Journal of Ecological Anthropology

Volume 4
Issue 1 *Volume 4, Issue 1 (2000)*

Article 2

2000

The Conceptual Utility of Models in Human Ecology

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Abstract

Anthropology and bioecology are currently at a point in their development where researchers in both fields are working towards an integration, which can be described as a form of human ecology. Integration of such disparate disciplines is not easily achieved. Important steps which facilitate integration are the clear definition of terms relevant to the disciplines, and the development of a common framework which would allow the overlapping of domains of the disciplines. The objective of this paper is to contribute to an understanding of human ecosystems by discussing (1) the definition of human ecosystems, and (2) the use of models in illustrating the integration of bio-physical and socio-cultural components of human ecosystems. Icons from the systems modeling languages of H.T. Odum and J.M. Forrester are applied to the modeling of human ecosystems. Specifically, models of R.A. Rappaport's work with the Tsembaga Maring are discussed in terms of their depiction of the components of human ecosystems. Modeling allows one to conceptualize the complexity of human ecosystems, and is an important step towards a human ecology.

Introduction

In E.P. Odum's (1969) discussion of the development of ecosystems through their "lifetime," he makes it a point to focus part of his discussion on human ecosystems. Noting bioecology's historical omission of humans from ecosystem analysis, he called for a form of ecosystem analysis that considers humans as a part of, not apart from, nature. The recognized role of humans in ecosystem analysis has not changed much since then. Bioecologists continue to treat humans as external to their notion of system, searching for "undisturbed" and "pristine" ecosystems in which to conduct basic research. By focusing on the negative effects of humans on ecological processes, ecologists continue to reinforce the idea that humans are not "natural" biological or ecological entities.

Some attempts have been made to integrate humans into ecosystem analysis, but progress among bioecologists is slow. Within conservation and applied ecology there are attempts to integrate humans into ecological systems. A recent book (McDonnell and Pickett 1993) reports a conference in which researchers approached humans as components of ecosystems. The National Science Foundation has recently provided funding to establish Phoenix and Baltimore as Long Term Ecological Research (LTER) sites, where the city itself is treated as an ecosystem. So, bioecologists are beginning to consider humans to be ecological entities, not simply external disturbance factors.

Cultural anthropologists, beginning with the cultural ecology of Steward (1949) and White (1949) attempted to develop ecological models of human systems. Although these models included energy and (implicitly) matter, they tended to exclude much of the non-human environment. Like bioecology, they also tended to avoid addressing the need to model information. Other cultural anthopologists, like Rappaport (1968), and archeologists (cf. Flannery 1968, Kowalewski et al. 1983), attempted to formalize the modeling of human systems, but this approach began to lose favor by the early 1990s. Current biocultural and life-history approaches (cf. McElroy 1990, Hill 1993) have tended to downplay the systems approach and limited the scope of analysis to a few key variables. If our goal is to gain a complete and

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useful understanding of human ecology, we still need to develop approaches that incorporate human systems, the non-human environments, and the ephemeral nature of information in human decision making and non-human ecological function.

In this paper, I attempt to integrate several concepts and ideas that contribute to our understanding of human ecosystems. I will begin by defining some terms relevant to human ecology. Then I briefly discuss some shortcomings of the bioecological treatment of humans. Lastly, I discuss the role that modeling can play in working toward an integration of the physical, biological, social, and cultural components of human ecosystems.

Ecosystems and Environments

In the development of a scientific theory, an important step is the definition of core concepts (Pickett et al. 1994). Imprecise thought and the use of jargon as an intellectual crutch reduces confidence and limits communication (Pickett et al. 1994). The clear definition of terminology reduces confusion. This section defines what can be considered a core concept of human ecology, the ecosystem.

In 1935, Tansley introduced the ecosystem as a holistic concept: "the more fundamental conception is . . . the whole system (in the sense of physics), including not only the organism-complex, but the whole complex of physical factors forming what we call the environment of the biome–the

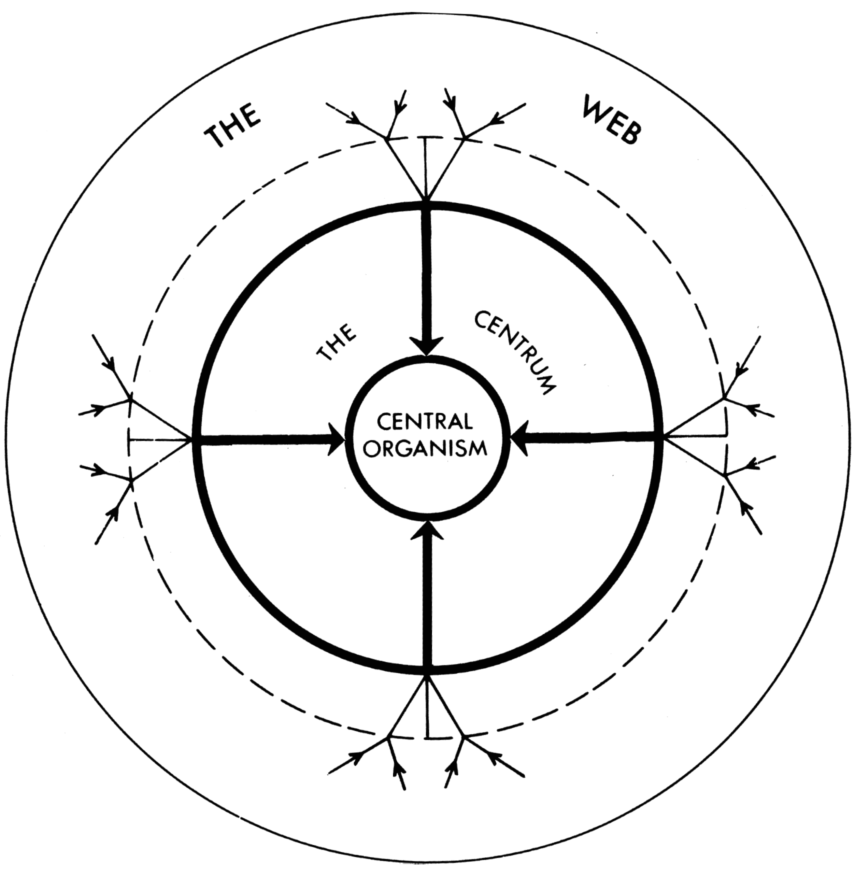

Figure 1. The input environment. (Modified from Andrewartha and Birch 1984.)

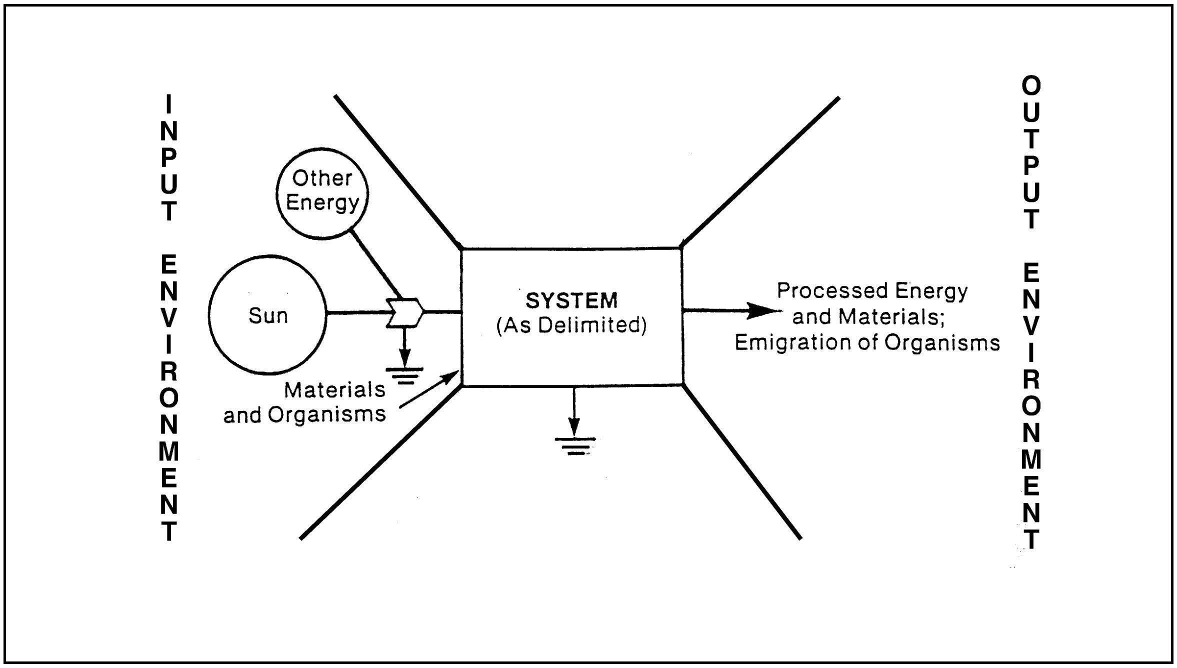

FIGURE 2. ENVIRONMENT AND ECOSYSTEM.
There are two environments, an input environment and an output environment, defined by the focal animal or system; altogether they define the ecosystem: IE+S+OE=ECOSYSTEM (Redrawn from Odum 1983; concept based on Patten 1978).

habitat factors in the widest sense." Tansley (1935) considered the ecosystem to be the basic unit of nature. The ecosystem can be used to conceptually integrate other levels in the hierarchy of biological organization (Allen and Hoekstra 1992), and can also be treated as a fundamental unit of analysis for human ecology.

The environment of an ecosystem is another concept, which has been defined and redefined in the past 50 years, and thereby affects the way one defines the ecosystem. For example, the input environment of Andrewartha and Birch (1984) includes all the biotic and abiotic factors which influence an organism's ability to survive and reproduce (Figure 1). This conception of environment is limiting because it ignores connections between ecosystems.

Patten (1978) has defined the environment to include both the inputs and outputs of the system. The output environment includes all energy, matter, and information that leaves the system, and influences other ecosystems (Figure 2). According to Patten (1978) the ecosystem is defined as made up of the system, the input environment, *and* output environment of the system. In a sense, the system is a locus in the environment. Addition of the output environment integrates the influences that organisms have on their environments, enabling concepts that include coevolving organisms and environments, such as the Gaia hypothesis (Lovelock 1987). Patten's definition of ecosystem can be considered a complete definition. Without the output environment, only the system, and not the ecosystem, is being analyzed.

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Previous definitions of environment have included only physical and biological components. When the ecosystem in question is a human ecosystem, there are additional layers of complexity to the environment. Humans exist in cultural and social environments as well as physical and biological environments (Figure 3). Accordingly, a human ecosystem is defined as an ecological system that includes humans and has multiple (physical, biological, social, and cultural) input and output environments which link to other ecosystems.

