Holarchic Analysis of Livestock Farming Systems in the US Midwest

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The idea of agroecosystem analysis has at least some roots in the frustration of researchers who saw their technological innovations too often ignored by farmers (Conway 1985;1986;1987). This led to a "systems" approach manifested in a variety of ways, but generally with a strong measure of farmer participation. The "Conway school" and most other systematic approaches to analyzing agroecosystems ultimately seek normative assessments, for comparisons among extant systems and with imaginable alternatives. However, such normative assessments quickly come into conflict with the morass of judgments that challenge the broader task of defining sustainability, i.e., "for whom, for how long, and at what cost?" (Allen, et al. 2003). Clashes of values and temporal horizons arise in the full range of agricultural situations, from the towns of Wisconsin, U.S.A. to the highlands of Vietnam.

At the farmstead level of analysis, agricultural production remains a predominately individual or family-based endeavor, but global scale influences powerfully affect the contexts in which these small entities operate, through trade agreements and the business interests of transnational food companies. The global food system is readily seen as an aggregation of entities of a wide range of type and scale, with innumerable issues likely to not be amenable to a mechanistic, deterministic epistemology. Overwhelmingly, though, the scientific agricultural establishment operates within just such a paradigm (Norgaard and Sikor 1995).

As an alternative, emerging tools of complex system analysis (Abel and Stepp 2003; Allen, et al. 2003) appear well suited to creating the narratives (Allen, et al. 2001) that must be developed to inform the public policy debates that continue to emerge about the changing role of agriculture in a world of expanding long distance trade, growing population, competition for land, and affluence that affords resources to care for nature. Such an agroecosystem analysis is directed at framing narratives that acknowledge that the challenging problems defy capture in a single model, and so limit the utility of most agricultural science, but demand detailed and novel conceptualization.

This alternative framework looks to recent advances in ecological (Allen, et al. 2001) and complex system theory (Giampietro 2003; Kay, et al. 1999). It departs from previous frameworks most importantly in that it seeks to avoid normative assessments, that is, the use of scales and indicators that imply knowledge of what is preferable among a set of alternatives. Use of normative indicators appears to me to be quite problematic: the mere inclusion of some parameters can be contentious, e.g., property rights, the health of stream invertebrates, or the nature of decision-making. Even if consensus is obtained on what to include in an analysis, relative weighting of the parameters and the scaling of each can be intractable for a diverse set of stakeholders. Thus the proposed framework emphasizes emerging views on how ecological and social systems organize and sustain themselves. A basic premise is that mitigation of aspects of current agricultural practice that are viewed as problematic by some stakeholders will most likely occur incrementally. If this is correct, those who seek change should first strive to understand why the system is as it is before designing and implementing interventions.

The initial approach to an analysis is decidedly holistic, but in the manner described by Allen and colleagues (2003, p. 43):

> "In such preliminary stages of the investigation of a new idea, a holistic approach generally works better than reductionist prescriptions. We should hasten to add that, according to our definition of holism, the holist does perform reductions. Because all explanations are a matter of reducing the system to a set of lower-level explanatory principles, when a holist offers an explanation, it is a matter of reduction. For our purposes, the difference between reductionism and holism turns on the manner of the search for the explanatory principles that will be used in the reduction. The holist is much less confident than the reductionist and so uses a more exploratory style. By looking for a repeated pattern, the holist seeks reassurance that the original observation that started the line of investigation is more than a local quirk of some observational procedure. Thus reassured that there is a reliable phenomenon at the base of it all, the holist analyzes the pattern of behavior surrounding the phenomenon to see what properties one might expect the explanatory principles to have. Thus informed, the holist says that he does not know what the explanatory principles are, but they should have such-and-such properties. When something fitting the bill is discovered it usually seems painfully obvious. Holism is the strategy that is more likely to reveal predictive principles when the endeavor is new, as is the search for principles of ecological sustainability. Reductionism emerges for us as a protocol, not a belief system, and is what follows when holistic approaches have delivered a set of reliable principles that can for the moment be taken for granted."

