol. 2. San Diego (CA), Academic Press, Inc., pp. 63-76.

Giampietro, M., and Bukkens, S.G.F., 1992. Sustainable development: Scientific and ethical assessment. *Journal of Agricultural and Environmental Ethics*, 5(1):27:57.

Giampietro, M., Bukkens, S.,G.,F., and Pimentel, D., 1997. *Linking technology, natural resources, and the socio-economic structure of human society: examples and applications.* In: Freese, L., (Ed.), *Advances in Human Ecology*, JAI Press 6: 129-199.

Giampietro, M., Cerettelli, G., Pimentel, D., 1992. Energy analysis of agriculture ecosystem management: human return and sustainability. *Agriculture, Ecosystems and Environment*, 38: 219-244.

Giordani, G. and Melotti, P., 1984. *Elementi di Acquacultura.* Edagricole, Bologna, Italy, 400 pp. (in Italian).

Gleick, J., 1987. *Chaos: Making a new sciences*. Penguin, New York, 352 pp.

Gliessmann, S.R., 2000. *Agroecology: Ecological processes in sustainable agriculture*. Lewis Publisher, Boca Raton, New York, 384 pp.

Gliessman, S.R., (Ed.), 2001. *Agroecosystem sustainability - Developing practical strategies.* CRC Press, Boca Raton, London, 244 pp.

Goitouni, A., and Martel, J-M., 1998. Tentative guideline to help choosing an appropriate MCDA method. *European Journal of Operational Research*, 109:501-521.

Goldman, A., 1995. Threats to sustainability in African agriculture: searching for appropriate paradigms. *Human Ecology*, 23(3): 291-315.

Gomiero, T., and Giampietro, M., 2003. *Multi-objective integrated representation (putting in perspective biophysical analyses) applied to aquaculture*. In Ulgiati, S., (Ed.): "*Proceeding of the 3° International workshop "Advances in Energy Studies: Reconsidering the importance of energy*" (Porto Venere, 21-26 September 2002), SGE Editoriali, Padova (Italy), pp. 187-199.

Gomiero, T., and Giampietro, M., 2001. Multiple-Scale Integrated Analysis of farming systems: the Thuong Lo commune (Vietnamese uplands) case study. *Population and Environment*, 22(3): 315-352.

Gomiero, T., Pettenella, D., Phan Trieu, G., Paoletti, G.M., 2000. The Vietnamese uplands: Environmental and socio-economic perspective of Forest land allocation and deforestation process. *Environment, Development and Sustainability*, 2 (2): 119-142.

Gomiero, T., Giampietro, M., Bukkens, S.G.F., Paoletti, G.M., 1999. Environmental and socioeconomic constraints to the development of freshwater fish aquaculture in China. *Critical Reviews Plant Sciences*, 18(3):359-372.

Gomiero, T., Giampietro, M., Bukkens, S.G.F., Paoletti, G.M., 1997. Biodiversity use and technical performance of fresh water fish aquaculture in different socio-economic contexts: China-Italy. *Agriculture, Ecosystems, and Environment*, 62: 169-185.

Grant, W., 1997. *The Common Agricultural Policy*. St. Martin's Press, New York, 244 pp.

Gunderson, LH.., and Holling, C.S., 2002. *Panarchy: Understanding transformations in human and natural systems*. Island Press, Washington, D.C., 506 pp.

Guo, J. Y. and Bradshaw, A. D., 1993. The flow of nutrients and energy through a Chinese farming system. *Journal of Applied Ecology,* 30: 86-94.

Haberl, H., 1997. Human Appropriation of Net Primary Production as an Environmental Indicator. *Ambio*, 26(3): 143-146.

Halberg, N., 1999. Indicators of resource use and environmental impact for use in a decision aid for Danish livestock farmers. *Agriculture, Ecosystems and Environment*, 76 (1): 17-30.

Hall, C.A.S., 1988. An assessment of several of the historical most influential theoretical models used in ecology and of the data provided in their support. *Ecological Modeling*, 43: 5-31.

Hall, C.A.S., Leclerc, G., Leon Perez, C., (Eds.). 2000. *Quantifying Sustainable Development: the future of tropical economies*. Columbia University Press, 761 pp.

Hall, C.A.S., Tian, H., Qi, Y., Pontius, G., Cornell, J., 1995. Modeling spatial and temporal patterns of tropical land use change. *Journal of Biogeography*, 22:753-757.

Hambrey, J., Beveridge, M., McAndrew, K., 2001. Aquaculture and poverty alleviation. I. Cage culture in freshwater in Bangladesh. *World Aquaculture*, March, pp. 50-68.

Hammit, J.K., 1997. *Data, risk, and science*. In: Chertow, M.R., and Esty, D.C., (Eds.), *Thinking ecologically: The next generation of enviornmental policy.*Yale University Press, New Haven, pp. 151-169.

Hardaker, J.B., 1997. *Guidelines for the integration of sustainable agriculture and rural development into agricultural policies.* (FAO agricultural policy and economic development series 4), FAO, Rome, 96 pp. The document is available at URL: http://www.fao.org/docrep/W7541E/W7541E00.htm

Harris, M., 1987. *Cultural anthropology*. (2nd edition), Harper & Row, New York, 384 pp.

Harris, M., 1968. *The rise of anthropological theory. A history of theories of culture*. Thomas Y. Crowell, Inc., New York, 832 pp.

Harvel, C.D., Kim, K., Burkholder, J.M., Colwell, R.R., Epstein, P.R., Grimes, D.L., Hofmann, E.E., Lipp, E.K., Osterhaus, A.D.M.E., Overstreet, R.M., Porter, J.W., Smith, G.W., Vasta, G.R., 1999. Emerging marine diseases – Climatic links and anthropogenic factors. *Science*, 285:1505-1509.

Headland, T.N., Pike, K.L., Harris, M., (Eds.), 1990. *Emics and etics: The Insider/Outsider debate*. Sage Publications Inc. A summary of the book by T.N. Headland, is available at URL: http://www.sil.org/~headlandt/ee-intro.htm

Heims, S.J., 1991. *The Cybernetics group*. MIT press, 348 pp.

Hermanides, G., and Nijkamp, P., 1998. *Multicriteria evaluation of sustainable agricultural land use: a case study of Losvos.* In: Beinat, E., and Nijkamp, P., (Eds.), *Multicriteria analysis for land-use management*. Kluwer Dordrecht, The Netherlands, pp. 61-78.

Herring, H., 2000. *Why energy efficiency is not enough*. In Ulgiati, S., (Ed.): "*Proceeding of the 2° International workshop "Advances in Energy Studies: Exploring supplies, constraints, and strategies*" (Portovenere, May 2000). SGE editoriali Padova (Italy), 698, pp. 349-359.

Herring, H., 1998. *Does energy efficiency save energy: The economists debate*. The Open University, EERU Report 074. The document is available at URL: http://www-tec.open.ac.uk/eeru/staff/horace/hh3.htm

Heyer, W., Hülsbergen, K.H., Wittmann, Ch., Papaja, S., Christen, O., 2003. Field related organisms as possible indicators for evaluation of land use intensity. *Agriculture Ecosystems and Environment*, 98: 453-461.

Hofstetter, P., 1998. *Perspectives on Life Cycle Impact Assessment: A structured approach to combine models of the Technosphere, Ecosphere and Valuesphere*. Kluwers Academic Publishers, 504 pp.

Hofstetter, P., Braunschweig, A., Mettier, T., Müller-Wenk, R., & Tietje, O., 1999. The Mixing Triangle: Correlation and graphical decision support for LCA-based comparisons. *Journal of Industrial Ecology*, 3(4), 97-115.