Since ecosystems are defined as any system with input and output environments, ecosystems can be defined at any spatial scale: thus, the ecosystem is a transcalar concept. The multiple environments of human ecosystems can be arranged in a spatially scaled hierarchy, so that human ecosystems can be located anywhere from the level of organisms and families up to the level of nations and world systems (Figure 4).

A distinction can now be drawn between the ecosystem and system approach. The system approach can explain the functioning of the internal system components through networks, nodes, flows, and linkages. The ecosystem approach includes an analysis of the system components, as well as the relation of the system to components in its input and output environments. Human ecosystem analysis can be defined simply: the study of ecosystems (a system with an input and output environment) that contain humans as components of the system, not merely the input and/or output environment(s).

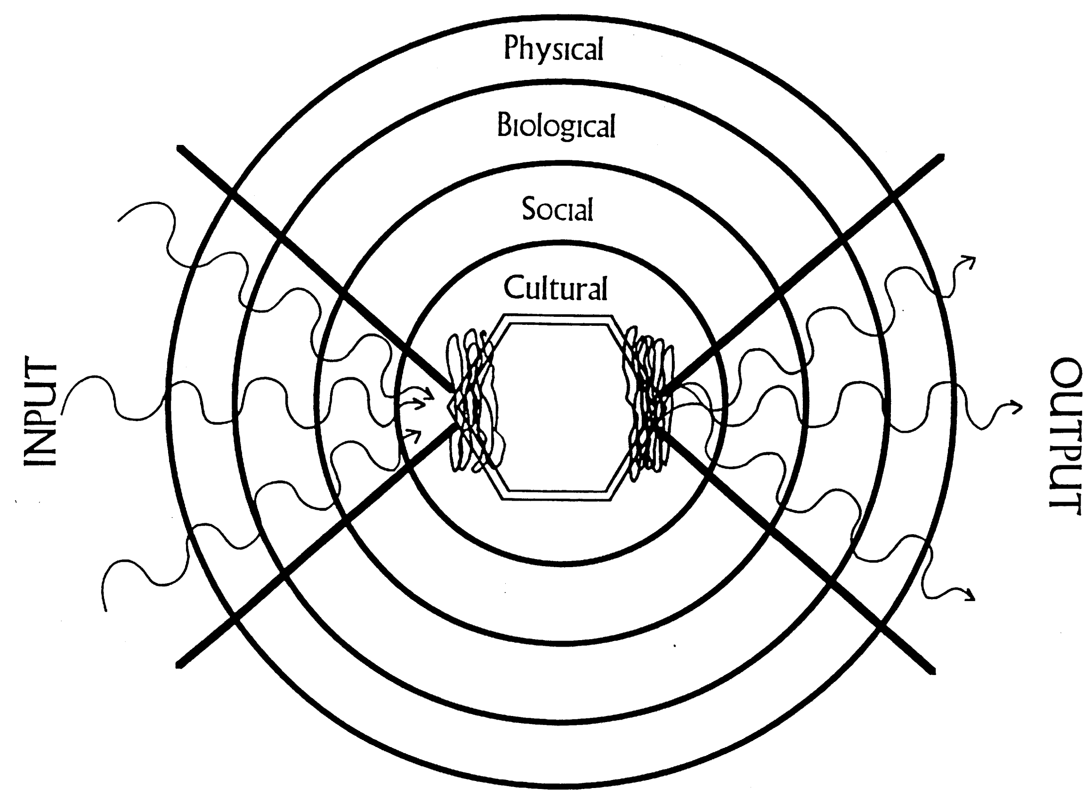


FIGURE 3. PARTIAL THEORY OF MULTIPLE ENVIRONMENTS.
The input-output structure and concept of filters follow Patten. The hierarchy of spheres is an evolutionary arrangement of the environments; other arrangements are possible (Stepp 1999).

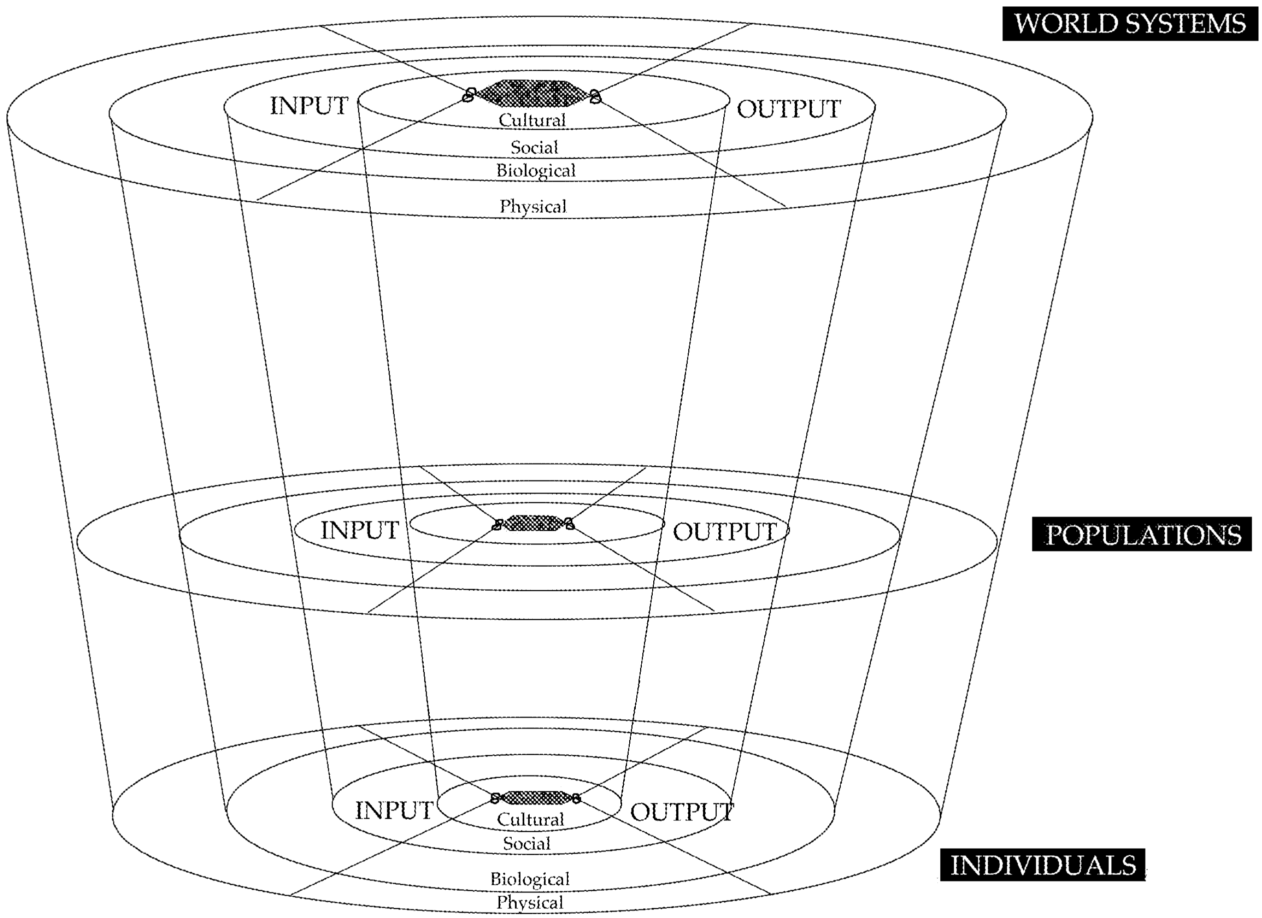


FIGURE 4. MULTIPLE ENVIRONMENTS CONCEPT APPLIED TO A SCALED HIERARCHY OF HUMAN ECOSYSTEMS.

Bioecological Approach To Humans

In addition to its treatment of humans as unnatural and external disturbance factors, two other criticisms of the bioecological approach to considering humans can be offered: the limited conception of environment and the lack of proper consideration of the role of information flows. All three shortcomings contribute to an incomplete understanding of human ecology within the discipline of bioecology. The concept of environment within bioecology is, in general, incomplete and insufficient to allow an understanding of human ecosystems. Recognition of the fact that, as ecological entities, humans operate not only in physical and biological environments, but also cultural and social environments, can lead to a theoretical framework that will allow bioecologists to gain a more complete understanding of the nature of human ecosystems.

The role of information in human ecosystems sets them apart from ecosystems that are traditionally studied within bioecology (Stepp 1999). But, bioecological attempts to understand human ecosystems have for the most part ignored this important component. For example, Figure 5 is an energy model of Maori culture by H.T. Odum (1983), and Figure 6 is a diagram of the input environment of hunter-gatherers by Andrewartha and Birch (1984). Both diagrams focus on the physical and biological components, ignoring the role that information has in generating the patterns and processes seen in the human ecosystems in question.

Visualizing Human Ecosystems Through Models

Integration of the cultural and social facets of humanity with the physical and biological components traditionally studied in bioecology is not easy. One stumbling block is the lack of overlap of the domains of the disciplines and the lack of a common theoretical framework (see Pickett et al. 1994). One starting point for integration would be a common framework of ecosystem modeling. Modeling is an appropriate place to begin to integrate the two disciplinary approaches because models serve as conceptual tools in the formulation of theories, helping one to visualize the patterns and processes of the ecosystems being represented. In this section I discuss a framework which has been used to model human ecosystems (Stepp 1999) and use this framework to discuss the modeling of Rappaport's work with the Tsembaga Maring (1968, 1984).

The human ecosystems (information ecology) group at UGA has been adapting the modeling approach of H.T. Odum to incorporate the role of information in human ecosystems (cf. Zarger 1998, Jones 1999, Stepp 1999). To illustrate this approach, I have applied it to a simplification of H.T. Odum's (1983) model of the aggregated US economy (Figure 7), while including the concept of input/output environments and information flows. The input environment for the US is composed of climate, water flows, geologic materials, and most notably, the output environments from other nations and regions of the world (Figures 8 and 9). The output environment of the US economy becomes the input environments of the other nations of the world. The quality and quantity of the flows composing the output and input environments in the diagram will vary depending upon the nation in question, as well as the point in time that the model is applied.

