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BIOPRODUCTIVE SYSTEMS IN LAND PLANNING*

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ABSTRACT

Productive biological systems encompass a wide variety of land uses, crossing the conventional boundaries among forestry, aquaculture, wildlife management, animal husbandry, and all the branches of agriculture. This article synthesizes available literature to provide a systemic model of bioproductive systems that can apply to physical land planning. Terrestrial systems include cultivated, perennial-plant, grassland, forest, and "ecosystem byproduct." In terrestrial animal production, plant food crops still occupy the land, but some combination of crops is dedicated to the larger animal system. Types of aquatic systems are distinguished primarily by the salinity of the water: fresh, brackish, or salt. Each type of bioproductive system has distinguishable physical structures, functional operations, and potential products. Systems can vary in their intensity of operation and their contribution in the other types of systems. Which type of systems are selected for implementation in a given situation can influence the economic, energy, environmental, and other effects of a plan.

Systems that use biological processes to produce useful crops occupy most of the land in the United States. Cropland, range and forest occupy 2.8 million square miles, or 79 percent of the nation's land. These immense areas are where twenty-two billion dollars in international trade surplus are generated, and where all of the nation's food, fiber and lumber are produced [1].

Contemporary economic and resource issues are creating demands for more information about and planning for such productive systems. Productive land is

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being cultivated and harvested more intensely. Farming operations are expanding onto once-fallow "marginal" lands to meet demands for production. The expanding and intensifying operations are causing greater erosion, depleting the soil base on which the operations depend [2]. Productive land and the systems that exploit it are now being recognized as resources deserving to be identified, preserved, and planned for [3-7]. Yet, urban development in rural regions is now increasing the frequency and intensity of conflicting demands for the use of productive land [8]. All of these issues require rational resolution.

Productive biological systems encompass a wide variety of land uses, crossing the conventional boundaries among forestry, aquaculture, wildlife management, animal husbandry, and all the branches of agriculture. For lack of any better umbrella term, they are lumped together under the designation, bioproductive systems.

This article synthesizes available literature to provide a generic model of bioproductive systems that can apply to physical land planning. It describes what happens tangibly on the land. In contrast, a socio-economic planner, who is interested possibly in the balance of international trade or the effect of land use upon employment, may look at bioproductive systems as "black boxes" of which only the inputs and outputs are relevant. No previous attempt at modeling the full scope of bioproductive systems for physical land planning is known.

A basic idea in physical planning is that a physical form or structure corresponds to the function or activity that takes place there. Hence, each of our classes of bioproductive systems aims to represent both a physical structure (of plant types, soil, etc.) and a functional category of things that people do there. This is in contrast to the classifications or rural land covers used by remote sensors, which are based strongly on how distinguishable different covers are when seen from above.

Our initial research was a survey of basic literature in agronomy, animal husbandry, forestry, and aquaculture. About 300 references from this multi-disciplinary literature gave us the names of over 200 crop types, and provided information about products, physical settings, and cultivation operations that allowed us to recognize similarities and differences among the systems. (Only the broadest references are cited in this article.) Since our initial research was completed, planners' feedback from a previous statement of our results [9], and continued experience in applied planning projects have allowed us to refine our conclusions.

AN OVERVIEW

Our conclusions are summarized in Table 1. Bioproductive systems are most easily understood by distinguishing first between the two fundamental types of environmental habitats in which they occur: terrestrial and aquatic. Within

Table 1. Summary of Bioproductive Systems[a]

Environmental Habitat	*Types of Bioproductive Systems*	*Types of Products*	*No. of Crops Listed in Text*
Terrestrial	Cultivated	Grains and Field Crops	36+
		Vegetables	21+
		Mushrooms	1+
	Perennial-Plant	Bush, Cane and Vine Crops	19+
		Tree Crops	32+
	Grassland	Emphasizing Fodder	1+
		Emphasizing Feed	1+
	Forest	Plantation	7+
		Successional	2+
	Ecosystem Byproduct	Water	1
		Air	1
		Species Preservation	1+
Aquatic	Fresh	Finfish, Shellfish, Other Animals, Plants, Ecosystem Byproducts	28+
	Brackish	Finfish, Shellfish, Other Animals, Plants, Ecosystem Byproducts	18+
	Salt	Finfish, Shellfish, Other Animals, Plants, Ecosystem Byproducts	26+
TOTAL			195+

[a] The individual crops are listed in the text. Additional crops in each group, not listed in the text, certainly exist.

those habitats, we have distinguished eight general types of bioproductive systems on the basis of physical structure, type of functional operations, and types of products.