Holons and Holarchies

Central to the agroecosystem analysis proposed here are the complex systems concepts of the holon and a hierarchy of holons, the holarchy. Koestler (1967) coined the term, envisioning holons as entities that are simultaneously a whole and part of a whole. Checkland and Scholes (1999) went so far as to advocate adopting the phrase "holonic thinking" to replace the variants of systems-related terms, to make clear that what is being discussed is a conceptualization of reality, not reality itself. A holon has an identity in and of itself, but importantly is a part of something larger. This larger entity is simultaneously composed of constituent holons and constrains these components. Adjacent holons may be similar to the holon of interest and at the same level in a holarchy, or may be the holon of the next higher (usually larger and slower; Allen and Hoekstra (1992)) level of organization. A higher-level holon is, in part, a result of those below in the holarchy, i.e., it is a manifestation of lower level holons. Equally importantly, though, the upper-level holon likely constrains in various ways the behaviors of the lower-level holons. Human society is an example: we create laws that constrain our individual behavior. Thus there is constant tension between individual holons and the larger holon in which it is embedded. Lower-level holons create the possibilities for the holon above. Combining the above characteristics we envision a holon as an entity that seeks a tractable configuration within constraints imposed on it by the environment in which it is embedded, and this configuration is sustained by processing a resource stream.

Intentionality: Critical to the usefulness of the holarchy concept for thinking about farms and farmers (in contrast to the system as a tool for thinking about a tractor) is that the former admits intentionality. Holons can be seen to strive to create and maintain self-identity, even in the face of destabilizing forces. Organization and subsequent reinforcement is made manifest in various ways, e.g., the flow paths of water down the drain, the life of an organism, or a successful business. This intentionality may arise from the living being's drive to survive, a farmer's ego, or the design of engineered device, although the last of these lacks, in contrast to the others, the potential for *de novo* reactions to changing conditions. Perhaps this intentionality offers an opening for incorporating human belief systems into our analyses, an important challenge identified by Stepp et al. (2003).

Feedback: The persistence (or disintegration) of a holon is frequently facilitated by "feedback" phenomena. Typical discussions of feedback look to a concept of control, but a broader interpretation is possible, as a phenomenon helping stabilize a system at multiple scales. Feedback occurs when the outcome of a phenomenon "loops back" and exerts some control on the phenomenon from which it arose. Negative and positive forms of feedback are recognized. Negative feedback is said to occur when an output tends to work to reverse a recent trend. The common example of a heating system in a home can be interpreted as leading to persistence of the system as follows. When the exterior temperature is below some target (say 20 °C for human comfort or 0°C to prevent freezing of water in pipes), the heating system must produce heat rapidly enough to replace that lost to the outside environment. If the furnace's heat output exceeds this loss the interior of the house will continue to warm beyond what is necessary or comfortable. A thermostat supplies the necessary feedback to reduce the furnace output (usually to zero, but this is not the only possibility), so as to maintain the home interior within desired limits. If the furnace output is below the rate of heat loss to the exterior, the temperature inside the home will eventually decrease to the lower acceptable limit, at which time the thermostat will exert negative feedback to increase the rate of heating (usually from 0 to the maximum). Thus the thermostat creates a feedback loop that modulates the furnace output to maintain the home's interior temperature within a desired temperature range.

We can envision that the furnace-thermostat system stabilizes the home holon in two ways, at different scales. Firstly it maintains the home's temperature from hour to hour within a desired range. At a larger scale it prolongs the length of time that a finite fuel supply can serve to maintain the home's interior temperature above that at which the pipes would freeze.

Positive feedbacks occur when the outcomes of a phenomenon reinforce a trend. An example is that climatic warming might reduce snow and ice cover, which, in turn, will increase absorption of solar radiation, resulting in further warming. The transition from wood to coal as the primary fuel at the dawn of the Industrial Age in England was facilitated by positive feedback, as coal-fired engines and pumps made coal ever cheaper (Allen, et al. 2003). The teacher acknowledging a student's good work may foster even greater industriousness.

Processing a resource: A final key concept is that developing and maintaining a holonic entity can often be seen to require exploiting a stream of some resource. These resources may be of widely different natures, e.g., fossil fuels, soil, or human lives. In the classic case of the self-organization of the vortex that forms as water runs through a drain, gravitational potential energy sustains the whirlpool structure. In agriculture we are typically interested in both the nature and source of the resource, and the resulting stream of degraded forms of the resource.