In order to build on past modeling concepts to better represent information, a new symbol has been introduced with this model, being a combination of H.T. Odum and Forrester modeling symbols. A difference between Forrester's and Odum's modeling approaches is how their respective symbols are informed by the other components of the system (Figures 10 and 11). H.T. Odum's interaction represents simply the coupling and intersection of flows (Figure 10a). Forrester's valves, on the other hand, receive information flows from system components which make up the decision function and affect the flow through the valve (Figure 10b). H.T. Odum's interaction involves an implicit informing by system components and logical operations, while Forrester's valve requires the

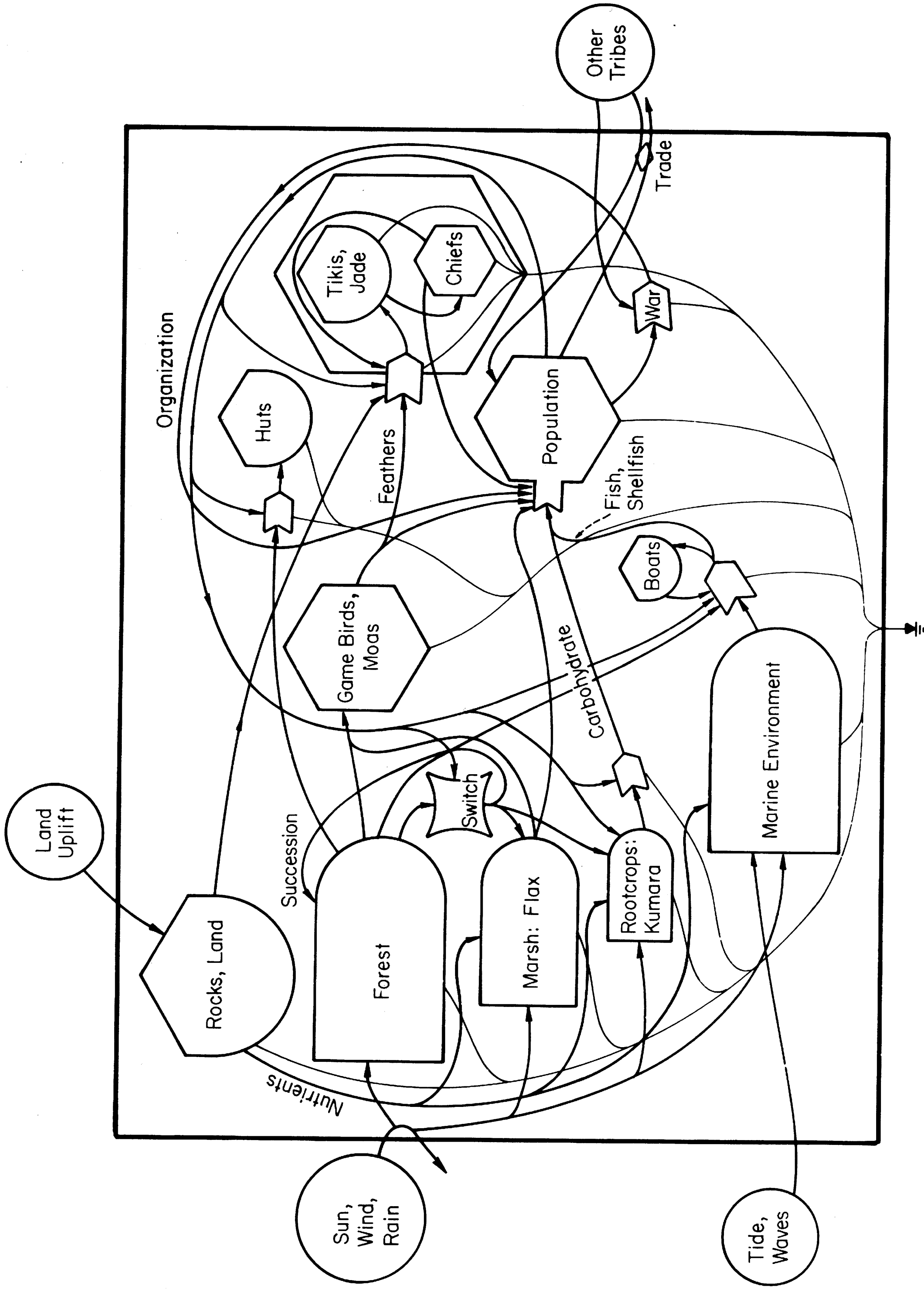


FIGURE 5. HUMAN ECOSYSTEMS WITHOUT INFORMATION: THE EARLY MAORI IN NEW ZEALAND (H. T. Odum 1983).

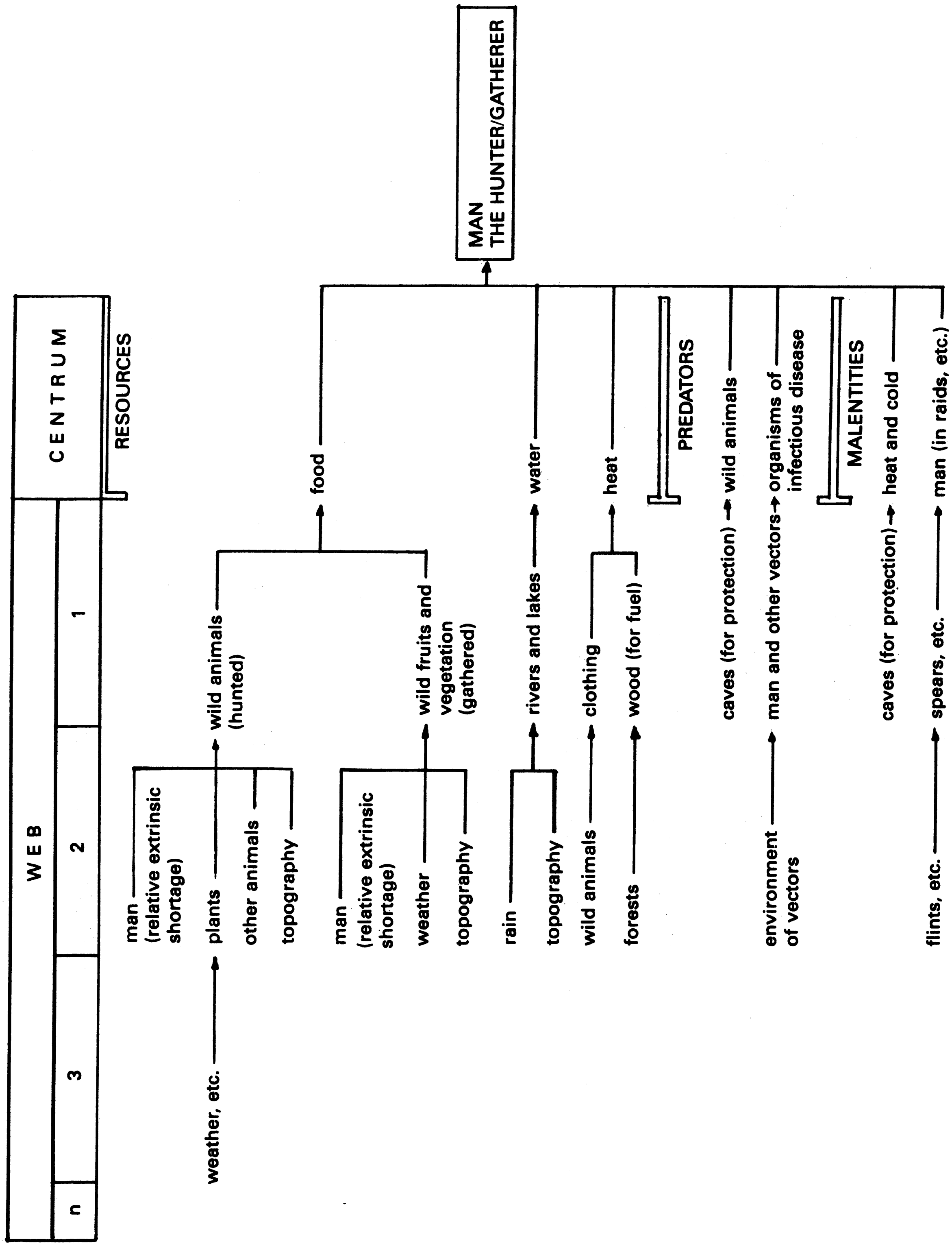


Figure 6. The hunter-gatherer ecosystem of Andrewartha and Birch (1984).

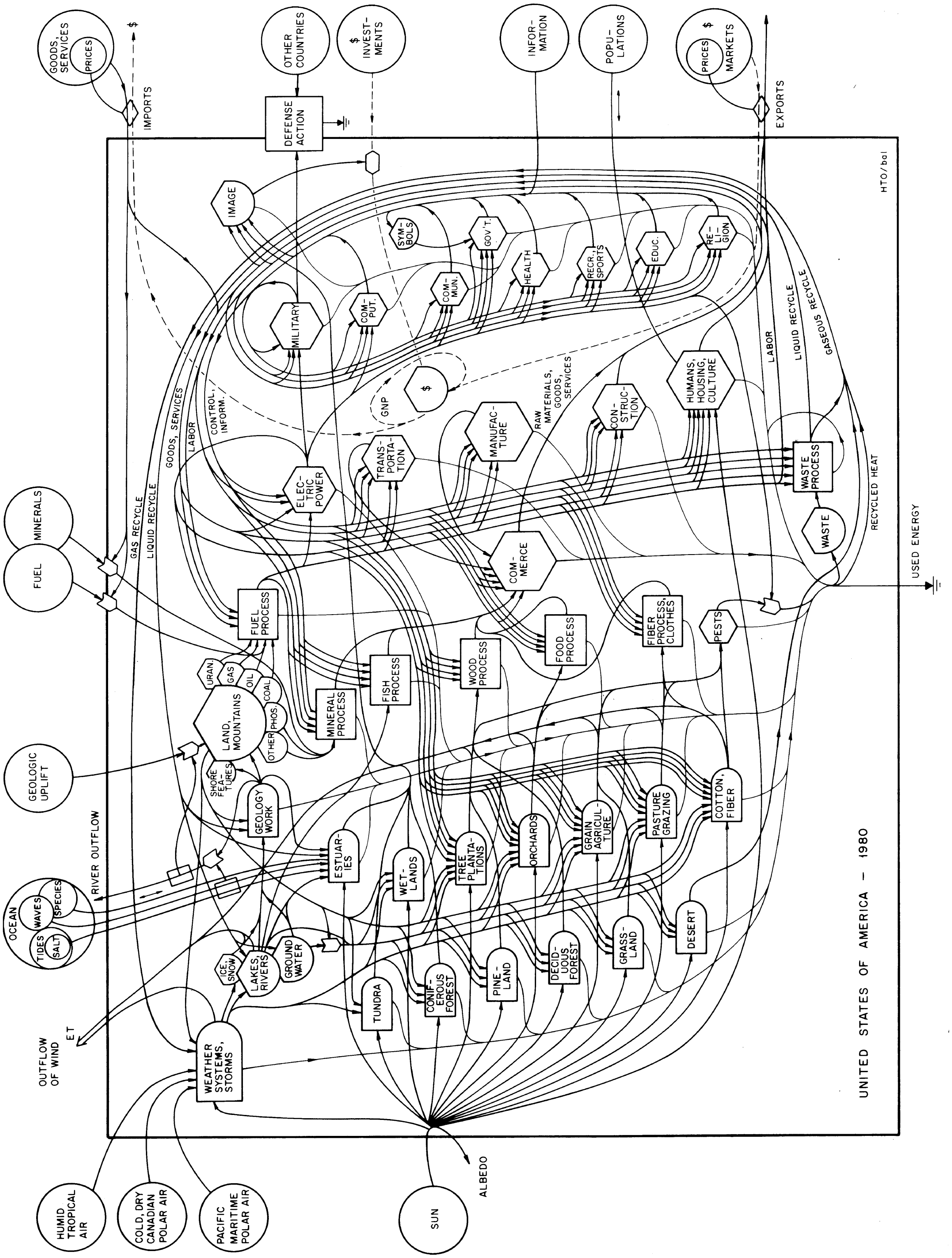


FIGURE 7. ODUM'S AGGREGATED MODEL OF THE UNITED STATES ECONOMY (from H. T. Odum 1983).

