EDITORIAL

This second issue for 1995 has a more diverse array of articles than usual: 'mainstream' ecology applied to integrated farming systems; cage culture materials science; African farming systems social science; and shrimp culture development and its public health aspects.

The first of these breaks new ground for *Aquabyte*. The debate is widening on the ecological and economic basis of the *sustainability* of production systems and it would be good to see more contributions to that debate in *Aquabyte*. Ecology is not just a 'green credo'. It's a well-established science, with robust methods that can and should be applied more widely in aquaculture. Thanks to Jens Peter Dalsgaard for pointing this out and for paving the way for further contributions. Despite this fine crop of articles we still need more, so please get writing and photographing. Thanks in advance. ***R.S.V. Pullin***

Applying Systems Ecology to the Analysis of Integrated Agriculture-Aquaculture Farms

JENS PETER TANG DALSGAARD
ICLARM

What is ecologically sound farming? Which characteristics of the farm may we look into in order to assess its ecological fitness? Are there indicators that could tell us something about its overall ecological state? If so, can these indicators be measured and quantified?

There is no easy answer to any of these questions. We may have intuitive ideas as to which types of design and management foster an ecologically healthy agriculture. But we have, as of yet, no generally accepted method for measuring and verifying these perceptions and no simple way of comparing the ecological states of different farms. Ecology is by nature a complex science as it deals with a complex issue. We should therefore expect to be on the lookout not for one, but more likely for a range of characteristics that will allow us to probe into the ecological conditions of a farm. The following discussion suggests a preliminary list of properties as a point of departure for quantifying various ecological facets of the farm. The terms employed should be familiar to ecologists but may introduce new concepts to agri- and aquaculturists.