Holland, J., 1995. *Hidden order: How adaptation builds complexity*. Addison-Wesley, Reading (MA), 184 pp.

Hölldobler, B., and Wilson, E.O., 1994. *Journey to the ants: A story of a scientific exploration*, Belknap Press, 304 pp.

Holling, C.S., 2001. Understanding the complexity of economic, ecological, and social systems. *Ecosystems*, 4: 390-405.

Holling, C.S., (Ed.), 1978. *Adaptive environmental assessment and management*. Wiley, Chichester, 377 pp.

Horgan, J., 1995. From complexity to perplexity. *Scientific American*, June: 104-109.

HPP–UNDP. 1997: *Highland Peoples Programme* - Regional Workshop Country comparisons on Highland Peoples development issues - Vietnam. March 1997. A background document. Inter-Ministerial Committee for Highland Peoples development in the North-East of Cambodia. Phnom Penh, 8 - 10 April 1997 Bangkok. Available on internet at URL: http://www.unv.org/projects/highland/ccompvi.html

Ikerd, J.E., 1993. The need for a system approach to sustainable agriculture. *Agriculture, Ecosystems and Environment*, 46: 147-160.

INEA, 1993. *Annuario INEA dell'Agricoltura Italiana,* Vol. 57. Società Ed. Il Mulino, Bologna, Italy (in Italian).

Janssen, R. 2001. On the use of multi-criteria analysis in environmental impact assessment in The Netherlands. *Journal of Multi-Criteria Decision Analysis*; 10(2): 101-109 - Special Issue: Multicriteria Analysis for Environmental Management.

Janssen, R., and Munda, G., 1999, *Multiple-criteria methods for quantitative, qualitative and fuzzy evaluation problems*. In: van den Bergh, J., (Ed.), Handbook of Environmental and Resource Economics. Edward Elgar, Cheltenham, UK, pp. 837-852.

Jesinghaus, J., 1999. *Indicators for Decision-Making*. European Commission, JRC/ISIS/MIA, TP 361, I-21020 Ispra (VA), 23 pp. The document is available at URL: <http://esl.jrc.it/envind/>

Jevons, S.W., 1865. *The Coal Question: An Inquiry Concerning the Progress of the Nation, and the Probable Exhaustion of our Coal-Mines*. 370pp (Reprinted by MacMillan)

Jing W, Jiebin Y Chunru H, Liewan C, Xibin L, Bukkens S.G.F, Paoletti G.M., 1999. Pesticides residues in agriculture produce in Hubei Province, PR China. *Critical Review in Plant Sciences*, 18(3): 402-416.

Jørgensen, S.E., 1988. *Fundamentals of ecological modeling*. Elsevier, Amsterdam, 391 pp.

Kahneman, D., 2000. *Preface*. In: Kahneman, D., and Tversky, A., (Eds.) 2000. *Choices, values, and frames*. Cambridge University Press, New York, pp. ix-xvii.

Kahneman, D., and Tversky, A., 1979. Prospect theory: An analysis of decision under risk. *Econometrica*, 47(2): 263-291.

Kampis, G., 1995. Self-modifying systems: A model for the constructive origins of information. *Biosystems*, 38: 119-125.

Kampis, G., 1991. *Self-modifying systems in biology and cognitive science: A new framework for dynamics, information and complexity.* Pergamon Press, Oxford, 543 pp.

Kanizsa, G., 1980. *La grammatica del vedere: Saggi su percezione e gestalt*. Il Mulino, Bologna, Italy, 360 pp. (In Italian, title translation “*The grammar of seeing: Essays on perception and gestalt*”).

Kauffman, S., 1993. *The origins of order: Self-organization and selection in evolution*. Oxford University Press, New York, 709 pp.

Kautsky, N., Ronnback, P., Tedengren, M., Troell, M., 2000. Ecosystem perspectives on management of disease in shrimp pond farming. *Aquaculture*, 191: 145-161.

Kay, J.J., Regier, H.A., Boyle, M., Francis, G., 1999. An ecosystem approach for sustainability: addressing the challenge of complexity. *Futures*, 31: 721-742.

Keeney, R., and Raiffa, H., 1976. *Decisions with Multiple Objectives*: *Preferences and Value Trade-Offs.* John Wiley & Sons, New York, 589 pp.

Kendall, H., and Pimentel, D., 1994. Constraints to the world food supply. *Ambio,* 23: 198-205.

Kent, G., 1995. Aquaculture and food security. *PACON conference on Sustainable Aquaculture*, Honolulu, Hawaii, June 1995, 226-232 pp.

Kuhn, T., 1962. *The structure of scientific revolutions*. The University of Chicago Press, Illinois, 212 pp.

Kingsland, S.E., 1995. *Modelling nature*: *Episodes in the history of population ecology*. Chicago University Press, (2nd ed.), 306 pp.

Kline, S., 1995. *Conceptual foundation for multidisciplinary thinking*. Stanford University Press, Stanford, 337 pp.

Koestler, A., 1969. *Beyond atomism and holism: the concept of the Holon*. In: Koestler, A., and Smythies, J.R., (Eds.) *Beyond reductionism*. Hutchinson, London, pp. 192-232.

Koestler, A., 1967. *The ghost in the machine*. First publication by Hutchinson & Co., Republished in 1989, by Arkana Books (Penguin), London, UK, 384 pp.

Köhler, W., 1947. *La psicologia della gestalt*. Feltrinelli, Bologna, Italy, 248 pp. (original: *Gestalt psychology*. Liveright Publishing Corporation, New York).

Korzybski, A., 1933. *Science and Sanity: An Introduction to Non-Aristotelian Systems and General Semantics.* (5th in edition 1994, 806 pp. The book in available on-line at the web site of the European Society for General Semantics at URL: <http://www.esgs.org/uk/art/sands.htm>

Kosslyn, St.M., 1989. Understanding charts and graphs. *Applied Cognitive Psychology*, 3: 185-226.

Kropff, M.J., Bouma, J., Jones, J.W., 2001. Systems approaches for the design of sustainable agro-ecosystems. *Agricultural Systems*, 70(2-3): 369-393.

Kuangfei L, Yalin X, Xuefeng L, Pastore G., 1999. Loss of nitrogen, phosphorus and potassium through crop harvest in agroecosystems of Qianjiang, Hubei province, P.R. China. *Critical Review in Plant Sciences*, 18(3): 393-402.

Kuik, O., and Verbruggen, H., (Eds.), 1991. *In search of indicators of sustainable development.* Kluwer Academic Publisher, Dordrecht, The Netherlands, 126 pp.

Kurien, J., 1998. Traditional ecological knowledge and ecosystem sustainability: new meaning to Asian coastal proverbs. *Ecological Applications*, (8)1,Supplement:S2-S5.

Lal, R. 1989. Land degradation and its impact on food and other resources. In: D. Pimentel and C.W. Hall (Eds.), *Food and Natural Resources,* pp. 85-140. San Diego, Academic Press.

Laloë, F., Lauckner, B., Piron, M., Rahim, K., 2001. Surveys and decisions in the context of multidisciplinary programmes: estimators and indicators. *Agriculture, Ecosystems and Environment*, 87(2): 129-140.

Landau, K., and Brazil, M., (Eds.) 1992. *Tropical home gardens*. United Nation University Press, Tokyo, 257 pp.

Larkin, J.H., and Simon, H.A., 1987. Why a diagram is (sometimes) worth ten thousand words. *Cognitive Science,* 11: 65-99.