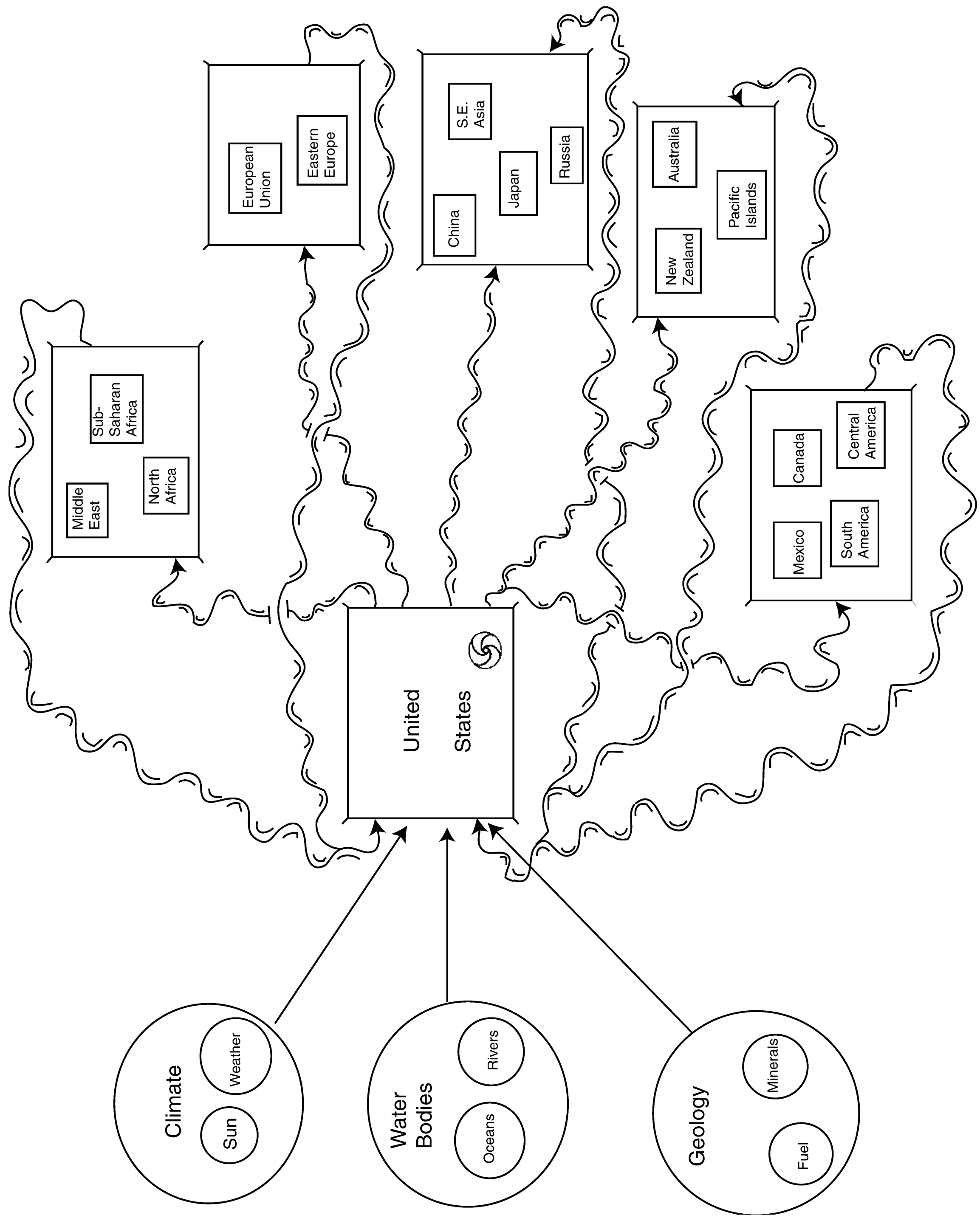


Figure 8. The US aggregated economy in ecosystem perspective (wavy lines indicate information flow, see Appendix B for a key to symbols).

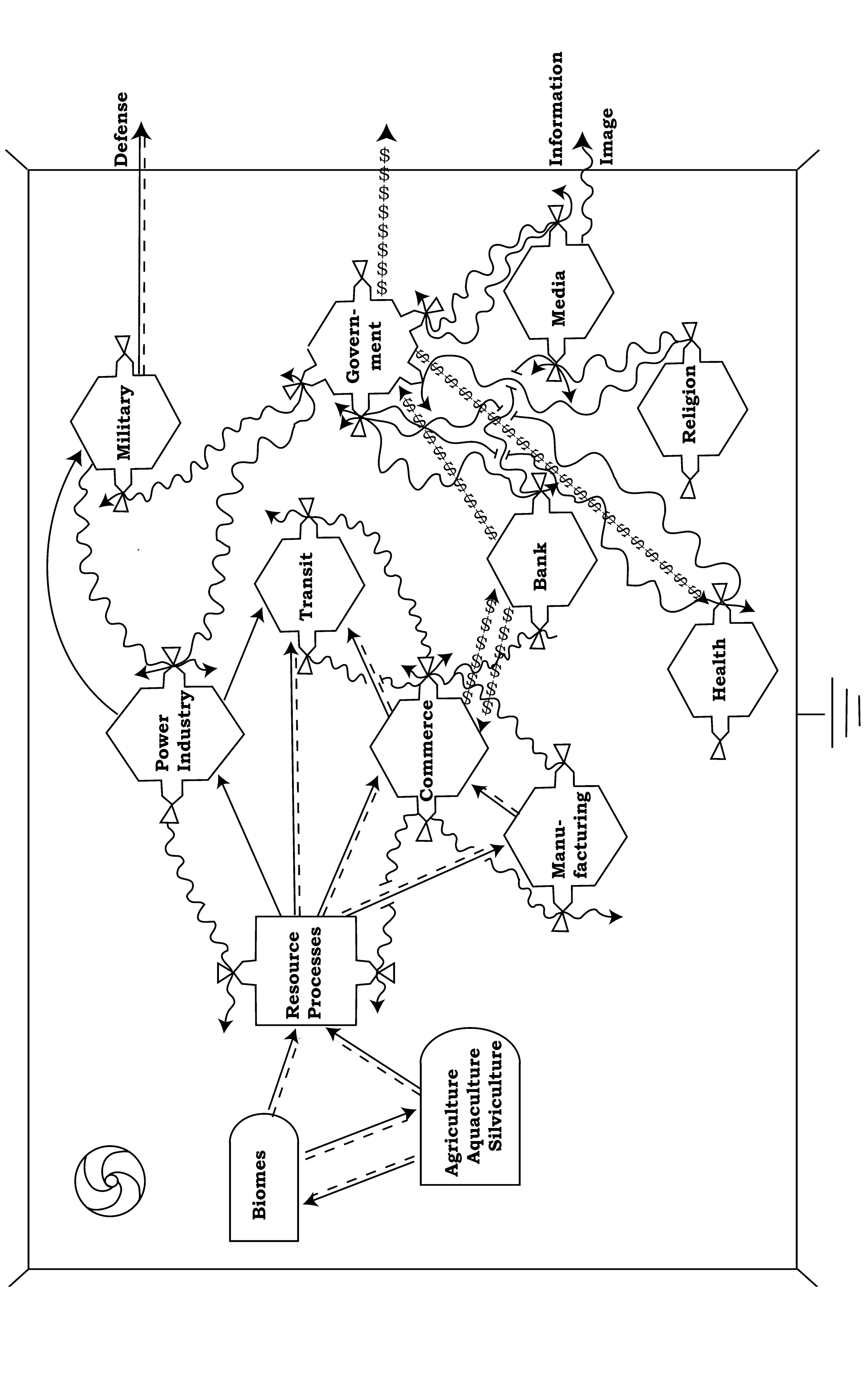


FIGURE 9. THE INTERNAL SYSTEM STRUCTURE OF THE US ECONOMIC SYSTEM (wavy lines indicate information flow, see Appendix B for a key to symbols).

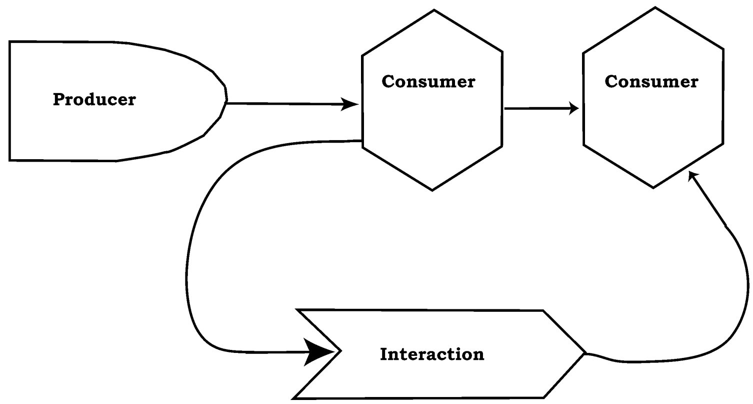


Figure 10a. H.T. Odum modeling language.
The enclosure symbols (e.g., producer and consumer) have dual functions, both transforming flows, and the storage of inputs minus outputs. Symbols such as the interaction also modify flow rates. The modification of flows and rates involves implicit informing and logical operation by system components.