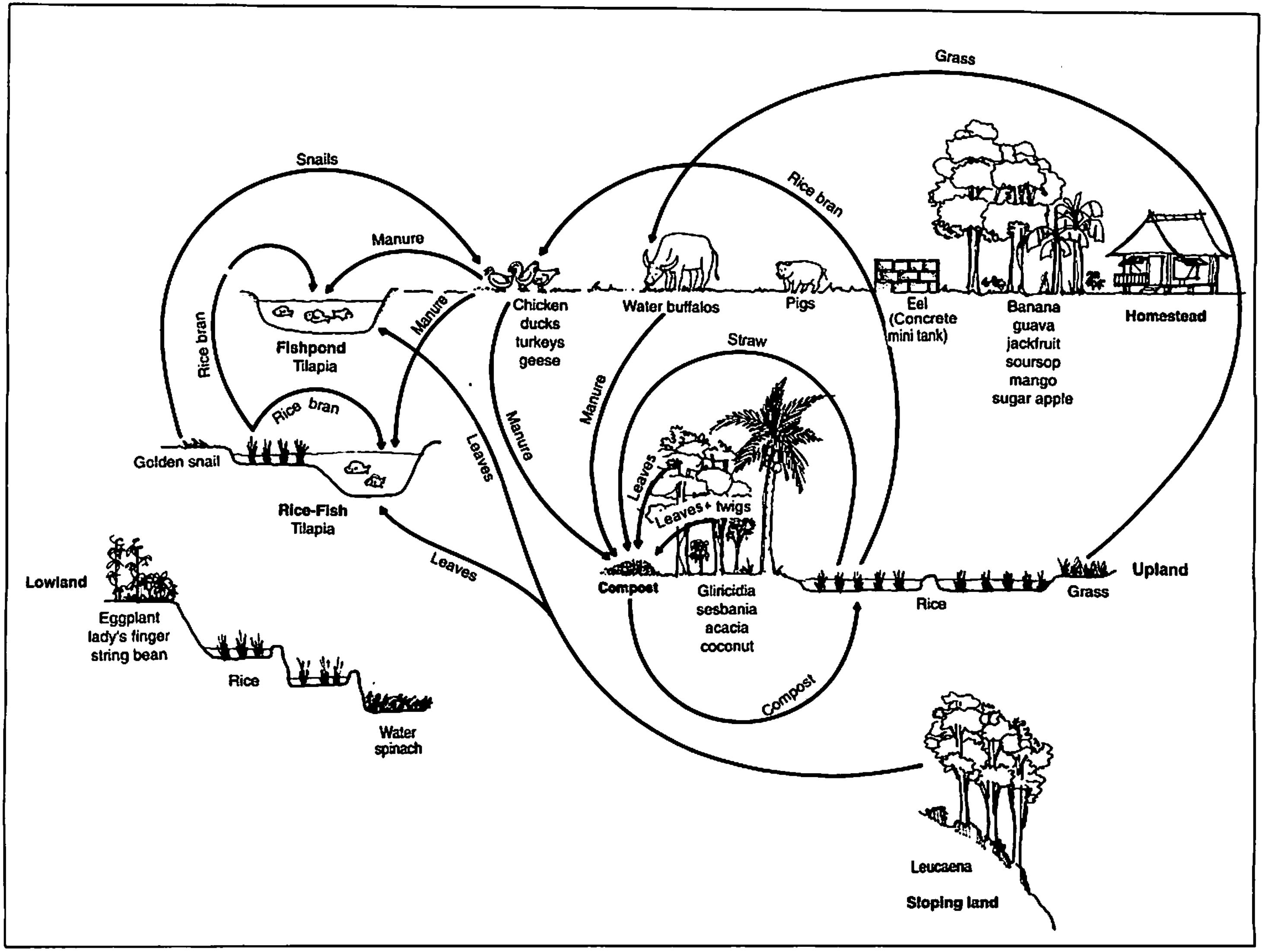
The Agroecosystem View

One of the appealing features of integrated farming, such as integrated agriculture-aquaculture (Fig. 1) is that it leads us to view the farm in terms of interdependent components, i.e., as a system. This perspective is useful. Systems can be described, modeled, analyzed and compared. Systems are guided by principles and have properties as a result of the parts that make them up and the way these parts are related.

Farms are systems - agroecosystems (Conway 1985; Altieri 1987). If we adopt a narrow perspective that ignores the surrounding natural, human and socioeconomic environment, and limit our view to the biota of the farm itself, we find that these agroecosystems may be made up of several parts (Fig. 1), or of just a few parts (Fig. 2). In fact farms are often made up of surprisingly many components. These components may be combined (Fig. 1) or managed more or less separately (Fig. 2). Crop by-products may be fed to animals and animal manures returned to the crop. Fish may feed on (harmful) insects, snails and weeds in the ricefield and in turn increase the availability of nutrients to the crop, e.g., by stirring up sediments. Poultry may feed over or in fishponds and fertilize them, and so on.

Diversity

The brief description of the agroecosystem structure above leads us to the first two potential descriptors: system components and their connections. Both of these properties can be quantified in various ways. We can do a simple count of utilized and farmed plants and animals and determine agricultural species richness. Or we can be a little more sophisticated and calculate agricultural species diversity, weighting each individual species in terms of its standing biomass or its content of a major nutrient [Box 1]. The focus suggested here is on the species which are in one way or another farmed and utilized, thus the phrase 'agricultural species', thereby ignoring the remaining wild flora and fauna present within the farm. The approach assumes that an increase in 'agricultural diversity' somehow reflects an increase