Contexts and Triadic Readings

The requirement to think of holons simultaneously as a coherent entity and as a component of a holarchy suggests that study of a particular holon requires thinking about three levels of organization: the holon of interest, the internal components of the holon, and the holarchic level in which it is embedded. Salthe (1985) called this a "triadic reading" of a holarchy. The level of the holarchy in which we are primarily interested is placed at the "focal" level, and focal level holons both comprise, and are constrained by, the higher level. Looking into the holon reveals the lower (with respect to focal) level. The triadic reading helps us to appreciate that the focal level is simultaneously a product of both its higher and lower levels. Thus any effort to understand a holon necessarily requires thinking about these adjacent higher and lower levels of the holarchy. The idea that three levels must be considered is common in thinking about systems. Agronomist Gary Fick (personal communication, 2003) recalls that in the early days of computer modeling of agricultural systems C. T. de Wit emphasized the role of three hierarchical levels: the system you were modeling, the smaller level of algorithms from which the model was constructed, and the higher level at which the model was evaluated. In landscape ecology questions surrounding the scale of analysis loom large and the triadic reading is seen as essential (Turner, et al. 2001).

A number of triadic readings that are relevant to agroecosystems are proposed in Figure 1. These are offered as examples to illustrate the concept, rather than as a set from which to choose the best for a particular problem. They are more general than a specific analysis would yield, and graphic representations are only necessary to the degree that they can help communicate a particular understanding. Every situation and problem is unique, but envisioning the focal level and giving it a triadic reading will yield useful insights.