Larsson, J., Folke, C., Kautsky, N., 1994. Ecological limitation and appropiation of ecosystem support by shrimp farming in Colombia. *Environmental Management*, 18(5):663-676.

Latham, M.C., 1997. *Human nutrition in the developing world.* FAO series, Rome, 508 pp.

Law, R., 1991: Fishing in evolutionary waters. *New Scientist*, 2 March:35-37.

LEEC, 2000. Laboratories of Ecotoxicology and Environmental Chemistry (I) State general laboratory of the republic of Cyprus. *Integrated monitoring & early warning system to sustain quality and multifunctionality of surface waters in Cyprus for man and the ecosystem*. Documents concerning project, tools and results can be found at the project website "Life 95/CY/B2/CY/868 MED - The document is available in internet at URL http://www.life95cy-amoeba.gov.cy/

Leopold, A., 1966. *A sand county almanac - with essays on conservation from Round River*. Ballantine Books, New York, 295 pp. (*A sand county almanac* was first pubished in 1949).

Levin, S.A., 1998. Ecosystems and the biosphere as complex adaptive systems. *Ecosystems*, 1:431-436.

Lewin, R., 1993. *Complexity: Life on the edge of chaos*. Phoenix, London, 208 pp.

Li, K., 1992. Rice-fish farming system in China: past, present and future. In: C. Lightfoot, B.A. Costa-Pierce, C.R. della Cruz,V.R.Carangal and M.P. Bimbao (Eds.), *Rice-Fish Research and Development in Asia,* pp. 17-26. ICLARM Conference Proceedings, Vol. 24. ICLARM.

Li, S. F., 1995. A review of freshwater fish genetic conservation research and practices in China. In: AA.VV.: Key Laboratory of Ecology and Physiology in Aquaculture, Ministy of Agriculture, Shanghai Fisheries University (1993-1995), pp. 70-81.

Li, S. F., 1987. Energy structure and efficiency in a typical Chinese integrated fish farm. *Aquaculture* 65: 105-118.

Li, S.F. and Mathias, J., (Eds.), 1994. *Freshwater Fish Culture in China: Principle and Practice* (Development in Aquaculture and Fisheries Science, Vol. 28), 466 pp. Elsevier, Amsterdam.

Lin, H. R., 1982. Polycultural system of freshwater fish in China. *Can. J. Fish. Aquat. Sci.* 39: 143-150.

Lo, C.P., 1996. Environmental impact on the development of agricultural technology in China: the case of the dike-pond ("jitang" system of integrated agriculture-aquaculture in the Zhujiang Delta of China. *Agriculture, Ecosystem and Environment*, 60:182-195.

López-Ridaura, S., Masera, O., Aster, M., 2002. Evaluating the sustainability of complex socio-environmental systems. the MESMIS framework. *Ecological Indicators*, 35:1–14.

Lowrance, R., Hendrix, P., Odum, E., 1986. A hierarchical approach to sustainable agriculture. *American Journal of Alternative Agriculture* 1: 169-173.

Ludwig, D., Hilborn, R., Walters, C., 1993. Uncertainty, resources exploitation, and conservation: lesson from history. *Science*, 260: 17 (continued on page 36).

Luo, S.M., Han, C.R., 1990. *Ecological agriculture in China*. In: Edwars C.A., Rattan, L., Madden, R.H., and House, G., (Eds.), *Sustainable Agricultural Systems*. Soil and Water Conservation Society Press, Ankeny, Iowa, pp. 299-322.

Lux, K., 2003. The failure of the profit motive. *Ecological Economics*, 44: 1-9.

Lynam, J., 2002. Book review (A History of Farming Systems Research), Edited by M. Collinson, CABI Publishing, Wallingford, 2000, 432 pp.). *Agricultural Systems*, 73: 227–232.

Mandelbrot, B.B., 1983. *The fractal geometry of nature*. W.H. Freeman and Co., 468 pp.

Mandelbrot, B.B., 1967. How long is the coast of Britain? Statistical self-similarity and fractal dimensions. *Science*, 156: 636-638.

Marchant, J., 2001. Unleash the aliens. *New Scientist*, 7 July, 16-17.

MARD, 1996. *Approaches to Social Forestry in Viet Nam.* Proceedings of the Seminar Workshop hold in Hanoi, Viet Nam - September 28-29, 1995. 85 pp.

Martinez-Alier, J., 1987. *Ecological economics: Energy, environment and society*. Basil Blackwell, Oxford, 237 pp.

Martinez-Alier, J., Munda, G., O'Neill J., 1998. Weak comparability of values as foundation for ecological economics. *Ecological Economics*, 26:277-286.

Masera, O., and López-Ridaura, S., (Eds.), 2000. *Sustentabilidad y sistemas campesinos. Cinco experiencias de evaluación en el México rural.* Mundi-Prensa, Cuauhtémoc, México, 350 pp. (in Spanish).

Maturana, H.R., and Varela, F., 1980. *Autopoiesis and cognition: The realization of the living.* Reidel, Dordrecht, 180 pp.

Mayumi, K., 1991. Temporary emancipation from land: from the industrial revolution to the present time. *Ecological Economics*, 4: 35-56.

McConnell, D.J., and Dillon, J.L.,1997. *Farm management for Asia: A system approach*. FAO, Rome, 355 pp.

McCown, R.L., 2002. Locating agricultural decision support systems in the troubled past and socio-technical complexity of 'models for management'. *Agricultural Systems*, 74: 11–25.

McCullagh, P., and Nelder, J.A., 1989. *Generalized linear models*, (2nd ed). Monographs on statistic and applied probability no. 37 Chapman & Hall, London.

McKenzie, D.H. Hyatt, D.E., McDonald, V.J., (Eds.), 1992 Ecological Indicators, Volume 2, pp. 1542-1544. Proceedings of the International Symposium on Ecological Indicators, Fort Lauderdale, Florida, October 16-18, 1990. Elsevier Applied Sciences, New York, New York. 1561 pp in two volumes

Meentemeyer, V., 1989. Geographical perspectives of space, time, and scale. *Landscape Ecology,* 3/4: 163-173.

Melotti, P., Regazzi, D., Roncarati, A., Sirotti, C., and Trincanato, A., 1994. Indagine sullo Stato dell'Acquacultura Italiana. 94 pp. CIERRE grafica, Verona, Italy (in Italian).

Merriam Webster Dictionary on Line, free consultation at URL: http://www.m-w.com

Merton, K.R., 1948. The self-fulfilling prophecy. *Antioch Review*, 8: 193-210.

Meyer, J.H., 1993. The stalemate in food and agricultural research, teaching, and extension. *Science*, 260: 881 and 1007.

Milo, R., Shen-Orr, S., Itzkovitz, S., Kashtan, N., Chklovskii, D., Alon, U., 2002, Network motifs: Simple building blocks of complex networks. *Science*, 298, 824-827.

Milstein, A., 1992. Ecological aspect of fish species interaction in polycultural ponds. *Hydrobiology,* 231: 177-186.

Moldan, B., Billharz, S., Matravers, R., (Eds.), 1997. *Sustainability indicators: A report on the project on indicators of Sustainable Development*. John Wiley & Sons, New York, (SCOPE 58), 415 pp.