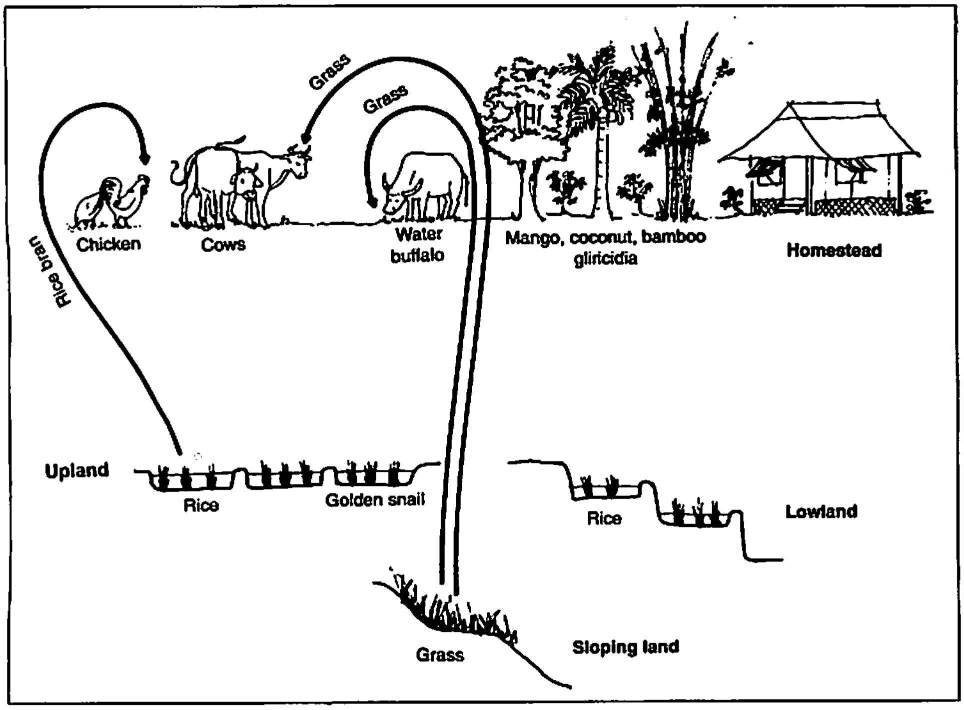


Fig. 1. *Bioresource flow model of an integrated agriculture-aquaculture farm (2.26 ha), Philippines, wet season 1991.**

Fig. 2. *Bioresource flow model of a conventional type rice farm (2.48 ha). Philippines, wet season 1991.**

** Although based on actual datasets, both bioresource flow models should be considered hypothetical as some of the yield, flow, and standing stock data were inferred from succeeding years' datasets.*

Box 1. Diversity

	Figure 1	Figure 2
• Species richness (simple species count, including grasses/weeds as one species)	25	10
• Species diversity (using Shannon's index*)		
Each species measured in terms of its average standing biomass in kg/ha	1.93	1.19
Each species measured in terms of its N content in kg/ha	1.95	1.61
Each species measured in terms of its exergy content/ha	2.00	1.54
Functional diversity (diversity of agricultural guilds, each guild measured in terms of its average standing biomass in kg/ha)	1.37	1.10

* (Magurran 1988)

Box 2. Cycling

	Figure 1	Figure 2
• Number of bioresource flows	15	3
• Bioresource flow diversity (bioresource flows quantified in terms of their biomasses in kg/ha)	1.42	0.71
• Bioresource flow diversity (bioresource flows quantified in terms of their N contents in kg/ha)	2.22	0.87
• Finn's cycling index (the fraction of a systems throughput that is recycled. Computed using the ECOPATH II* software with N as model currency)	46% (of total throughput)	32% (of total throughput)

* (Christensen and Pauly 1992)

in overall system biodiversity, and a potential improvement in system fitness.

However, it is not only species *per se* that concern us. We are also interested in the way plants and animals complement each other, utilize different niches, and function together. We thus emphasize functional diversity. In ecology, functionally similar groups of species are referred to as guilds. We could divide farmed species into 'agricultural guilds,' i.e., into groups that are managed in similar ways and perform similar functions within the agroecosystem. A tentative list of agricultural guilds might read: rice; cereals; legumes/pulses; nonleguminous vegetables; roots and tubers; sugar and beverage crops; fibers; herbs, spices and medicinal plants; forage grasses; fruit trees; multipurpose trees; poultry; pigs; livestock; aquatic animals; aquatic plants; insects. This subjective grouping of plants and animals could also be used as a basis for calculating diversity. It captures elements of the heterogeneity, trophic structure and trophic diversity of the agroecosystem, and reflects a potential functional diversity [Box 1].

Cycling

In the same way that we account for species, we can count the number of bioresource flows or calculate the bioresource flow diversity as a first approximation of the cycling of biomaterials within the agroecosystem [Box 2]. Bioresource flows are here defined as the outputs and by-products which are applied by the farmer for reuse within the farm. What is important, however, with respect to bioresource flows is not only their number and volume(s) but also their direction and the closing of mineral cycles. In the extreme case, all flows may be unidirectional into one particular field or pond, thus acting as a sink for nutrients and organic matter and a drain on the surrounding area. A straight count of flows would not in such a case adequately express the extent to which resources are efficiently recycled. A cycling index (Finn 1980), taking into account both farmer-managed bioresource flows and 'natural flows' (e.g., plant nutrient uptake), may represent a better proxy for integration and cycling [Box 2].