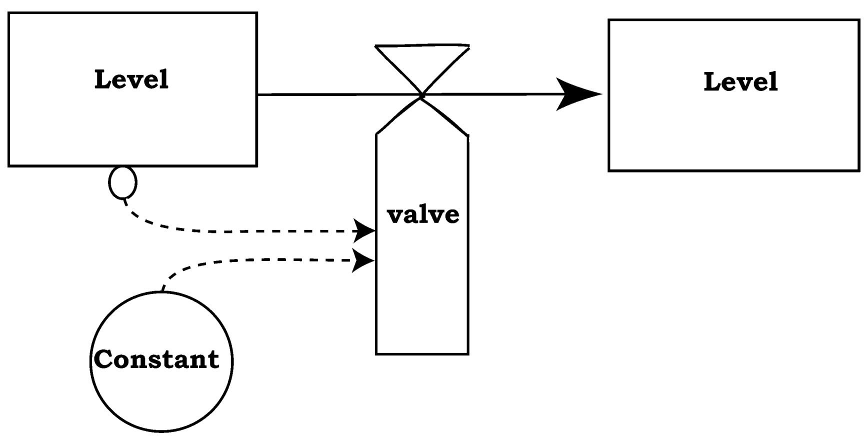


Figure 10b. Forrester modeling language.
Decision functions are used to determine the rates of flows (valves). The valve receives information flows (dashed lines) from system components. Information flows make up the decision function and affect the material flows through the valve. The basic enclosure symbols are levels, which indicate the state of a variable.

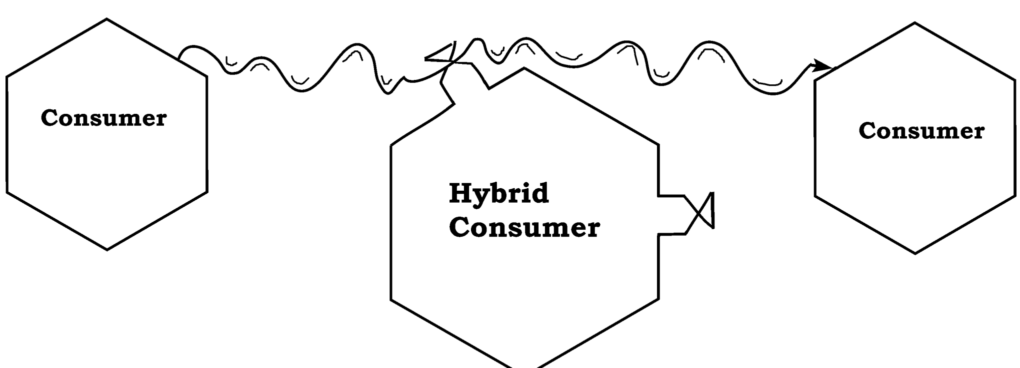


Figure 10c. Odum-Forrester Hybrid.
This new symbol incorporates the explicit role of information used in Forrester models, with the enclosure symbols of H.T. Odum. This hybrid symbol both receives information flows from the system components, and uses this information to modify other flows (e.g., energy or matter) through the enclosure symbol (note the curvy-dashed line indicates the flow of information and matter/energy).

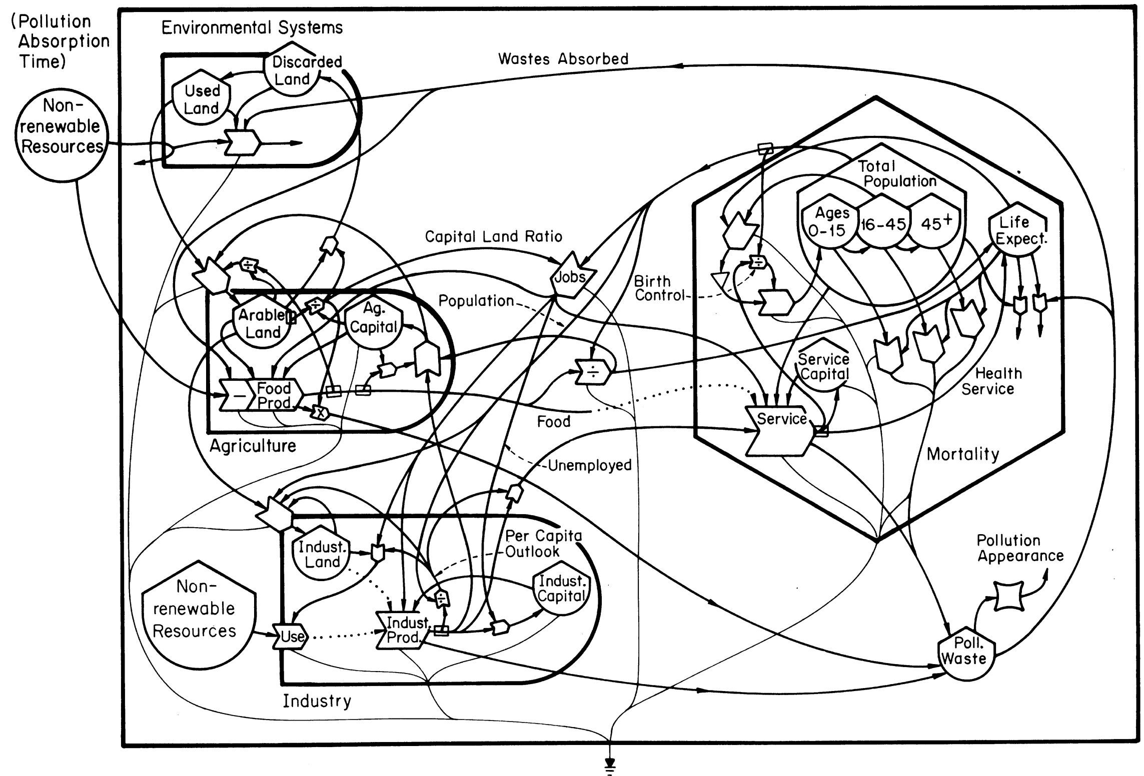


FIGURE 11. WORLD MODEL OF POPULATION AND NATURAL RESOURCES SHOWN IN BOTH FORRESTER AND H.T. ODUM MODELING LANGUAGES (from Odum 1983). (Note that the model has been over-simplified by H.T. Odum from the original Forrester model.)

explicit modeling of information transfer between system components. Since Forrester's models operate without implicit logic and with explicit information flows, his valve symbol would more clearly indicate the decision making role of Odum's consumer/producer symbol, so the two symbols have been merged (Figure 10c).

With a framework for modeling human ecosystems in hand, we can now turn to a classic study from human ecology. Rappaport's (1968) work with the Tsembaga Maring of New Guinea can be used to illustrate the potential that this framework for human ecosystem modeling has for integrating the cultural, social, biological, and physical components of human ecosystems. In *Pigs for the Ancestors*, Rappaport reported on a small tribe that practiced swidden agriculture on about 1000 acres of arable forest land, of which about 100 acres was in garden at any time. Forests were cleared by burning, used for a year or two, and then as productivity began to decline, were left fallow. The Tsembaga women also practiced pig husbandry, the pork providing an important protein supplement. Pigs were slaughtered at many ritual occasions. The festival was triggered by the perception of the pig population increasing to the point at which they are consuming too much of the Tsembaga's garden crops. The **kaiko** was an important event in the Tsembaga ritual cycle, consisting of the ritual slaughter of most of the pigs and the sharing of pork with one's allies. After allies were given pork the **rumbim** (a sacred plant) was uprooted, indicating that the ritual taboo on warfare was lifted. Neighbors then went into active conflict, which ended after both sides sustained a few casualties. The cycle was completed by the planting of **rumbim**, signifying that the taboo on warfare once again stood (see also Appendix A).

Rappaport described the Tsembaga population as being self-regulated. He proposed that the interplay of the pig population and the ritual cycle served to keep the Tsembaga population at a level which did not overshoot the carrying capacity of the biophysical environment. The human ecosystem of the Tsembaga is characterized by the cycling of the human population, cycling of the pig population, and the ritual cycle. Periodic warfare regulated the Tsembaga population, while the pig populations served as an unconscious information monitor for this population regulation (Shantzis and Behrens 1973).

Several models of Rappaport's work have been constructed since *Pigs for the Ancestors* was first published. Padoch (1973) used H.T. Odum-type energy model language to run computer simulations of the relation between human population, pig population, festival, and warfare in the Tsembaga ecosystem (Figure 12a). These simulations resulted in cycles similar to those proposed by Rappaport. Shantzis and Behrens (1973) used Forrester-type information computer model simulations to show that human populations can by regulated by the ritual warfare, which in turn is informed by the pig population cycling (Figure 12b). Again, these simulations produced cycles similar to those proposed by Rappaport.

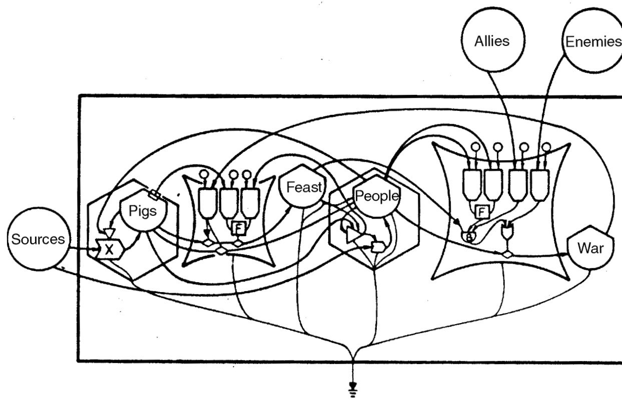
Other computer model simulations have been constructed to challenge the notion that human populations can be self-regulated, as hypothesized by Rappaport, and confirmed through simulation by the model of Shantzis and Behrens (1973). Samuels (1982) constructed a computer simulation model which included the effect of disease epidemics on the Tsembaga populations. His computer simulation results indicated that the role of the ritual cycle as a regulator was not valid when the effects of disease epidemics were included in the simulation models. Foin and Davis (1984, 1987) then adapted the model of Shantzis and Behrens (1973) to run simulations, as they also did not agree with Rappaport's suggestion that ritual had a self-regulatory role in the Tsembaga ecosystem. In their first paper (1984) they questioned the choice of parameter values used by Shantzis and Behrens (1973). Running the model with what they considered to be more realistic parameters, the ritual cycle played no role in regulating the ecosystem. In their second paper (1987) they compared models of local stability (i.e., the Tsembaga are self-regulated), regional stability (i.e. local populations are unstable, but there is always a population existing at the broader scale), and disequilibrium (there is no stability at all). Again, the model of Shantzis and Behrens (1973) was used to simulate local stability (Figure 12c). In this second paper, Foin and Davis (1987) found that depending on the scale of perspective one takes, it is possible for the disequilibrium model to best represent the Tsembaga ecosystem.