Among terrestrial systems there is great diversity in structure, function and products. Cultivated systems are based on plants that are harvested and replaced at least annually. Perennial-plant systems such as orchards and vineyards involve plants that last in the ground for more than one year, but which regularly bear crops such as fruit or fodder. Grasslands are pastures and ranges where grasses are grown for consumption by animals. Forest systems involve perennial plants that are harvested whole at the end of some number of years. "Ecosystem byproducts" systems are where the maintenance of the overall ecosystem yields pure air or water, or allows the natural regeneration of species.

Among aquatic systems, the salinity of the water sets the fundamental stage for structures, functions, and products. Salinity is the primary limitor on the types of crops that can be grown. It is correlated with site types such as stream and estuary, which are further correlated with potential operations such as caging and fertilization.

Figure 1. Cultivation: corn on sandy soil in Pennsylvania, just emerging in the early summer. This is a "no-till" field, with a layer of accumulated plant mulch.

As shown in Table 1, each general type of bioproductive system has groups of products that are distinguished by plant forms, cultivation operations, or other important physical or functional factors.

CULTIVATED SYSTEMS

Cultivated systems involve plants that are harvested and replaced at least annually. Crop production occurs in cultivated fields or beds (Figure 1), supplemented by a relatively small working area for crop processing and storage and equipment handling. Cultivated systems occupy about a quarter of the productive rural land, and a fifth of all the land, in the U. S. [1, Chart 45]. They produce three general types of products: grains and field crops, vegetables, and mushrooms.

The grains and field crops compose a broad, commercially valuable, intensely cultivated group of plants that tend, in the United States, to be grown at a large scale for sale to processors and distributors. They are listed in Table 2 under seven general crop types.

Vegetable crops tend to receive intense, specialized care and are therefore seen as often in home gardens and "truck" farms as in large specialized farms.

Table 2. The "Grains and Field Crops" Group of Cultivated Crops[a]

General Crop Type	*Crops*	*Principal Product*	*References*
Large Grains	Maize (Corn), Sorghum	Large, directly edible seeds	Montgomery, 1920 [10]
Small Grains	Oats, Millet, Rye, Wheat, Barley, Triticale, Rice	Small seeds, processed for consumption	Anderson, 1973 [11]
Cultivated Feed and Forage Crops	Grasses, Legumes, Vetch, Clover, Alfalfa, Soybean Cowpeas	Animal feed or forage	Heath, et al., 1973 [12]
Oil Seed Crops	Rape Seed, Mustard, Castor, Sunflower, Sesame, Safflower	Seed processed for oil	Weiss, 1971 [13]
Sugar Crops	Sugar Cane, Sugar Beet, Sweet Sorghum	Processed for sugar	Barnes, 1974 [14]
Tobacco	Tobacco	Leaf for Tobacco	
Fiber Crops	Flax, Hemp, Cotton, Jute, Ramie, Kenaf, Rosalle, Urena, China Jute, Sunn Hemp	Materials: textile, rope, packaging, etc.	Dempsey, 1975 [15]

[a] Only the principle products are listed; some crops have secondary purposes as well.

Vegetable crops include spinach, broccoli, peas, lettuce, tomato, pepper, melon, asparagus, potato, onion, eggplant, sweet corn, cucumber, squash, beans, rhubarb, carrot, celery, cabbage, kale, kohlrabi, and others [16]. Technically some of these crops are not cultivated vegetables. For instance, tomato is actually a fruit, and asparagus is a perennial plant. However, their settings and production methods are similar to those of the other crops in this group, and they are commonly included in discussions of vegetables.

The setting of mushrooms is often different from that of other cultivated crops. In place of the cultivated fields of other crops, mushrooms are grown in cultivated beds in the shaded environments of houses, barns, caves, and outdoor enclosures.

Many of the cultivated crops are rotated with each other, one crop replacing another in the field from season to season or year to year. An area of rotated crops may be identified by the combination of crops in the rotation, rather than by a single primary crop.

PERENNIAL-PLANT SYSTEMS

Perennial-plant systems involve plants which remain in the ground for more than one year, but which regularly yield some crop after reaching a mature bearing age. The production of crops occurs in a permanent plantation – an orchard or vineyard – rather than a cultivated field or bed (Figure 2). The plantation is supplemented with a relatively small working area for crop storage and processing, and equipment handling.

Perennial-plant crops are most usefully broken down according to the form of plant: bush, cane, vine, and tree. Each form of plant is associated with a physical setting, a group of cropping operations, and a group of potential products.