Moll, S., Femia, A., Hinterberger, F., Bringezu, S., 1999. *An Input-Output Approach to Analyse the Total Material Requirement of National Economies.* In Kleijn, R., *et al* (Eds.): *Ecologising Societal Metabolism - Designing Scenarios for Sustainable Materials Management*. ConAccount workshop proceedings, CML report 148, Leiden, pp. 39-46, The document is available at URL: <http://www.leidenuniv.nl/interfac/cml/conaccount/ws-nov98.html>

Muir, J., 1990. Worldwide production trends in aquaculture. In: Rosenthal, H. and Grimaldi, E. (Eds): Technology improvements in farming systems. Proceedings of the 4th International Conference on Aquafarming "Acquacoltura 88" Verona - Italy, October 14-15, 1988. pp.17-20.

Müler, F., 1997. State-of-the-art in ecosystem theory. *Ecological Modelling*, 100:135-161.

Munda G., 2004. Social multi-criteria evaluation (SMCE): methodological foundations and operational consequences. *European Journal of Operational Research*. (In press).

Munda, G., 2000. *Conceptualising and responding to complexity*. Environmental Valuation in Europe (EVE) - Policy research Brief, n° 2, 18 pp. Available on internet at URL: http://www.landecon.cam.ac.uk/eve/publ.html#PRB

Munda, G., 1997. Environmental economics, ecological economics, and the concept of sustainable development. *Environmental Values*, 6(2): 213-233.

Munda, G., 1995. *Multicriteria evaluation in a fuzzy environment*. Physica-Verlag, Contributions to Economics Series, Heidelberg, 255 pp.

Munda, G., 1993. Multiple-Criteria Decision Aid: Some epistemological considerations, *Journal of Multi-Criteria Decision Analysis*, 2: 41-55.

Munda, G., and Nardo, M., 2003. On the methodological foundations of composite indicators used for ranking countries. Draft paper available in internet at URL: <http://webfarm.jrc.cec.eu.int/uasa/events/oecd_12may03/Background/material/MundaNardo.pdf >

Munda, G., and Giampietro, M., 2001. *Integrated Assessment of Complex Adaptive Systems: an overview of policy challenges and available tools.* In Ulgiati, S., (Ed.): "*Proceeding of the 2° International workshop "Advances in Energy Studies: Exploring supplies, constraints, and strategies*" (Portovenere, May 2000). SGE editoriali Padova (Italy), pp. 329-341.

Munda, G., Nijekamp, P., Rietveld, P., 1994. Qualitative multicriteria evaluation for environmental management. *Ecological Economics*, 10:97-112.

Murray, T.P., Kay, J.J., Walter-Toews, D., Raez-Luna, E., 1999. Adaptive methodology for ecosystem sustainability and health (AMESH): An introduction. Paper presented to Conservation Medicine Conference, White Oak Conservation Center. Available in internet at URL: <http://www.ovcnet.uoguelph.ca/popmed/ecosys/amesh3.htm>

Musters, C.J.M., de Graaf, H. J., ter Keurs, W.J., 1998. Defining socio-environmental systems for sustainable development. *Ecological Economics*, 26: 243-258.

Myers, N., and Kent, J., 2001. *Perverse subsidies: How misused tax dollars harm the environment and the economy*. Island Press, Washington, D.C., 240 pp.

Myers, N., and Simon, J., 1994. *Scarcity or abundance?* W.W. Norton & Company, New York, 254 pp.

Myrdal, G., 1969. *Objectivity in Social Research*. Phanteon Books, New York, 112 pp.

Nam, P., X., Dang, B.,V., Hainsworth, G., B., 2000. *Rural development in Viet Nam: the search for sustainable livelihoods.* In: Boothroyd, P., and Nam, P.,X., (Eds.). Socioec*onomic renovation in Vet Nam*. IDRC/ISEA, 200 pp. Available on internet at URL: <http://www.idrc.ca/acb/showdetl.cfm>

Needham, J., 1936. *Order and life*. New Haven, Conn.

NERA (National Economic Researc Associates), 2002. Multi-criteria analysis manual. 145 pp. The document is available in internet at URL: <http://www.odpm.gov.uk/stellent/groups/odpm_about/documents/pdf/odpm_about_pdf_608524.pdf> and at URL: <http://www.odpm.gov.uk/stellent/groups/odpm_about/documents/page/odpm_about_608524.hcsp>

Neumayer, E., 2000. On the methodology of ISEW, GPI and related measures: some constructive suggestions and some doubt on the "threshold" hypothesis. *Ecological Economics*, 34: 347-361.

New, M.B., 1997. Aquaculture and the capture fisheries – balancing the scale. *World Aquaculture*, June, 28:11-30.

Newell, A., and Simon, H.A., 1972. *Human problem solving*. Prentice-Hall, New Jersey, 901 pp.

Nguyen Hoan Tri, Ader, W.N., Kelly, P.M., 1998. Natural resource management in mitigation climate impacts: the example of mangrove restoration in Vietnam. *Global Climate Change*, 8(1):49-61.

Nguyen Huu Dung, and Tran Thi Thanh Dung, 1998. *Economic and health consequences of pesticides use in paddy production in the Mekong delta, Vietnam.* Paper presented at the IX Pacific Science Inter-Congress S-III-2 Economics of Sustainable Development:

Linking Economics and the Environment organized by the Institute of Economics, Academia Sinica November 16-17, 1998.

Nguyen, Van Thang, 1995. *The Hmong and Dzao people in Vietnam: Impact of traditional socioeconomic and cultural factors on the protection and development of forest resources.* In: Rambo, T.A., Reed, R.R., Le, C.C., DiGregorio, M.R., (Eds.), 1995. *The Challenges of Highland Development in Vietnam*. East-West Center, Honolulu, USA, pp. 101-119.

Nhat Hanh, T., 1973. *Introduzione allo Zen*. Sonzogni, Milano (In Italian), 141 pp. (Original editino in French, title: *Cleft pour le zen)* .

Nicolis, G., and Prigogine, I., 1989. *Exploring complexity: An introduction*. W.H. Freeman, New York, 328 pp.

Nijkamp, P., 1979. *Multidimentional spatial data and decision analysis.* John Wiley & Sons, 319 pp. (in association with Rietveld, P., Spronk, J., van Veenedaal, W., Voogd, H.)

Nijkamp, P., and Vreeker, R., 2000. Sustainability assessment of development scenarios: Methodology and application to Thailand, *Ecological Economics,* 33:7-27.

Nijkamp, P., and Ouwersloot, H., 1998. *Multidimensional Sustainability Analysis: the Flag model.* pp. 255-277. In: van den Bergh, C.J.M., and Hofkes, M.W., (Eds.), *Theory and implementation of economic models for sustainable development*, Kluwer.

Norgaard, R.B., 1994. *Development betrayed: The end of progress and a co-evolutionary revisioning of the future*. Routledge, New York, 296 pp.

Norgaard, R.B., 1990. Economic indicators of resource scarcity: A critical essay. *Journal of Enviornmental Economics and Management*, 19: 19-25.

Norton, B.,G., and Ulanowicz, R.,E., 1992. Scale and biodiversity policy: A hierarchical approach. *Ambio*, 21(3): 244-249.

Novikoff, A.B., 1945. The concept of integrated levels in biology. *Science*, 101: 209-215.

Nylon, R.L., Williams, S.L., Strong, D.R., 2001. Aquaculture - A gateway for exotic species. *Science*, 294:1655-1656.

Nylon, R.L., Goldburg, R.J., Primavera, J.H., Kautsky, N., Beveridge, M., Clay, J., Folke, C., Lubchenco, J., Mooney, H., Troell, M., 2000. Effect of aquaculture on world fish supplies. *Nature*, 405(29): 1017-1024.