Productive Capacity

Other characteristics emerge as we view the whole farm, e.g., its overall ability to produce biomass. This 'capacity' reflects the quality of the underlying soil and the availability of water. Productive capacity may, in the crudest form be quantified as biomass produced in kg/ha - thereby measuring 'net community production' in ecological terminology [Box 3].

A related property applied within traditional ecosystem theory is the B/E ratio or the biomass supported per unit of energy flow. The ratio has been presented as a measure of how mature a system is: the higher the ratio the more mature the system (Odum 1971). It also tells us something about the productive capacity of the system, namely its ability to convert available energy into something useful such as biomass. By substituting nitrogen for energy we derive an expression

Box 3. Productive Capacity

	Figure 1	Figure 2
- Net community production (biomass output in kg/ha, including increases in standing stocks)	23.0 t	29.4 t
- B/E ratio (computed using the ECOPATH II* software, with N as model currency)	0.54	0.26
- Yield (kgN/ha)	73.8	90.8
- Output/input ratio (1) (yield over external inputs measured in terms of N contents)	3.24	0.84
- Output/input ratio (2) (yield over external inputs + bioresource flow inputs measured in terms of N contents)	1.73	0.77

* (Christensen and Pauly 1992)

of the system's ability to convert a nutrient into something useful [Box 3].

The output/input ratio is often computed for a farm or for a particular enterprise in order to assess its efficiency (Spedding et al. 1981). This ratio also expresses a unit's capacity for capturing and converting resources into a useful product. It is usually computed as yield over external inputs, measured either in energy, nutrient, or monetary terms. With the additional details provided in the bioresource flow model one could derive a more comprehensive expression of the ratio [Box 3].

System Currency

In deriving and computing system properties we need to make choices regarding which 'currency' to use: do we measure kilograms of the standing biomasses of crops and animals and fresh weights of material flows; do we use energy conversions; or do we try to quantify everything in terms of nutrient contents and flows? In the above examples, we chose nitrogen as the dominant currency. There is no one ideal currency, and any choice may be acceptable as long as it can be justified within and fits the type of analysis one wishes to make. Recent explorations within ecosystem theories suggest alternative potential currencies:

- *Emergy*, short for embodied energy, accounts for the energy required in the formation of organisms at different trophic levels (Odum 1988). There is a concentration factor of approximately ten from one step in the foodchain to the next and this is widely used in calculating the potential productivity of systems (e.g., Pauly and Christensen 1995). One may, for example, thus give the energy of zooplankton a ten times higher weight than that of phytoplankton, by arguing that a zooplankton concentration of 1 contains the same number of solar energy equivalents as a phytoplankton concentration of 10. In other words, it is assumed that equivalent amounts of energy go into the formation of 1.0 kg of zooplankton and 10.0 kg of phytoplankton. The multiplication by a factor of ten, as one moves through the foodchain from one trophic level up to the next, although simplifying things, does point out something important, namely that energy is utilized in the production of and is somehow 'hidden' within the organization and construction of living things. Organisms at different trophic levels may comprise similar quantities of calories or kilojoules, but it has cost very different amounts of energy to produce them. Emergy should be viewed as an attempt to account for the energy, measured in solar equivalents, that has been expended in the construction of organisms.

- *Exergy* has the same aim; to capture the energy expended in the organization and construction of living organisms. But exergy suggests another way to do this, by accounting for the genetic information accumulated within organisms (Jørgensen 1992). Organization of an organism is here seen as being expressed through the information contained in its genes. The higher the organization of an organism, the higher its exergy, as it has cost more exergy to construct a more complex organization.

Both emergy and exergy are expressions of energy with a built-in measure of quality. Compared with energy they may represent more accurate currencies for direct quantitative comparisons of complex systems containing diverse components and producing such differing outputs as grains, fish, livestock, vegetables and fruits. Neither emergy nor exergy can be measured, but both can be computed for each of the components present within a system and summed up for the whole system. How about for instance quantifying each species in terms of its exergy content, using the derived values in the computation of system diversity? On the basis of approximate numbers of genes and biomass (Jørgensen 1994) one can derive a measure of the exergy contained within each species present and apply these values in the computation of Shannon's diversity index [Box 1].