Bush and cane crops include a large group of berry crops, and some other shrubs grown for other plant parts. The berries are grown on shrubs and canes for human consumption. Their production tends to be labor-intensive and therefore concentrated on small acreages. Some berry crops are strawberry, currant (black, red, and white), gooseberry, blackberry, raspberry, loganberry, huckleberry, blueberry, dewberry, juneberry, bulberry, and buffaloberry [16]. Cacao (for chocolate) and coffee are shrub seed crops. Tea shrubs produce leaves that are processed for the drink.

Grapes are the great vine crops. They are often grown on a large scale, for wine production or direct consumption.

The tree crops are fruits, nuts, sap-producing trees, and fodder and forage trees.

"Fruits" are the pome-like or citrus products grown on woody plants for human consumption. Although other perennial-plant crops are technically "fruits" as well, the members of this group are commonly distinguished by this

Figure 2. Perennial plants: a pecan grove in Georgia.
The grass between stems is mown regularly.

name. Among fruits are avocado, cherry, pomegranate, mango, quince, apple, peach, pear, persimmon, plum, nectarine, apricot, orange, grapefruit, and date [7].

Nuts are nutlike edible fruits grown on trees for human consumption. In this group are walnut, almond, cashew, pecan, chestnut, coconut and hazelnut [18].

Sap-producing trees are tapped for their sap. In this group are maples (for sugar), rubber (for latex), and eucalyptus (for oil) [19].

Fodder and forage trees are those that produce fruit or leaf litter which is edible by livestock, and which is either collected and ground into feed, or foraged directly. Some of their fruits are also used for human consumption. Their use is more common outside North America. Among the many trees in this group are honey locust, carob, mulberry, gingko, weeping willow, maples, and oaks [19].

GRASSLAND SYSTEMS

Grasslands are meadows, pastures and ranges where perennial grasses and similar plants are grown for consumption by animals. The plants are either sown regularly for feeding to the animals (fodder crops), or grazed directly by the

Figure 3. Grasslands: baling of hay for winter feeding to cattle in Montana. The grass on the hills in the background is grazed directly by sheep.

animals (forage crops) (Figure 3). This is a simple type of system without major internal distinctions. However, it is worthy of separate mention because of its size: it occupies 26 percent of the land in the United States [1, p. 25], mostly in the vast semiarid ranges of the West. It is distinguished from cultivated feed and forage crops (cultivated grasses, alfalfa, etc.) by the perennial character of the plants and their management, and from other perennial plants by the herbaceous form of the vegetation.

FOREST SYSTEMS

Forest systems are those in which the entire plant is harvested after growing for some number of years. Production occurs in a permanent woodland (Figure 4), supplemented in the more intense systems with a small working area. There are two types of forest systems: plantation and successional. Their distinguishing characteristics are summarized in Table 3. The products from any of these systems can be lumber, pulp, cordwood, or any other wood product, depending on species, frequency of cutting and other factors.

Plantation forests are where the species composition is controlled through artificial plantings. Coppice plantations are hardwood plantings where the root

Figure 4. Forest: an uneven-aged successional hardwood-pine forest in New Hampshire.

Table 3. Forest Systems

Forest System	*Tree Age Distribution*	*Harvest Method*	*Species Type*	*References*
Plantation: Coppice	Even-Aged	Clearcut	Hardwood	Gansner, et al., 1977 [20] Todd Bowersox, Pennsylvania State Univ., Personal Communication, 1981
Plantation: Replanted	Even-Aged	Clearcut or Staged Thinning	Usually Shade-Intolerant	Pennsylvania Department of Forests and Waters, 1951 [21]
Successional: Even-Aged	Even-Aged	Clear cut or Seed-Tree Cut	Shade-Intolerant	Pennsylvania State Univ., 1977 [22]
Successional: Uneven-Aged	Uneven-Aged	Selection Cut	Mostly Shade-Tolerant	Pennsylvania State Univ., 1977 [22]

stocks sprout after each cutting, growing strongly with the support of the old root systems. Some of the most intense forest production systems are coppice plantations involving dense plantings of selected species, maintenance of the crop during growth, and frequent harvesting of the entire block. Examples are hybrid poplar, cottonwood, sycamore, and tulip tree. Replanted forests are usually composed of softwoods, which tend not to sprout after cutting, but which have commercial lumber value. After each cutting, seedlings are placed to restore the desired species composition. Most replanted forests are densely planted and even-aged in order to force long, straight stems for lumber and to shade out weeds. Harvest is usually by clearcut. One example of a mixed plantation is a combination of scotch pine and white pine, with the faster-growing scotch pine being harvested at about ten years for Christmas trees, and the white pine then filling in the gaps.