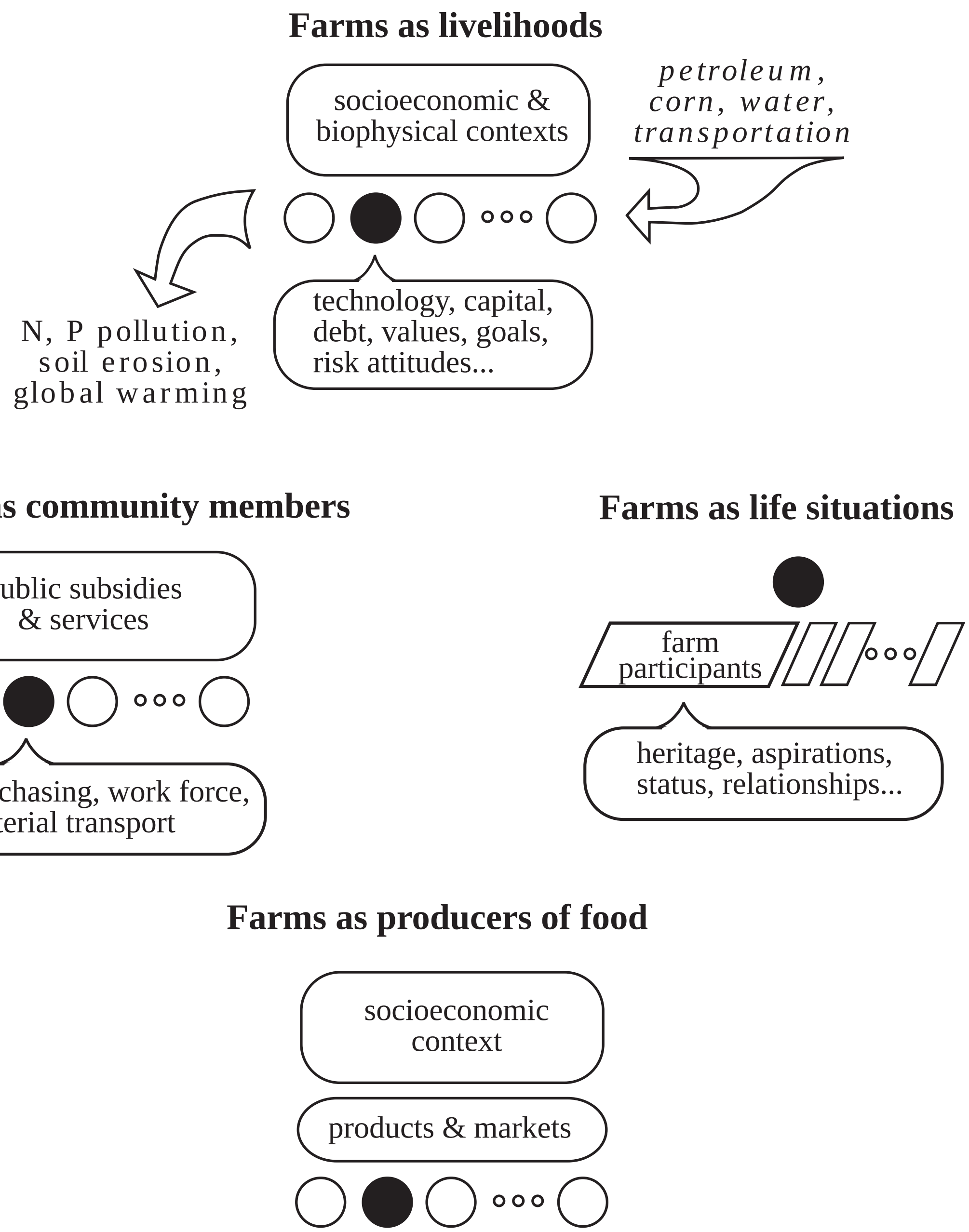

Figure 1. Example triadic readings of holarchies involving farms. The top level in each triad constrains holons at the level below, the mid or focal level. Each representative of the focal level holons may contain smaller holons and other resources. A circle represents a farm, and in some triads a population of (unique) farms is shown; the filled circle is a particular farm that is common to all of the diagrams. In some readings a farm or population of farms is at the focal level, but in others at higher or lower levels of the holarchy. To maintain its structure the farm processes resource streams and externalizes their degradation products, and this is illustrated in the “Farms and livelihoods” triad. Central to a complex systems approach is to see a farm as simultaneously shaped by a number of incommensurable contexts. This is captured using the figure by merging all of the triads so that the filled circles are coincident. Triads (contexts) could then be separated by rotating the plane of each out of the paper, while still maintaining linkage to the others at the center of the filled circle. This reveals that the farm holon represented by the filled circles is shaped by several contexts, and must seek stability within them all.

In the examples provided here we note how individual farms (denoted as circles) enter into triadic readings of various focal holons. We are interested in a single, particular farm that appears in all four of the readings. In the three readings in which several farms are indicated, the particular farm we are studying is one of a class of similar entities.

Let us begin with the triad at the top, “Farms as livelihoods,” in which farms are at the focal level. Note that the graphical representation does not fully convey that each successively lower level is contained within that above. Each particular farm is the manifestation of a unique integration by the farmer of available biologic, land, financial, and cognitive resources. Great farmers skillfully and subtly create a synthesis that sustains at least a business, and, we hope, natural and social capital. But equally important in shaping the farm are the higher-level constraints in which it is organized and operates. Farms are constrained and, therefore, shaped by numerous aspects of their context. Examples include social issues such as norms and markets, freedoms to operate with minimum regard for the environment, such as disposal of wastes and use of toxins, and local land use policies that may encourage fragmentation of agricultural land.

I have chosen to note in this triad the resource streams that are stabilizing the farms included in the analysis. Again, a particular analysis will likely be more specific. In this example, I envision that the ready availability of inexpensive corn and transportation (because of government subsidies) are high-quality resource streams that, for example, make large-scale feedlots a viable way of producing meat. The degradation products of these streams include atmospheric $CO2$ enrichment and a relatively dilute fertilizer, manure, distant from where the feeds were grown.

The center-left triad places farms at the focal level to investigate their potential roles as members of a local community. A given farm’s manifestation from this perspective emerges from its decisions about interactions with the local economy, such as purchases of supplies, machinery, and services, the demands that it places on roads and air quality, and how its labor needs are met. Potentially constraining the behavior of a farm as a community member are the expectations and willingness of the local government and neighbors to bear costs resulting from the farm’s presence. Strong constraints might prevent a particular sort of farm in an area, and weak (or unheeded) constraints may lead to negative opinions of a farm by other residents.