Nylon, R.L., Goldburg, R.J., Mooney,H., Beveridge, M., Clay, J., Folke, C., Kautsky, N., Lubchenco, J., Primavera, J.H., Williams, M., 1998. Nature's subsides to shrimp and salmon farming. *Science*, 282:883-884.

O'Neill, R.V., Milne, B.T., Turner, M.G., and Gardner, R.H., 1988. Resources utilization scales and landscape patterns. *Landscape Ecology*, 2:63-69.

O'Neill, R.V., DeAngelis, D.L., Waide, J.B., Allen, T.F.H., 1986. *A hierarchical concept of ecosystems.* Princeton University Press, N.J., 253 pp.

Oberdorff, T. and Porcher, J.P., 1994. An index of biotic integrity to asses biological impacts of salmonid farm effluents on receiving waters. Aquaculture, 119: 219-235.

Odum, E. P., 1983. *Basic ecology*. CBS College Publishing. , Philadelphia, 480 pp.

Odum, H.T., 1996. *Environmental Accounting. Emergy and Environmental Decision Making*. John Wiley & Sons, New York, 384 pp. A summary by H.T. Odum is available in internet at URL : http://dieoff.org/page170.htm

Odum, H.T., 1971. *Environment, power, and society*. Wiley-Interscience, New York, 331 pp.

Odum, H.T., 1988. Self-organization, transformity, and information. *Science*, 242:1132-1139.

Odum, W., and Heald, E.J., 1975. *Mangrove forests and aquatic productivity.* In: Hassler, A.D., (Ed.). *Coupling of land and water systems*. Springer Verlag, New York, pp. 129-136.

Oltvai, Z. N., and Barbási, A-L., 2002. Life's complexity pyramid. *Science*, 298: 763-764.

Ostrom, E., Burger, J., Field, C.B., Norgaard, R.B., Policansky, D., 1999. Revisiting the commons: Local lessons, global challenges. *Science*, 284: 278-282.

Palm, C.A., Swift, J.M., Woomer, P.L., 1996. Soil biological dynamics on slash-and–burn agriculture. *Agriculture, Ecosystems and Environment* 58: 61-74.

Paoletti, G.M., 1999. Using bioindicators based on biodiversity to assess landscape sustainability. *Agriculture, Ecosystems and Environment*, 74(1-3):1-18.

Paoletti, G.M., and Pimentel, D., 1992. *Biotic diversity in agroecosystems*. Elsevier, Amsterdam, 356 pp.

Passet, R., 1997. *L'economia e il mondo vivente*. Editori Riuniti, Roma, 363 pp. (in Italian) (Orig. 1996. *L'économique et le vivant.* In French)

Pastore, G., Giampietro, M., Li, Ji., 1999. Conventional and land-time budget analysis of rural villages in Hubei Province, China. *Critical Review in Plant Sciences*, 18(3): 331-357.

Patten, B.C., 1978. Systems approach to the concept of environment, *Ohio J. Sci*., 78:206-222.

Pattee, H.H., 1973. *Hierarchy theory: The challenge of complex systems*. George Braziller, New York, 156 pp.

Patten, B.C., and Odum, E.P., 1981. The cybernetic nature of ecosystems. *American Naturalist*, 118(6): 886-895.

Pauly, D., and Christensen, V., 1995. Primary production required to sustain global fisheries. *Nature*, 374:255-257.

Pearce, D.W., and Turner, R.K., 1990. *Economics of natural resources and the environment*. Harvester Wheatsheaf, New York, 378 pp.

Pearce, D.W., and Turner, R.K., 1990. *Economics of natural resources and the environment*. Harvester Wheatsheaf, New York, 378 pp.

Pearce, F., 2001a. Gotta catch them all. *New Scientist*, March:19.

Pearce, F., 2001b. Breaking the Banc. *New Scientist*, June: 32-35.

Pearson, C.J., and Ison R.L., 1997. *Agronomy of Grassland Systems*. (2nd Edition), Cambridge University Press, New York, 234 pp.

Peters, R.H., 1991. *A critique for ecology*. Cambridge University Press, New York, 365 pp.

Pezzey, J., 1992. *Sustainable development concepts: An economic analysis*. World Bank Environment paper No. 2, The World Bank, Washington, D.C. 71 pp.

Pianka, E.R., 1994. *Evolutionary ecology*. Harper Collins College Pubbisher, Fith edition, New York, 486 pp.

Pike, K.L., 2003. *A stereoscopic window on the world: Two views of swaying branches*. The document is available at URL: http://www.oakland.edu/~kitchens/150d/pike.htm

Pike, I.H., and Barlow, S.M., 2000. The dilemma of the fish feed formulator. *Feed Tech*, 4(9): 42-44.

Pimentel, D., and Hall, C.W., (Eds.) 1984. *Food and energy resources*. Academic Press, New York, 268 pp.

Pimentel, D., and Pimentel, M., 1996. (Eds.) *Food, energy, and society*. Revised edition. University Press of Colorado. 363 pp.

Pimentel, D., Shenks, R.E., Rylander, J.C., 1996. Bioethics of fish production: energy and the environment. *J. Agric. and Environ. Ethics*, 9(2):144-164.

Pimentel, D., Stachow, U., Takacs, D.A., Brubacker, H.W., Dumas, A.R., Meaney, J.J., O'Neil, J.A.S., Onsi, D.E., Corzilius, D.B., 1992. Conserving biological diversity in agricultural / forestry systems. *Bioscience*, 42(5):354:362.

Polanyi, M., 1968. Life's irreducible structure. *Science*, 160:1308-1312.

Popkin, S.L., 1979. *The rational peasant: The political economy of rural society in Vietnam.* University of California Press, Berkeley, 306 pp.

Postel, S., 1998. Water for food production: Will there be enough in 2025? *BioScience*, 48:629-637.

PR China MA, 1995 (Ministery of Agriculture) Chinese agriculture forges ahead. Ministry of agriculture of the People 's Republic of China, 30 pp.

PR China MABF, 1995 (Ministry of Agriculture Bureau of Fishery): China fishery. Bureau of fisheries, Ministry of agriculture The People's Republic of China. (in Chinese with English translation), 20 pp.

Pré Consultants, 2000. *Eco-indicator 99 – The Triangle Concept*. In internet at URL <http://www.pre.nl/eco-indicator99/triangle.htm>

Prescott-Allen, R., 2001. *The Wellbeing of Nations - A Country-by-Country Index of Quality of Life and the Environment*. IDRC/Island Press, 350 pp.

Prescot-Allen, R., 1996. *Indicators for sustainable development. What it's for and how to use it.* The World Conservation Union (IUCN), Gland, Switzerland. 25 pp. Document available on internet at URL: <http://www.iunc.org/themes/eval/english/barom.htm>

Pretes, M., 1997. Development and infinity. *World Development*, 25(9): 1421-1430.

Pretty, J.N., 1995. *Regenerating Agriculture: Policies and Practice for Sustainability and Self-Reliance*. National Academy Press, 320 pp.

Pretty, J.N., Brett, C., Gee, D., Hine, R.E., Mason, C.F., Mirison, J.I.L., Raven, H, Rayment, M.D., van der Bijl, G., 2000. An assessment of the total external costs of UK agriculture. *Agricultural Systems*, 65 (2): 113-136.

Prigogine, I., 1980. *From being to becoming: Time and complexity in the physical science*. W.H. Freeman & Co., New York, 272 pp.

Prigogine, I., and Stengers, I., 1984. *Order out of chaos: Man's new dialogue with nature*. Random House, 349 pp.