Most of the forest land in the United States is successional forest, involving the harvesting of naturally occurring trees. Species composition is controlled only by methods of cutting, which induce the light conditions that favor the desired seedlings. Even-aged successional forests tend to be composed of species that are adapted to the open habitat remaining after a clearcut. Uneven-aged systems tend to be composed of mixed ages of trees whose seedlings can survive in the shady environment remaining after selection cutting. Coppices (both even and uneven-aged) that evolved from original successional vegetation are common in England, and are beginning to be noticeable in American successional forests that have been cut over once or twice.

ECOSYSTEM BYPRODUCTS

Ecosystem byproducts include water, air, and species preservation. These are products of the maintenance of systemic biophysical processes, rather than of direct harvest of plants (Figure 5). Systemic products are sometimes considered the primary products of designated areas, such as municipal watersheds [23], municipal airsheds [24], and wilderness reserves [25].

Water is a product of ecosystems in terms of both quantity and quality. Watershed soil and vegetation regulate the quantity of streamflow, influencing flood peaks, base flows, and total annual water yield. Vegetation and soil also regulate erosion, filter water, and contribute to the nutrient balance of streams [26]. The quantity and quality of the water's yield can be controlled through the management of watershed vegetation.

Air is a product of ecosystems in terms of quality. Vegetation filters many particulate and gaseous pollutants out of the air as it passes through the leaves and branches [15].

Species preservation is accomplished where a refuge area for a species or community is designated. Water supply, vegetative management and other operations may be included in order to supplement natural processes [27].

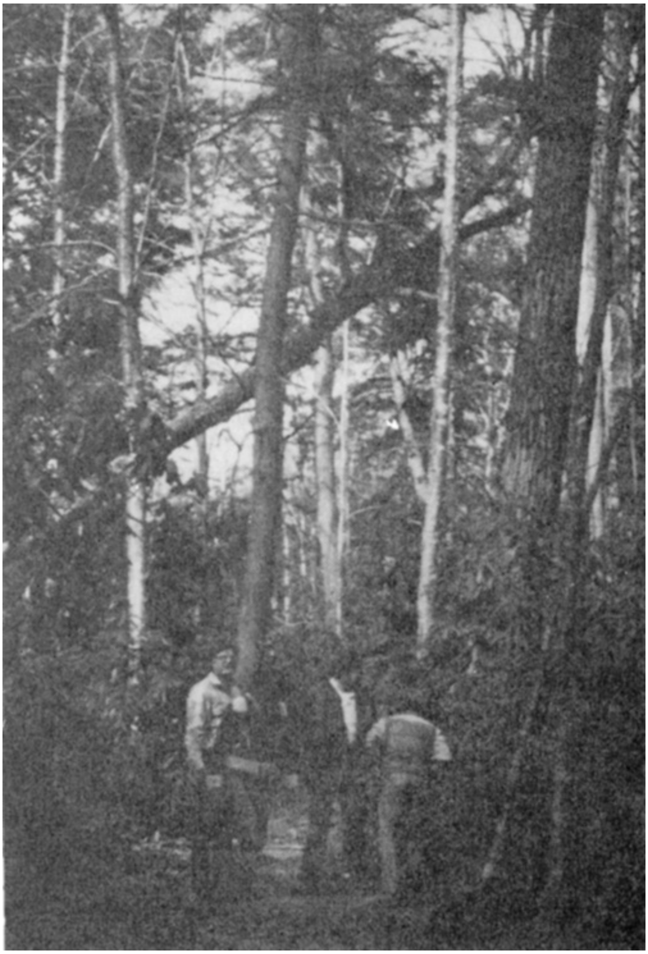

Figure 5. Ecosystem byproducts: a natural reserve in Pennsylvania. This is a rare virgin mesic community which is preserved for its educational, scientific, and ecological value.