The center-right triad prompts consideration of “Farms as life situations,” i.e., environments that powerfully shape the lives of farm families and workers. Every person immediately engaged in the operation of a farm has a unique set of internal drivers of behavior, including heritage, aspirations, personality, intelligence, and status. The farm environment constrains how these are manifested (so long as the participant remains on the farm), and each participant influences life on the farm.

Finally, “Farms as producers of food,” the triad at the bottom of Figure 1, has as focal level the market for agricultural products in a region. A study of regional food systems might begin with this construct. Here farms are at the lower level, producing an array of agricultural goods that greatly influences the local markets. Constraining the products and markets, though, are likely wider agricultural policy decisions and consumer interests and willingness to pay for particular goods (including those produced in particular ways, e.g., antibiotic-free meat). Note that the focal level of this triad, “products and markets,” could be part of the upper level in the first triad we discussed. Collectively the four triadic readings offer a complex systems analysis of a farm, because we use several, incommensurable perspectives. Each farms appears as it does in order to create and retain its identity simultaneously in a number of contexts.

There need not be a set of resource streams unique to each triadic reading. The farm holon degrades resource streams in order to sustain its organization, but many of the higher level constraints on the nature of this holon may be unrelated to what resources are exploited.

Following are brief descriptions of contemporary situations in which holarchic narratives could usefully inform debates related to public policy surrounding livestock production in the Midwest, U. S. Only the faint outlines of a proper narrative is offered, and there are a number of conjectures amenable to further research. The examples are offered to illustrate perspectives that the framework suggests, in contrast to a more conventional attempt to assess sustainability in economic, social, and environmental spheres.

Wisconsin Dairying

Dairy farming in the state of Wisconsin, U.S.A is in a period of transition, with traditional single-family-owned and -operated farms being replaced by farms with an order of magnitude more cows and which are largely operated by hired laborers. The continued loss of smaller farms and of total numbers of cows raises fears that the dairy infrastructure (cheese makers and equipment manufacturers) will not reinvest in Wisconsin, but rather move to states in which milk production is increasing. This concern enabled industry boosters to convince the state government to intervene in two significant ways. Direct financial aid to farmers comes from grants to assist expansion planning and loans to relatively large farms for construction of manure management facilities and to purchase cows. Less directly, the state legislature is considering actions that will pre-empt some aspects of local control over land use decisions, to reduce the resistance toward expanded or new farms increasingly offered by local and statewide stakeholders.

The dairy industry looks to the very large dairies of California and the Southwest as models of the future. Yet analyses of dairy profitability in Wisconsin consistently fails to indicate that such very large farms are necessary. Many alternative configurations can apparently lead to success in Wisconsin dairying (e.g., Frank (1997)), and no compelling evidence is available that cost of production per unit milk falls with increasing herd size above a modest threshold. Thus there are no strong signals to guide public policy, either at the state level, where financial aids and regulatory relief are at stake, or at the local level, where elected and appointed government officials find themselves caught in the middle of conflicts over farm expansions and siting of new facilities. Nicole Vullings, Timothy Allen, and I are studying whether complex systems ideas can provide insights into fundamental differences between Wisconsin dairying and that of California, toward a narrative that can inform the many debates underway about the implications of government policy choices.

A holarchic approach leads the analyst to start from the assumptions that extant systems are as they appear because farmers organized them in response to multiple contexts, that because the systems are extant they represent viable configurations (at least in the current situation), and that they are processing resource streams. Are there important differences in the multiple contexts in which Wisconsin and California dairy farms are organized and persist which might argue against a simple scaling-up strategy to maintain competitiveness of Wisconsin dairy farmers? Possibly, in several quite diverse contexts: capital (sunken and new), coupling of farming operations to water quality, availability of feedstuffs, and in land use planning and zoning (Vullings, Bland, and Allen, in preparation).

California dairying began to serve the fluid (in contrast to use for cheese and other manufactured products) milk needs in the vicinity of Los Angeles. The state made deliberate efforts to foster a strong dairy industry because of the difficulty (at the time) of transporting milk from the Midwest. Tremendous and relentless population growth over the past century fueled appreciation of the real estate on which farms were sited, allowing several cycles of dairy buyouts and relocations. This has occurred to far lesser degrees in Wisconsin and not at all for the majority of farmers. Wisconsin dairy farm infrastructure is largely depreciated, while in California the urbanization-induced relocations make past investments in buildings and equipment irrelevant, fostering steady modernization. Further, capital gains taxation laws in California provide strong incentive to reinvest in dairy farming. Capital infusions from real estate appreciation are an important resource stream available to Californians but not Wisconsinites. Additionally, California dairies benefit from forages produced with highly subsidized irrigation water in a very favorable climate.