Pullin, R.S.V., Rosenthal, H., Maclean, J.L., (Eds), 1993. *Environment and aquaculture in developing countries*. ICLARM Conf. Proc. 31, 359 pp.

Pullin. R.S.V., 1993. *An overview of environmental issues in developing-country aquaculture*. In Pullin, R.S.V., Rosenthal, H., Maclean, J.L., (Eds): *Environment and aquaculture in developing countries*. ICLARM Conf. Proc. 31, 359 pp. 1-19 pp.

Pye-Smith, C., 2002. *The Subsidy Scandal: How Your Government Wastes Your Money to Wreck Your Environment.* Earthscan Publications, London, 250 pp.

Qian, Z., (Ed.) 1994. *The developement of the Chinese fisheries and manpowering aquaculture*. Agricutural Press China's. 212 pp. (in Chinese with English translation)

Quine, W.V., 1962. Paradox. *Scientific American*. April, 84-96.

Rees, W.E., 2000. Eco-footprint analysis: merits and brickbats. *Ecological Economics*, 32 (3): 371–374.

Rehm, S., and Espig, G.,1997. *La coltivazione delle piante tropicali*. Edagricole, Bologna, 448 pp. (In Italian). (Origin. 1984. *Die Kulturpflanzen der Tropen und Subtropen*. Eugen Ulmer GmbH & Co. Stuttgard, Germany, in German)

Reichhardt, T., 2000. Will souped up salmon sink or swim? *Nature*, 406:10-12.

Reinertsen, H., and Haaland, H., 1995 (Eds.). *Sustainable fish farming*. A.A. Balkema, Rotterdam, Brookfield. 310 pp. Proceeding of the first international symposium on sustainable fish farming, Oslo – Norway – August 1994.

Rennings, K., and Wiggering, H., 1997. Steps towards indicator of sustainable development: linking economic and ecological concept. *Ecological Economics*, 20:25-36.

Ridley, M., 1993. *Evolution*. Blackwell, Boston, 670 pp.

Rigby, D., Woodhouse, P., Young, T., Burton, M., 2001. Construction a farm level indicator of sustainable agriculture practice. *Ecological Economics*, 39: 463-478.

Rojstaczer, S., Sterling, S.M., Moore, N.J., 2001. Human appropriation of photosynthesis products. *Science*, 294: 2549-2552.

Röling, N., 1997. The soft side of land: socio-economic sustainability of land use systems. *ITC Journal*, 3-4: 248-262.

Röling, N., 1994. *Platforms for decision-making about ecosystems*. In: Fresco, L.O., Stronnsnijder, L., Bouma, J., van Keule, H., (Eds.), *The future of the land: Mobilising and integrating knowledge for land use options*. John Wiley & Sons, pp. 385-393.

Rosen, R., 2000. *Essays on life itself.* Columbia University Press, New York, 361 pp.

Rosen, R., 1991. *Life itself: A comprehensive inquiry into the nature, origin, and fabrication of life*. Columbia University Press, New York, 285 pp.

Rosen, R., 1985. *Anticipatory Systems: Philosophical, Mathematical and Methodological Foundations.* Pergamon Press, New York, 436 pp.

Rosen, R., 1977. Complexity as a system property. *International Journal of General Systems,* 3: 227-232.

Rosen, R., 1974. On the design of stable institutions. *International Journal of General Systems*, 1: 61-66.

Rosen, R., 1969. *Hierarchical organization in automata theoretic models of biological systems.* In: Whyte, L.L, Wilson, A.G., Wilson, D., (Eds.), *Hierarchical structures*. American Elsevier Publishing Company, New York, pp. 179-199.

Ruelle, D., 1992. *Caso e caos*. Bollati Boringhieri, Torino, Italy, 185 pp. (In Italian). Original: 1991. *Hazard et chaos*. Editions Odile Jacob, Paris (In French).

Russell, B., 1908. Mathematical logic as based on the theory of types. *American Journal of Mathematics,* 30: 222-262.

Russell, B., 1903. *Principles of Mathematics*. Cambridge University Press, Cambridge, 528 pp.

Rydin, Y., 2002. *Indicators into action: Local sustainability indicator sets in their context*. London, UK: The Pastille Consortium, London School of Economics, London. The document is available at URLhttp://www.lse.ac.uk/Depts/geography/Pastille/research.htm

Safina, C., 1995. The world's imperiled fish. *Scientific American*, November: 30-37.

Saisana, M., and Tarantola, S., 2002. *State-of-the-art report on current methodologies and practices for composite indicator development*. EUR 20408 EN Report, European Commission-JRC: Italy.

Salthe, S.N., 1985. *Evolving hierarchical system: Their structure and representation*. Columbia University Press, New York, 343 pp.

Sanne, C., 2000. Dealing with environmental savings in a dynamic economy – how to stop chasing your tail in the pursuit of sustainability. *Energy Policy*, 28: 487-495.

Sarewitz, D., 1996. *Frontiers of illusion: Science and technology, and the politics of progress*. Temple University Press, Philadelphia, 235 pp.

Schilizzi, S.G.M., and Boulier, F., 1997. "Why do Farmers do it?" Validating whole-farm models. *Agricultural Systems*, 54 (4): 477-499.

Schmitz, R.J., 1995. *Introduction to water pollution biology*. Gulf Press, Huston, 320 pp.

Schrödinger, E., 1944. *What is life? The Physical aspects of the living cell.* Cambridge University Press, Cambridge. The book is available on internet at URL: http://home.at.net/~p.caimi/schrdinger.html

SEAMEO, 1995. *Sustainable Agriculture Indicators,* Working Paper. SEAMEO Regional Center for Graduate Study and Research in Agriculture (SEARCA) Philippines, 101 pp.

Shan, J., (Ed.) 1987. *Integrated fish farming. Asian-Pacific regional research and training.* Centre for integrated fish farming, Wuxi, Jiangsu Province, China, 237 pp.

Shi, T., 2002a. Ecological economics in China: origins, dilemmas and prospects. *Ecological Economics*, 41(1):5-20.

Shi, T., 2002b. Ecological agriculture in China: bridging the gap between rhetoric and practice of sustainability. *Ecological Economics*, 42:359-368.

Simon, H.A., 1991. *Models of my life (an autobiography)*. Basic Books, New York, 415 pp.

Simon, H.A., 1988a. *Rationality as process and as product of thought*. In: Bell, D.E., Raiffa, H., Tversky, A., (Eds.), 1988. *Decision making: Descriptive, normative, and prescriptive interactions*. Cambridge University Press. New York, pp., 58-77.

Simon, H.A., 1988b. *The scientist as a problem solver*. In : Klahr, D., and Kotovsky, K., (Eds.), *Complex information processing: The impact of Herbert A. Simon*. Lawrence Erlbaum Associated Publisher Hillsdale, New Jersey, pp. 375-397.

Simon, H.A., 1983. *Reason in Human Affairs*. Stanford University Press, 128 pp.

Simon, H.A., 1978. *Rational decision-making in business organizations*. Lecture to the memory of Alfred Nobel, December 8, 1978. From: *Nobel Lectures, Economics 1969-1980*, World Scientific Publishing Co., Singapore, pp. 343-371. Available at: http://www.nobel.se/economics/laureates/1978/simon-lecture.pdf

Simon, H.A., 1976. *From substantive to procedural rationality*. In: Latsis, S.J., (Ed.), *Method and appraisal in economic.* Cambridge University Press, Cambridge, pp. 129-148.