So, computer models have shown that the Tsembaga are both (1) self-regulated, with ritual warfare playing a central role, as hypothesized by Rappaport, and (2) not self-regulated by ritual, and even out of equilibrium. What then are we to take away from this discussion of models of the Tsembaga ecosystem?

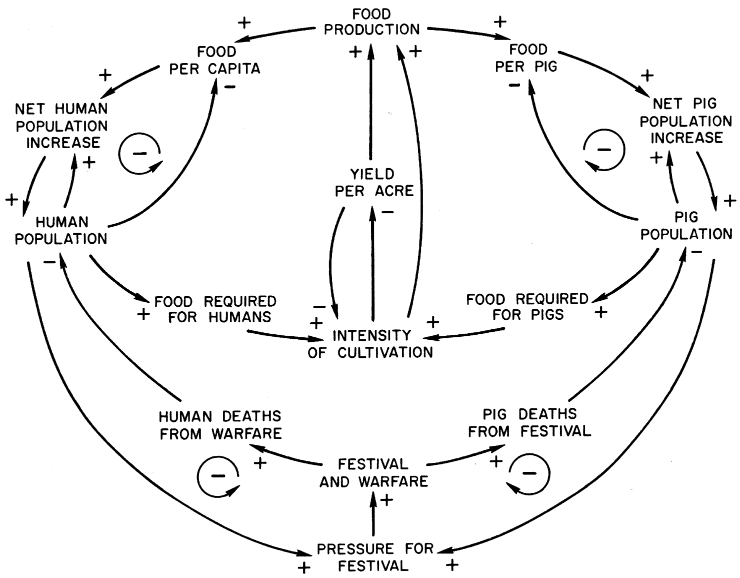
First, models are nothing more than simplifications of complex systems. The nature of this simplification depends upon the version of reality that the modeler wishes to describe (Levins 1966). Model simulations are never "true," but can only be taken as far as the nature of the model allows (Taylor 2000). As we have seen in the previous discussion, whether or not a modeler believes Rappaport's hypothesized self-regulation influences the nature of the model that is constructed and the parameter values that fill it. Therefore, the models can not be judged as tests of Rappaport's hypothesis. The models are representations of real systems, and can only be tested to see if they are internally consistent with what the modeler is trying to represent. In other words, a model is not an ecosystem, and an ecosystem is not a model.

Second, what modeling does have to offer is utility as a learning tool. Models have value in understanding complex systems in that the process of constructing them allows one to gain a per-

12A.



12B.



12C.

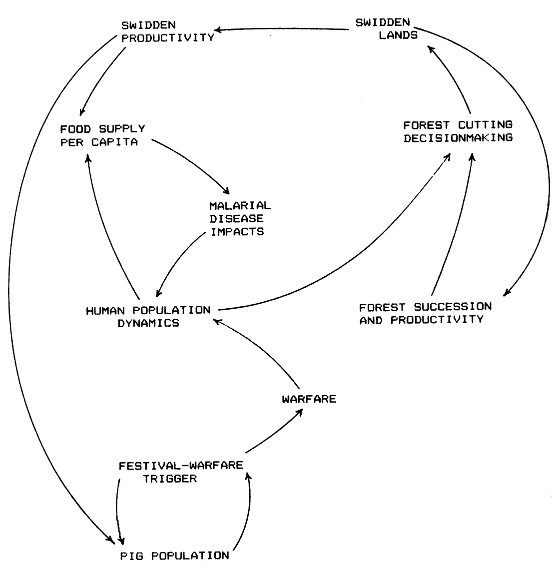


FIGURE 12. COMPUTER SIMULATION MODELS OF THE TSEMBAGA ECOSYSTEM. (12a, Padoch 1973; 12b, Shantzis and Behrens 1973; 12c, Foin and Davis 1987.)

spective on the connections and complex causalities of these systems (Levin 1966, Taylor 2000). Models therefore have a role to play as conceptual tools for understanding the complexity of human ecosystems.

To expand on this second point, I have applied the modeling approach developed at UGA (see Zarger 1998, Jones 1999, Stepp 1999) to the Tsembaga Maring as described by Rappaport. This modeling exercise was conducted to illustrate how information flows and stores are integrated into a cybernetic human ecosystem, rather than trying to illustrate the self-regulatory properties of the Tsembaga ecosystem. A system is cybernetic if it has feedback, where the input environment of the system is determined to some extent by the output environment of the system. Cybernetic systems are often assumed to have goals which drive system behavior, such as the temperature at which one sets a thermostat. However, Patten and Odum (1981) described ecosystems which are cybernetic, but do not operate via teleological goal functions. The behavior of these systems is determined by past causes, and "the interplay of material cycles and energy flows, under informational control, generates self-organizing feedbacks with no discrete controller required" (Patten and Odum 1981: 888). Flows from certain subsystems may steer other subsystems without the ecosystem as a whole being teleological. Extending this emergent property to the Tsembaga ecosystem, the question one should then be asking is how the components of this ecosystem are integrated such that self-organized feedbacks arise. Modelers seeking to find how the Tsembaga ecosystem regulates the population growth of humans at some optimal level are asking a false question. What the Tsembaga example allows us to understand is how the physical, biological, social, and cultural components of human ecosystems can be integrated.

The first model (Figure 13) consists only of the biological and physical components of the ecosystem. The forest and gardens draw energy from the sun and nutrients from the soil. The garden and forest are linked by the process of shifting cultivation. Energy flows from the gardens to the pigs, and from the gardens and pigs to the human population. This model is incomplete, because it leaves us asking: what steers the flow of energy from the pigs to the Tsembaga; what steers the shifting cultivation which links forest and gardens; what steers the growth of the human population; and how are the social and cultural characteristics of the Tsembaga integrated into this ecosystem?

To address these questions, the second model (Figure 14) includes the role of information flow in the form of the ritual cycle, using the Odum-Forrester hybrid symbol introduced above (Figure 10c). The ritual cycle itself is depicted as an exponential delay within a system, and represents the merging of several levels and flow rates which compose the delay function (Forrester 1961). The delay is informed by the perception of the impact of the pig population on the gardens. When this information accumulates to a certain point (where the women notice it and complain) the ritual cycle produces warfare. The ritual cycle delay is also informed by the results of the warfare, and when casualties are considered to be sufficient, the ritual cycle produces a truce. The flow of pig protein to the Tsembaga is also informed by the ritual cycle delay. Notice that the shifting of land between forest and garden is controlled by the perceived swidden productivity. This productivity is informed by both the amount of food produced and the human population size (in effect, food per capita). The human population size is affected by the casualties sustained during warfare, and it is here that the ritual cycle integrates with the dynamics of the Tsembaga population and their impact on the forests that provide land for their swidden agriculture.

Figure 14 shows a conceptualization of Rappaport's self-regulation hypothesis in the Tsembaga Maring ecosystem. The model illustrates how the biophysical and sociocultural components of the ecosystem may integrate to produce self-organized feedback mechanisms. The model also illustrates the role that information flows have in this system. Previous models have a more static conceptualization of the rela-

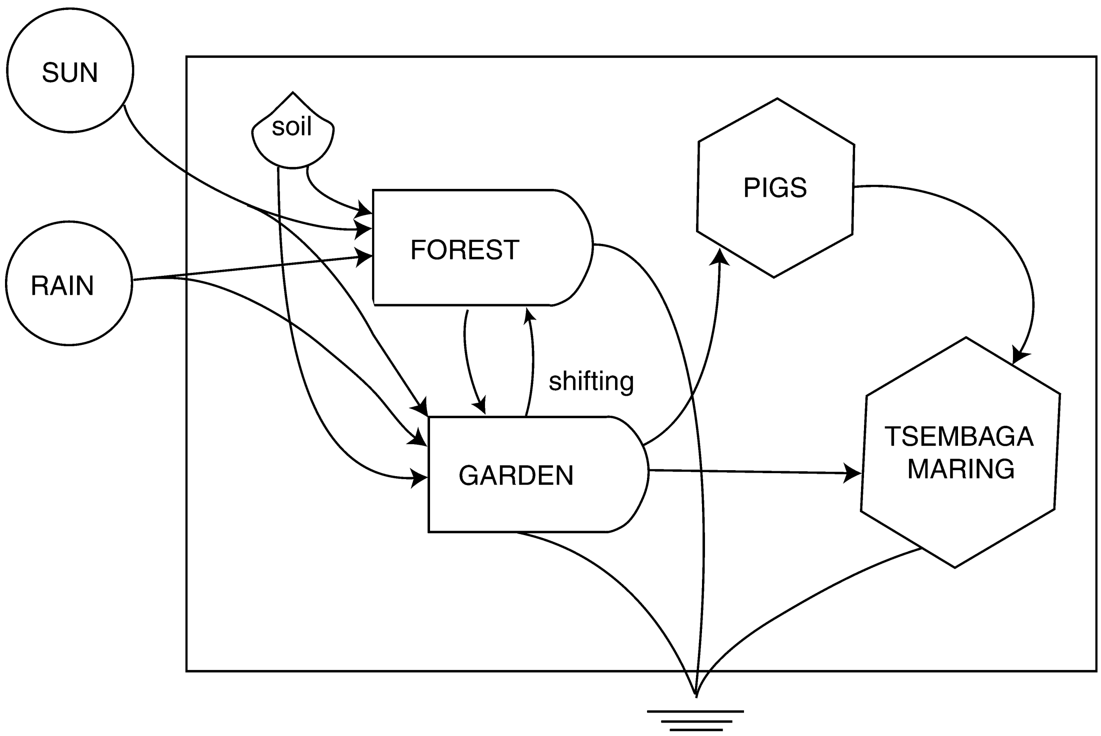


Figure 13. Biophysical model of the Tsembaga ecosystem. (See Appendix B for a key to symbols.)

tionship between pigs, festival, and warfare; the ritual cycle just happened because it was preprogrammed into the simulations. The model developed here depicts how information is transmitted and processed in such a way that the ritual cycle comes about. It falls short of Rappaport's diagrammatic model (Figure 15) in the second (enlarged) edition of his book (1984), in the sense that he reveals a higher level of information flow in also depicting the spirit world as it plays a role in the system. Comparing Rappaport's model with the model here suggests that another generation of modeling could carry the Forrester method further to accommodate even more of the information causality in the Tsembaga system.[2]

[2] See Appendix A for an example of modeling Rappaport's Maring systems from a primarily informational/belief systems perspective.