Integrated agriculture-aquaculture farms like this one in Cavite, Philippines (1994) may be ecologically healthy, but how can this be investigated? Ecological concepts and methods can be applied. **(PHOTO BY J.P.T. DALSGAARD)**

Sustainability Insights

There is plenty of scope in agroecosystem analysis for exploring the identification and application of different properties, measures and 'currencies . The application of ecological principles and ecosystem theory to the analysis of agroecosystem performance presents an interesting opportunity and challenge.

It could turn out to be a fruitful endeavor if, in the process, we are able to derive a list of quantifiable properties that adequately describe different ecological aspects of farms, thereby permitting us to assess and compare their agro-ecological states.

For monoculture systems, relying largely on external inputs and only limited recycling of nutrients we would intuitively expect diversity and cycling as defined above to yield relatively low values, whereas we would expect the values for integrated polyculture systems to be higher. For productive capacity the picture appears somehow less clear and it is possible to mask a low inherent system's capacity by importing nutrients. The preliminary quantitative comparison of the farms in Figs. 1 and 2 confirms our intuitive perceptions. It also indicates that what is perceived as ecologically sound farming may not have to be associated with any great reduction in total output by utilizing natural resources more efficiently. The diverse, integrated farm (Fig. 1) grows rice on just over half (56%) of the total area using compost and relying only marginally on chemical fertilizers with 15 kg urea applied on a small area of vegetables, whereas the more conventional type rice farm (Fig. 2) grows rice on 91% of the farm and imports 225 kg of urea. Yet in terms of aggregate system yield the two farms produce similar quantities on a per hectare basis.

This exploratory analysis suggests that quantification of selected attributes may help us verify our perceptions and facilitate the comparison of systems across space and time. Thinking ahead, such quantifications and comparisons may prove useful in the identification of indicators of ecological sustainability in agroecosystems (Dalsgaard et al. 1995).

Acknowledgements

Thanks to ICLARM colleagues Roberto Oficial, Teresita Lopez, Farlyz Villanueva and Mary Ann Bimbao for assistance in fieldwork and model articulation; the International Institute of Rural Reconstruction, Silang, Cavite, Philippines, for collaboration in our common effort to generate and investigate new integrated agriculture-aquaculture farming systems; and ICLARM artist Albert Contemprate. The work of the author is funded by the Danish International Development Assistance (Danida).

References

Altieri, M.A. 1987. Agroecology, the scientific basis of alternative agriculture. Westview Press, Boulder, Colorado.

Christensen, V. and D. Pauly. 1992. ECOPATH II - a software for balancing steady-state ecosystem models and calculating network characteristics. Ecol. Modelling 61:169-185.

Conway, G.R. 1985. Agroecosystem analysis. Agric. Admin. 20:31-55.

Dalsgaard, J.P.T., C. Lightfoot and V. Christensen. 1995. Towards quantification of ecological sustainability in farming systems analysis. Ecol. Engineering. (In press)

Finn, J.T. 1980. Flow analysis of models of the Hubbard Brook ecosystem. Ecology 61:562-571.

Jørgensen, S.E. 1992. Integration of ecosystem theories: a pattern. Kluwer Academic Publishers, Dordrecht.

Jørgensen, S.E. 1994. Review and comparison of goal functions in system ecology. Vie Milieu 44:11-20.

Magurran, A.E. 1988. Ecological diversity and its measurement. Croom Helm, London.

Odum, E.P. 1971. Fundamentals of Ecology. W.B. Saunders Co., Philadelphia.

Odum, H.T. 1988. Self-organisation, transformity, and information. Science 242:1132-1139.

Pauly, D. and V. Christensen. 1995. Primary production required to sustain global fisheries. Nature 374:256-257.

Spedding, C.R.W., J.M. Washington and A.M. Hoxey. 1981. Biological efficiency in agriculture. Academic Press, London.

J.P.T. DALSGAARD *is an Assistant Scientist in the Inland Aquatic Resource Systems Program, ICLARM.*

ICLARM Contribution No. 1132.