Simon, H.A., 1969. *The science of artificial*. The M.I.T. Press, Cambridge, 126 pp.

Simon, H.A., 1962. The architecture of complexity. *Proc. Am. Philos. Soc.*, 106(6): 467-482.

Simon, H.A., 1956. Rational choice and the structure of the environment. *Psychological Review*, 63:129-138.

Simon, H.A., 1955. A behavioural model of rational choice. *Quarterly Journal of Economics*, 69:99-118. (Also available at: <http://cowles.econ.yale.edu/P/cp/p00b/p0098.pdf>

Sinclair, F.L., 2001. Process-based research in sustainable agricultural development: integrating social, economic and ecological perspectives. *Agricultural Systems*, 69 (1-2): 1-3.

Skop, E., and Schou, J.S., 1999. Modelling the effects of agriculture production. An integrated economic and environmental analysis using farm account statistics and GIS. *Ecological Economics,* 29: 427-442.

Smil, V., 1993. *Global ecology: Environment change and social flexibility.* Routledge, London, 240 pp.

Smil, V., 1987. *Energy, food, environment: Realities, myths, options*. Clarendon Press, Oxford, 361 pp.

Smil, V., 1985. China's food. *Scientific American*, 253(6):104-112.

Smith, T.D., 1994. *Scaling fisheries. The science of measuring the effects of fishing, 1855-1955.* Cambridge University Press, New York, 329 pp.

Spash, C.L., and Clayton, A.M.H., 1997. *The maintenance of Natural Capital: Motivation and Methods*. In Light, A., and Smith, J.M., (Eds.), *Philosophy and Geography I: Space, Place and Environmental Ethics*, Lanhem, Boulder, New York, London: Rowman & Littlefield Publisher, Inc. I: 143-173.

Stanford Encyclopedia of Philosophy, free at URL: <http://plato.stanford.edu/entries/russell-paradox/>

Stocking, M., 1987. *Measuring land degradation*. In: Blaikie, P., and Brookfiel, H., (Eds.), *Land degradation and society*. Routledge, London, New York, pp. 49-63.

Stonich, S.C., 1995. The environmental quality and social justice implication of shrimp mariculture development in Honduras. *Human Ecology*, 23(2):143-161.

Suchman, A.L., 1987. *Plans and situated actions: The problem of human-machine communication*. Cambridge University Press, New York, 220 pp.

Sucur, A., 1993. *The state of the environment of the Aegean Ionian Sea - Greece*. IHE-Delft, 91 pp. IHE-Delft home page is located at URL: www.ihe.nl

Sumari, O., 1986. *Feed and waste water in aquaculture.* In: Grimaldi, E., and Rosenthal, H., (Eds): *Trends and problem in aquaculture development*. Proceeding of the 2th international conference on aquafarming "Acquacultura '84", Verona - Italy, October 12-13. pp. 231-243.

Tacon, A.G.J., 1997. *Contribution to Food Fish Supplies*. Chapter 1.2, In: AAVV, Review of the state of world aquaculture. FAO Fisheries Circular No. 886 FIRI/C886(Rev.1), FAO, Rome. The document is available in internet at URL: <http://www.fao.org/docrep/003/w7499e/w7499e17.htm>

Tainter, J.A., 1988. *The collapse of complex societies*. Cambridge University Press, New York, 250 pp.

Tainter, J.A., 1996. *Complexity, problem solving, and sustainable societies*. In: Costanza, R., Segua, O., Martinez-Alier, J., *Getting down to earth: Practical application of ecological economics*. Island Press, Washington D.C., pp. 61-76.

ten Brink, B., 1992. *The AMOEBA approach as useful tool for establishing sustainable development?* In: Kuik, O., and Verbruggen, H,., (Eds.). *In search of indicators of sustainable development*. Kluwer, Dordrecht, The Netherlands. pp. 71-87.

ten Brink, B., Hopser, S.H., Colijn, F., 1981. A quantitative method for description and assessment of ecosystems: the AMOEBA approach. *Marine Pollution Bulletin*, 23: 265-270.

Tenner, E., 1996. *Why things bite back: Technology and the revenge effect*. Fourth Estate, London, 346 pp.

The Bedford Introduction to Literature, List of terms provided by the Santa Fe Institute at the web site http://inst.santafe.cc.fl.us/~akress/dl1102/literary.htm

The definition can be found also in other web site, see at URL: <http://www.oceansatlas.com/world_fisheries_and_aquaculture/html/glos/terms/1874.htm>

Thompson, J.N., 1994. *The coevolutionary process*. University of Chicago Press, Chicago, 376 pp.

Tisdell, C., 1993. *Environmental economics: Policies for environmental management and sustainable development*. Edward Elgar, UK, 259 pp.

Tonon, S., Brown, M.T., Luchi, F., Mirandola, A., Stoppato, A., Ulgiati, S., 2001. *Integration of thermodynamic, economic and environmental parameters for the evaluation of energy systems*. Pp. 635-647. In Ulgiati, S., (Ed.): "*Proceeding of the 2° International workshop "Advances in Energy Studies: Exploring supplies, constraints, and strategies*" (Portovenere, May 2000). SGE editoriali Padova (Italy), 698 pp.

Tononi, T., and Edelman, G.M., 1998. Consciousness and complexity. *Science*, 282: 1846-1851.

Torgerson , W.S., 1958. *Theory and methods of scaling*. John Wiley & Sons, New York, 460 pp.

Traub, J.F., and Wozniakowski, H., 1994. Breaking intractability. *Scientific American*, January: 102-107.

Tudge,C., 1998. *Neanderthals, bandits and farmers: How agriculture really began*. Weidenfeld & Nicolson, London, 64 pp.

Tufte, E.R., 1990. *Envisioning information*. Graphics Press, Cheshire, Connecticut, 126 pp.

Tufte, E.R., 1983. *The visual display of quantitative information*. Graphics Press, Cheshire, Connecticut, 197 pp.

Tversky, A., and Kahenman, D., 1981. The framing of decision and the psychology of choice. *Science*, 211: 453-458.

Ulanowicz, R.E., 1997. *Ecology, the ascendent perspective*. Columbia University Press, New York, 201 pp.

Ulgiati, S., (Ed.), 2003. "*Proceeding of the 3° International workshop "Advances in Energy Studies: Exploring supplies, constraints, and strategies*" (Portovenere, September 2002). (In press)

Ulgiati, S., (Ed.), 2001. *Proceeding of the 2° International workshop: "Advances in Energy Studies: Exploring supplies, constraints, and strategies*". (Portovenere, 23-27 May 2000). SGE editoriali Padova (Italy), 698 pp.

Ulgiati, S., (Ed.), 1999. *Proceeding of the 2° International workshop: "Advances in Energy Studies: Energy flows in ecology and economy*". (Portovenere, 26-30 May 1998). MUSIS (Museum of Science and Scientific Information, Rome, Italy), 636 pp.

UNEP (Unite Nation Enviornmental Programme), 2004. See the documents available at URL: <http://earthwatch.unep.net/about/docs/indicat.htm>

Udo, H.M.J., Ifar, S., Steenstra, F.A., 1997. *Testing livestock interventions for marginal upland areas in East Java*. In: Sørensen, J.T., (Ed.) *Livestock Farming Systems. More than Food Prod*uction. EAAP Publication n° 89, Wageningen Pers, Wageningen, pp. 124-129.

van der Sluijs, Potting, J., Risbey, J., van Detlef, V., de Vries, B., Beusen, A., Heuberger, P., Corral Quintana, S., Funtowicz, S., Kloprogge,P., Nuijten, D., Petersen, A., Ravetz, J., 2002.