These brief comments on our ongoing analysis demonstrate that multiple incommensurable contexts must be investigated simultaneously, and that an unambiguous technical reason for one alternative over another that trumps all other considerations should not be expected.

Iowa Swine Production

A holarchic approach also helps the analyst identify and articulate how history, both personal and broader, e.g., markets, shaped, stabilize, and threaten to destabilize an approach to farming. An example is to compare three Iowa swine production approaches studied in the summer of 2003. Two were confinement systems in which the animals lived indoors on slotted cement floors and the third used both pasture and deep-bedded (straw) techniques. One of the confinement systems reared animals under contract, while the other sold on the open market. The pastured-swine farmer had grown up using the system, but had tried confinement rearing some years ago to allow year-around production. He found the system unsatisfying because of the work environment and his perceptions of the welfare of the animals. This led him to the deep-bedded system, which was satisfying in ways that traditional confinement was not, but the higher labor costs meant that in order to be profitable he had to be able to sell to a premium antibiotic-free marketing company. A disease outbreak had forced him to temporarily use antibiotics, so the price premium was unavailable for a time, causing great financial stress. Family members were seeking off-farm employment for the first time in decades, signaling a fundamental reconfiguration of their farm. Will his aversion to systems other than pasturing and deep-bedding force him out of the business?

One of the confinement growers sold on the open market, and was also in partnership with his son in corn-soybean grain production. It appeared that the swine operation was still recovering from the collapse of the market in 1998, with outdated facilities and a cost of production too high to be profitable. His son hoped that some coupling of the crop and swine operations could make the latter profitable, but he felt strongly that the two enterprises must be able to stand on their own. The future of swine production on the farm seemed highly dependent on the father's self-perception that he was a hog farmer.

The third swine producer contracted with an integrator to finish swine in three barns that he owned. The integrator supplied the animals, feed, and veterinary care, and specified most management practices. Payment came to the farmer as both monthly rent and in the manure created, which he used to fertilize crops on land that he owned. Formerly he raised alfalfa and personally delivered it by truck, which meant frequent trips away from his family. Contract growing swine initially attracted him because it allowed him to stay at home and work with his wife, and he seemed happy with the situation. It appeared that he had successfully reconfigured his (formerly hay) farm to exploit opportunities presented by the recently emerged contracting system in the hog business. His lack of an earlier-formed self-image as a swine farmer allowed him to not resent deferring to the integrator, while the second farmer above may be unable to function in this way. To describe him a member of a new rural peasantry (as detractors of contract production do) is to ignore important contexts.

Each swine farmer sought a stable farm configuration within the context of the U.S. market. The alternative, premium system of pasture and deep-bed production may be a profitable attractor, but it is easily destabilized by disease. The swine operation of father of the father-son team may be a victim of vertical integration in the market, or reluctance to invest in newer, larger facilities following recent money-losing years. A destabilizing threat to contract growers is insolvency of the integrator, and a constraint may arise if soil N and P levels are regulated, potentially limiting the amount of manure that a farmer can apply to a given land area.

The holarchic approach allows personal history to lie alongside economics and soil nutrient levels in creating a narrative. Those seeking a definitive finding to declare one system the only viable path will not be satisfied, but good policy makers and politicians know that such a finding is indeed rare.

Conclusion

A complex system analysis results from the willingness of the analyst to simultaneously envision multiple incommensurable perspectives. Each perspective suggests a context within which the entity of interest is organized in such a way as to maintain viability. Multiple contexts and history shape entities of study, e.g., farms, and the analyst should begin by studying the whole and why it appears as it does. The conceptual device of the holarchy appears to be useful. A complex system analysis can inform choices about research and educational investment, by illuminating that extant systems are often as they are for multiple reasons that cannot all be ignored if one is to induce change.

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