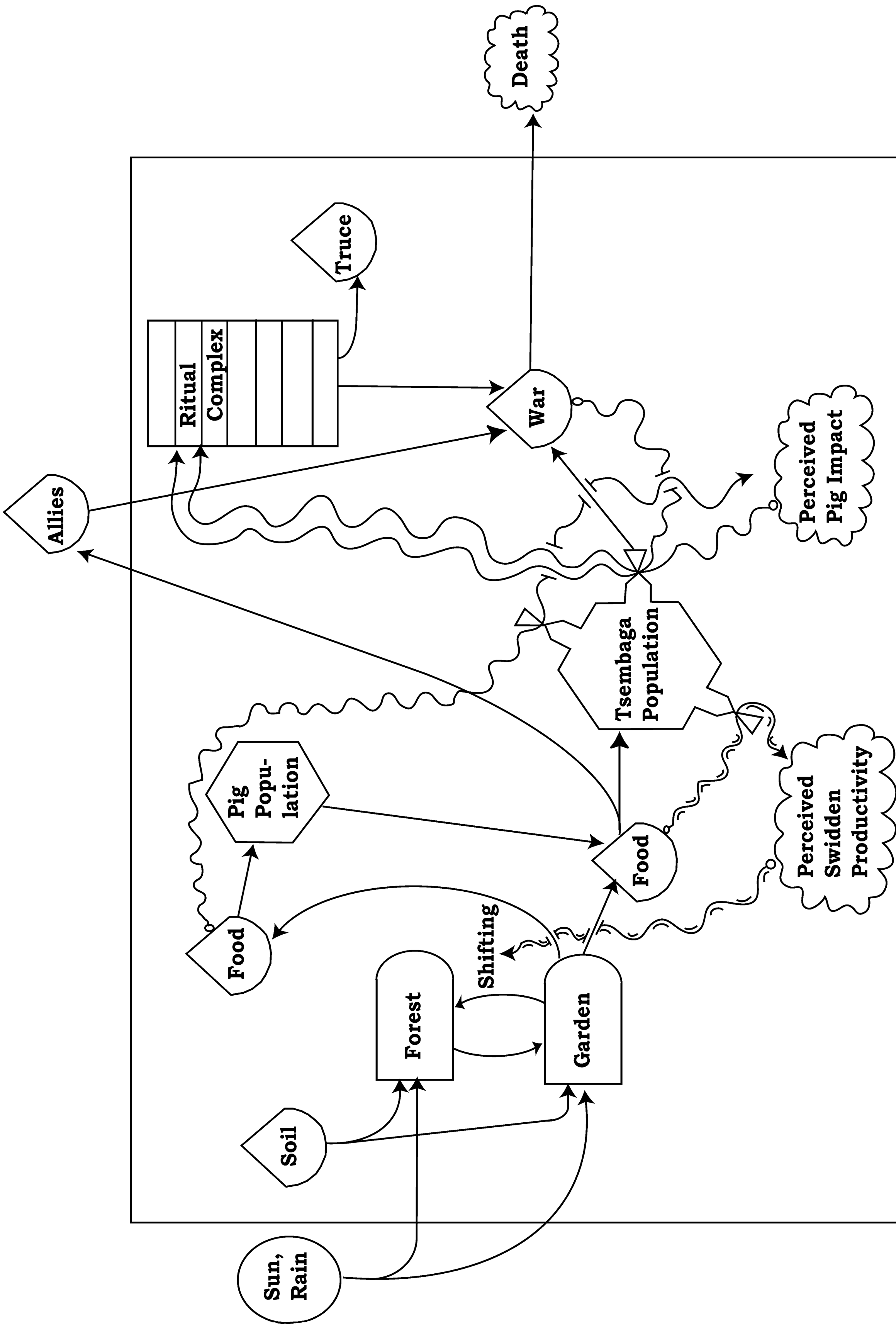


Figure 14. Model of the Tsembaga human ecosystem. (See Appendix B for a key to symbols.)

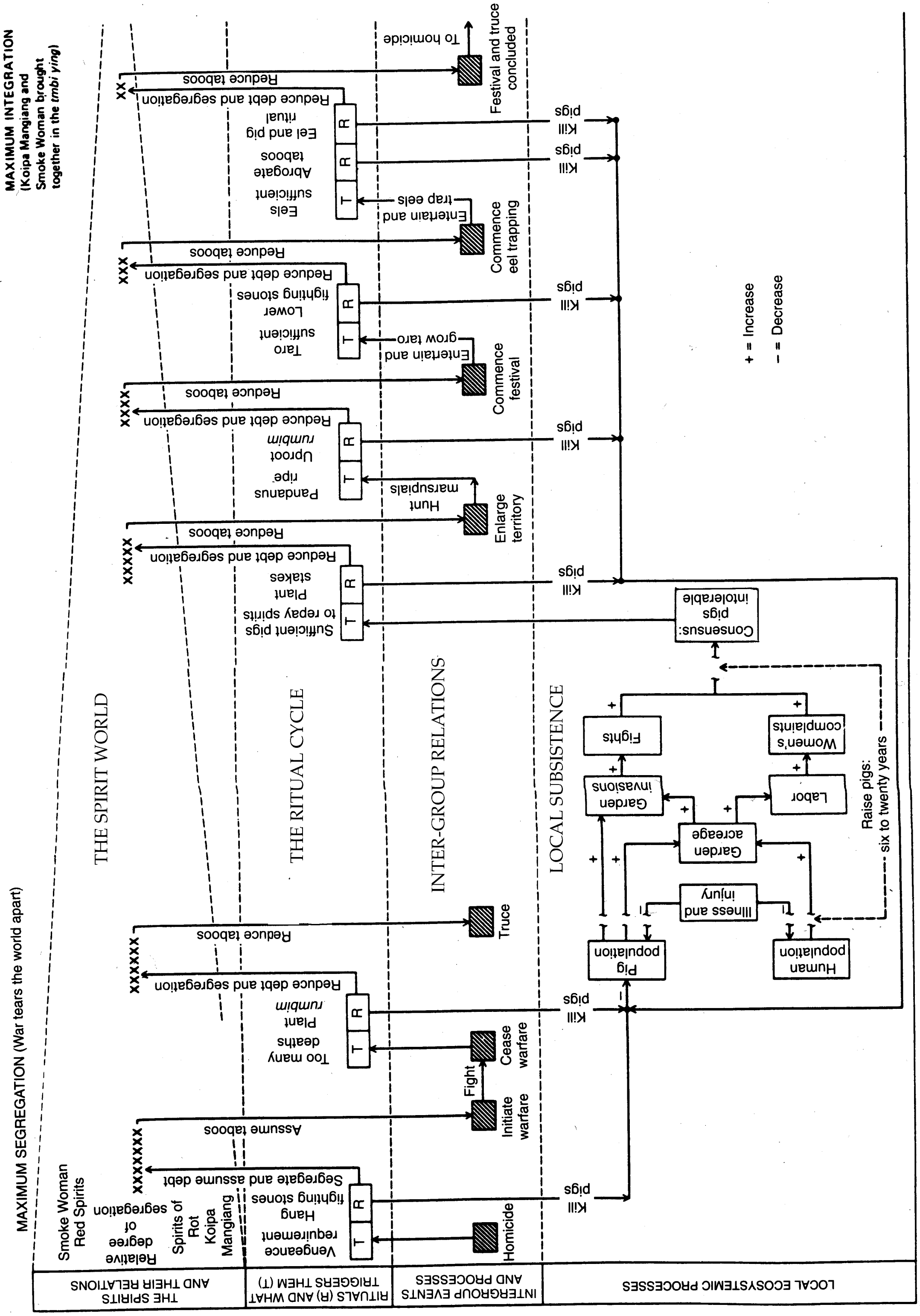


FIGURE 15. RITUAL REGULATION AND ECOSYSTEM FUNCTION AMONG THE MARING (slightly modified from Rappaport 1984).

Conclusion

With conceptual models of human ecosystems in hand, one can pose questions which require the overlapping of anthropological and bioecological frameworks into a human ecology. Integration between theories and disciplines is made easier if the components one wishes to integrate are broad (Pickett et al. 1994). Examples of broad integrative questions for human ecology include:

> How do complex belief systems interact with complex biophysical systems?
>
> Do social and cultural systems exhibit dynamics similar to the dynamics which have been described for biophysical ecosystems?
>
> What are constraining/affording implications for human ecosystems if the dynamics of physical, biological, social, and cultural phenomena are not similar?

Once again, the integration into a human ecology is aided by the use of clearly defined concepts and terminology. This paper has defined the core concepts of the human ecosystem and its environments. The ecosystem concept is useful for human ecology because it allows researchers to follow many conceptual approaches (such as population dynamics, community interactions, systems analysis) within the overarching framework of the human ecosystem. The construction of models is an important tool in achieving integration between diverse disciplines such as anthropology and bioecology. Both fields work with extremely complex systems. The formulation of visual representations of the components and networks of linkages of these complex systems is a useful tool for conceptualizing this complexity. In particular, models can help one grasp the complexity of the role of information in human ecosystems. Visualizing the components and connections, one can begin to see where biophysical and sociocultural phenomena interact, and where they do not. However, building a picture of complex systems is only the beginning of building an integrated human ecology. Modeling techniques need to be refined, and new icons may need to be devised (as this paper illustrates). Once models of human ecosystems have been developed, the next step will be to operationalize integrated research to test hypotheses and evaluate linkages between biophysical and sociocultural phenomena.

Acknowledgements

The ideas presented in this paper are the result of discussions with several participants in the Information Ecology Group at the University of Georgia. While their creative input to this paper has been integral, the author assumes full responsibility for its content. The contribution, editorial assistance, and encouragement of David Casagrande, Charles Peters, and Felice Wyndham is greatly appreciated. Eric Jones, Rebecca Zarger, and Rick Stepp contributed additional insights.

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Appendix A: The Role of Complex Information Flows in a Maring Ecosystem (excerpted from Felice Wyndham, unpublished manuscript).

This adaptation of Rappaport's Maring Ecosystem model (Figure A1, next page) showcases the role of belief system interaction with other systems. It follows Rappaport (1984) in organization and in content (Figure 15), with the vertical column of triggers (T) and rituals (R) forming the basis for the Maring ritual cycle, which "regulates" the ecosystem. The Maring ecosystem is divided into three general panels or systems, the "Spirit World," at left, "Inter-Group Relations," upper right, and "Local Subsistence," lower right. "The Ritual Cycle" mediates, and in this model, works the interactions between systems. First, a guided reading of the system panels.