Uncertainty assessment of the IMAGE/TIMER B1 CO2 emissions scenario, using the NUSAP method. Dutch National Research Programme on Global Air Pollution and Climate Change. JRC Report no: 410 200 104, 225 pp.The document is available in internet at URL: <http://www.nusap.net/workshop/report/finalrep.pdf>

van der Werf, H.M.G., and Petit, J., 2002. Evaluation of the environmental impact of agriculture at farm level: a comparison and analysis of 12 indicators-based methods. *Agriculture, Ecosystems and Environment*, 93: 131-145.

Verburg, P., 2000. *Exploring the spatial and temporal dynamics of land use, with special reference to China.* Ph.D. thesis dissertation, Wageningen University, 148 pp.

Vereijken, P., 1999. *Manual for prototyping integrated and ecological arable farming systems (I/EAFS) in interaction with pilot farms.* (en) Stichting Cereales, Wageningen, The Netherlands, 53 pp. A summary is available in internet at URL: <http://www.gcw.nl/i_eafs/i_eafs.pdf>

Vereijken, P., 1999. *Manual for prototyping integrated and ecological arable farming systems (I/EAFS) in interaction with pilot farms.* (en) Stichting Cereales, Wageningen, The Netherlands, 53 pp. A summary is available in internet at URL: <http://www.gcw.nl/i_eafs/i_eafs.pdf>

Vereijken, P., 1997. A methodological way of prototyping integrated and ecological arable farming system (I/EAFS) in interaction with pilot farms. *European Journal of Agronomy*, 7: 235-250.

Vereijken, P., 1992. A methodic way to more sustainable farming system. *Neth. J. Agric. Sci*., 40: 209-223.

Verhagen, J.H., 1999. *Netcoast Open Learner - Coastal Monitoring: Amoeba of the Aegean Sea*. IHE Delf. (the Duch International Institute for Infrastructural, Hydraulic, and Environmental Engineering) 11 pp. The document is available in internet at URL: <http://www.ihe.nl/he/dicea/monitor/aegean.htm>

Vineis, P., 1990. *Modelli di rischio: epidemiologia e causalità*. Einaudi, Torino, Italy, 159 pp. (In Italian - Title translation, *Models of risk: epidemiology and causality*.)

Vitousek, P.M., Mooney, H.A., Lubchenco, J., Melillo, J.M., 1997. Human domination of earth's ecosystems. *Science*, 277: 494-499.

Vitousek, P.M., Ehrlich, P.R., Ehrlich, A.H. and Matson, P.A. 1986. Human appropriation of the products of photosynthesis. *Bioscience*, 36: 368-373.

Vreeker, R., Nijkamp, P., Ter Welle, C., 2001. *A multicriteria decision support methodology for evaluating airport expansion plans*. TI 2001-005/3 - Tinbergen Institute Discussion Paper, 21 pp. The document is available in internet at URL: <http://greywww.kub.nl:2080/dgr/uvatin/01005.pdf>

Vu Biet Linh, and Nguyen Ngoc Binh, 1995. *Agroforestry Systems in Vietnam.* (Vietnam APAN) Agriculture Publishing House, Hanoi. 160 pp.

Wackernagel, M., Rees, W., 1996. *Our Ecological Footprint*. New Society Publishers, Gabriola Island, BC., 176 pp.

Waldrop, M.M., 1994. *Complexity: the emerging science at the edge of chaos.* Penguin Books, Harmondworth, London, 356 pp.

Watanabe T. 1986. Fish feed and their quality. In Grimaldi E. and Rosenthal H. (Eds): Trends and problem in aquaculture developement. Proceeding of the 2th international conference on aquafarming "*Acquacultura '84*", Verona - Italy, October 12-13 pp.190-217.

WCED, 1987. *Our common future: The Burtland report*. Oxford University Press for the World Commission on Environment and Development, New York, 400 pp.

Weaver, W.,1948. Science and complexity. *American Scientist*, 36:537-544. (Based upon material presented in Chapter 1, "*The Scientists Speak*." Boni & Gaer Inc., 1947). Available at http://www.ceptualinstitute.com/genre/weaver/weaver-1947b.htm

Wefering, F.M., Danielson, L.E., White, N.M., 2000. Using the AMOEBA approach to measure progress toward ecosystem sustainability within a shellfish restoration project in North Carolina. *Ecological Modelling*, 130:157-166.

Whitemore, T.H., 1998. *An introduction to tropical rain forests.* Oxford University Press, 232 pp.

Whyte, L.L., 1969. *Structural hierarchies: A challenging class of physical and biological problems*. In: Whyte, L.L, Wilson, A.G., Wilson, D., (Eds.), *Hierarchical structures*. American Elsevier Publishing Company, New York, pg. 3-16.

Wiener, N., 1948. *Cybernetics*. John Wiley, New York, 212 pp.

Wiens, J.A., 1989. Spatial scaling in ecology. *Functional Ecology,* 3: 385-397.

Wilson, D., 1969. *Forms of hierarchy: A selected bibliography*. In: Whyte, L.L, Wilson, A.G., Wilson, D., (Eds.), 1969. *Hierarchical structures*. American Elsevier Publishing Company, New York, pp. 287-314.

Wilson, E.O., 2002. The bottleneck. *Scientific American*, February: 82-91.

Wolf, S.A., and Allen, T.F.H., 1995. Recasting alternative agriculture as a management model: The value of adept scaling. *Ecological Economics*, 12:5-12.

Wolfram, S., 2002. *A New Kind of Science.* Wolfram Research Inc. 1192 pp.

Wong Chor Yee, A., 1999. New developments in integrated dike-pond agriculture-aquaculture in the Zhujiang Delta, China: ecological implications. *Ambio*, 28(6): 529-533.

World Bank (1995), *World Bank 1995,* Baltimore: The Johns Hopkins University Press. 700 pp.

Yan, J.S., and Yao, H.L., 1989. *Integrated fish culture management in China*. In: Mitsch, W.J., and Jorgensen, S.R., (Eds.), *Ecological Engineering: An introduction to ecotechnology*. John Wiley & Sons, Inc., pp. 375-408.

Ye, X.J., Wang, Z.Q., Li, Q.S., 2002. The ecological agriculture movement in modern China. *Agriculture, Ecosystems, and Environment,* 92:261-281.

Zar, J.H., 1984. *Biostatistical analysis*. (2nd ed.) Prentice Hall, Englewood Cliffs, New Jersey, 718 pp.

Zhao, S., 1994. *Geography of China: environment, resources, population and development*. John Wiley and Sons, New York. 332 pp.

Zhong, G.F., 1990. The types, structure and results of the dike-pond system in south China. Geojournal. Kluwer Academic Publishers (USA). ??????

Zhong, G.F., 1989. The structural characteristics and effects of the dyke-pond system in China. *Outlook in Agriculture*, 18(3): 119-123.

Zhong, G.F., 1982. The mulberry dike-fish pond system complex: A Chinese ecosystem of land-water interaction on the Pearl River Delta. *Human Ecology*, 10(2):191-202.

Zhong, L., (Ed.) 1992. *Pond fishery in China*. Pergamon Press, Oxford. 160 pp.

Zhu, Y., Yang, Y., Wan, J., Hua, D., Mathias, J.A., 1990. The effect of manure application rate and frequency upon fish yield in integrated fish farm pond. *Aquaculture*, 91:233-251.

Zorpette, G., 1999. To save a salmon. *Scientific American*, January: 100-105.