The Spirit World is dyadic. Two kinds of spirits exist in dialectical (usually harmonic) opposition to each other (high vs. low, smoke vs. rot, dry vs. wet, strength vs. death, etc.). The Red Spirits and the Spirits of Rot are associated, respectively, with Smoke Woman (a female spirit in the male domain) and **Koipa Mangian** (a male spirit in female domain). The low ground is associated with women, female genitalia, fertility and gardens, while the high ground harbors the fierce spirits that are called upon during war and conflict. The focal point of interest in Maring ritual is in the interaction between these two kinds of spirits (dialectical spiral middle left) and attendant segregation/integration of the world. Warfare forces the two spirit factions apart, increasing the scope of taboo: men and women are kept apart, the spirits' "pigs" (marsupials and eels) are restricted and actions must be taken by the living to reintegrate the world through ritual.

Inter-Group Relations primarily shows conflict and truce relationships with neighboring populations, a necessary part of the whole. The local shaman receives information and strength from Smoke Woman, which he passes on to warriors. In turn, men killed in battle (skull sink) join the ranks of the Red Spirits, completing a feedback loop of information and (spiritual) material. Likewise, those people that die of illness or accident become Spirits of Rot; these in turn feedback to increase the fertility of swidden gardens in support of pig and human populations.

Starting at the top of the ritual cycle, a vengeance requirement is incurred from some offense (a murder or fighting death), which triggers the hanging of the Fighting Stones. This leads to ritual segregation and the assumption of debt to the Spirits. Taboos are assumed, restricting warrior and women's actions and making warfare tenable. With too many deaths, **rumbim** is planted, which reduces debt and segregation. Taboos are reduced, influencing interactions between men and women and facilitating truce with fighting neighbors, and so on through the cycle until it is complete, a further vengeance requirement is incurred, and it begins again. Because pigs are killed throughout the cycle, and they are needed in sufficient numbers to repay the debts owed to the spirits, they are a regulatory point in the biophysical systems.

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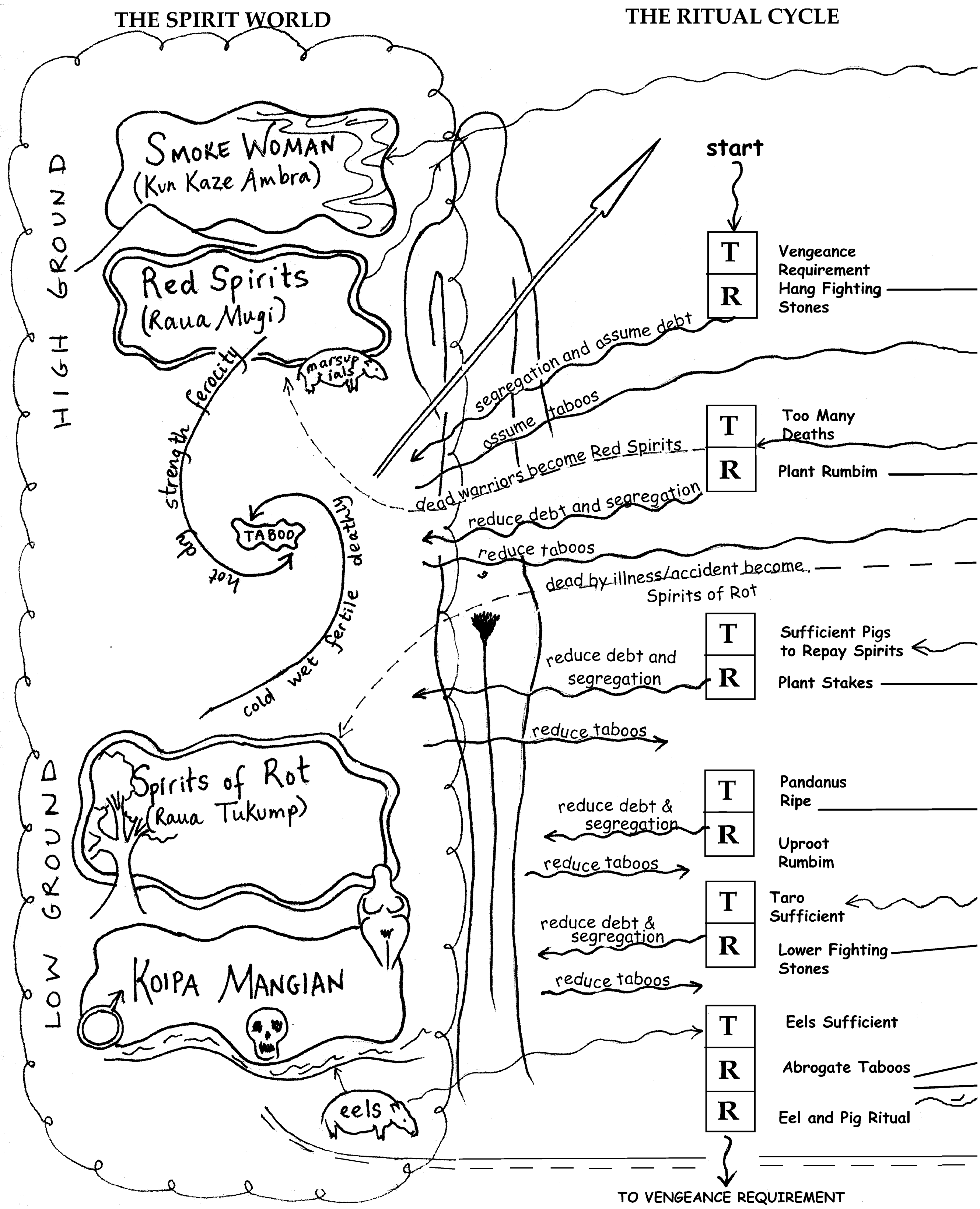
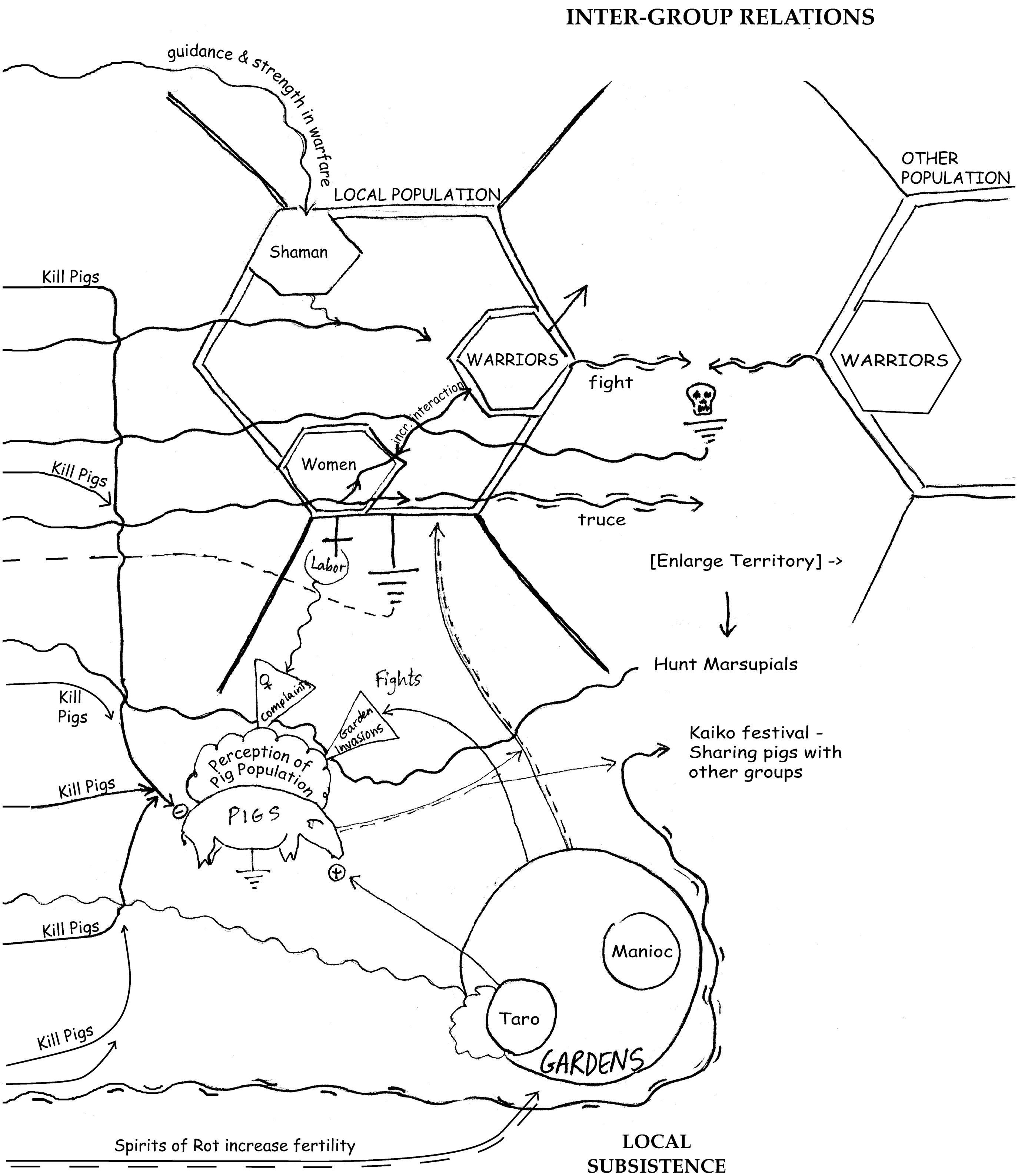


FIGURE A1. COMPLEX INFORMATION FLOWS IN A MARING ECOSYSTEM. (See Appendix B for a key to some of the signs, icons and symbols used here.)


INTER-GROUP RELATIONS
guidance & strength in warfare
LOCAL POPULATION
OTHER POPULATION
Shaman
WARRIORS
WARRIORS
fight
incr. interaction
Women
truce
Labor
[Enlarge Territory] ->
Hunt Marsupials
Kill Pigs
Kill Pigs
Kill Pigs
Kill Pigs
Kill Pigs
Kill Pigs
♀ complaints
Fights
Garden Invasions
Perception of Pig Population
PIGS
Kaiko festival - Sharing pigs with other groups
Manioc
Taro
GARDENS
Spirits of Rot increase fertility
LOCAL SUBSISTENCE

Appendix B: Key to Human Ecosystems Models.

Based on H. T. Odum (1983, *Systems Ecology*, New York: John Wiley and Sons) and conventions established by the Information Ecology Group of the Anthropology Department, University of Georgia.