TERRESTRIAL ANIMAL SYSTEMS

Animal-related systems involve plant crops that are grown to feed animals complemented by a water supply and, sometimes, housing and working areas. The animals in turn yield products such as milk, eggs, meat, fur, and horse power. The plant crops come from cultivated, perennial or grassland systems (Table 4). It is the plant crops that still occupy the land. The animal production

Table 4. Plant Crops Used for Animal Feed and Forage

Plant Source: Bioproductive Systems	*Feed Crops*	*Forage Crops*
Cultivated (Grains and Field Crops)	Large Grains Small Grains Cultivated Field Crops	Cultivated Forage Crops
Perennial-Plant	Fodder Bush Crops Fodder Tree Crops	Forage Bush Crops Forage Tree Crops
Grassland	Grass for Feed	Grass for Forage

comes about by dedication of some combination of plant-producing systems to animal feed and forage. They then become parts of the larger animal-producing systems (Figure 6).

The food supply is delivered to the animals by either harvesting and feeding to animals of feed crops, or direct grazing of forage crops. An animal-related system can be characterized as emphasizing feed, emphasizing fodder, or combining the two. The animals' water supply is usually delivered parallel to the food supply – conveyed from a source to the animals' housing area, or left available for them in the foraging areas.

The animals themselves can be considered usefully in two groups: those where each animal is maintained to yield a regular product such as milk or power, and those where the animal is harvested whole.

Products yielded regularly by living animals include milk, eggs, honey, wool, work, and recreation. Such systems tend to be relatively intensely managed, in order to maintain the animals and harvest the regular crop. Animals in this group include dairy cow, sheep, horse, ox, honeybee, and the egg-laying varieties of chicken, goose, and duck [27, 28].

Major products from animals harvested whole include meat, fur, and feathers. Such systems can occur at all levels of intensity, from intensive beef feedlots to extensive free-ranging grazing systems. Animals in this group include sheep, swine, broiler chicken, squab, goose, duck, turkey, fur bearing mammals such as mink and rabbit, and game animals such as bear, deer, antelope, grouse, wild turkey, wild duck, and wild goose [22, 28, 29].

AQUATIC SYSTEMS

Aquatic systems are distinguished by their aquatic environments such as streams, ponds, and wetlands (Figure 7). Aquatic environments account for probably less than 10 percent of the area outside open oceans. Although fisheries were formerly extractive operations without cultivation, managed

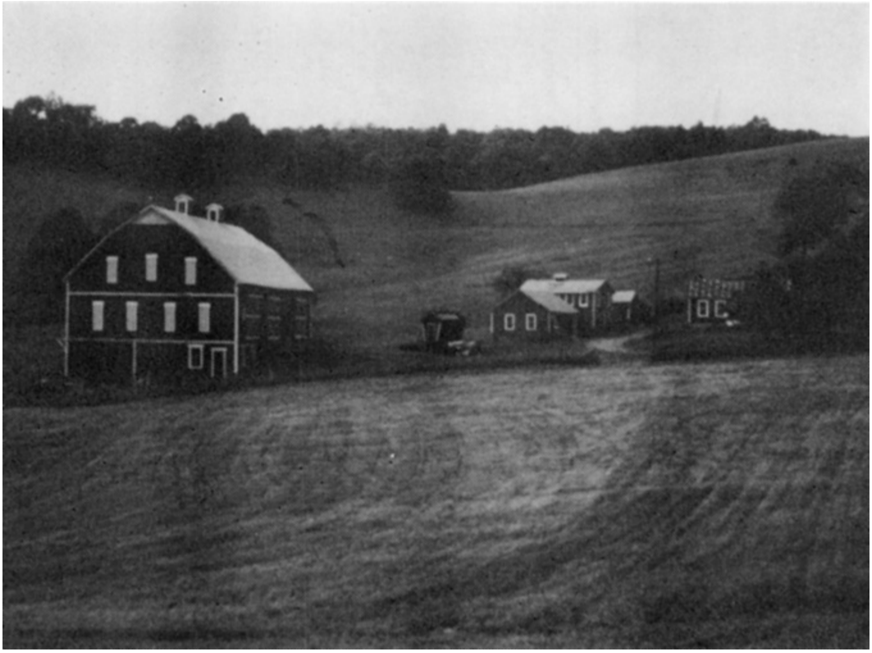

Figure 6. Terrestrial animals: a sheep farm in Pennsylvania. The field in the foreground is cultivated for feed crops. The grass on the hill in the background is grazed directly.

aquaculture is now accounting for 40 percent of the world's aquatic harvest, and even harvests on the open ocean are tending to be regulated in order to manage squatic populations.

Aquatic systems are characterized by the salinity of the water. The characteristics at each level of salinity are listed in Table 5. As shown in that table, salinity tends to control both the potential crop species and the potential physical habitat.

The connection of habitat to salinity results from the normal arrangement of salinity in the natural environment: fresh water is inland, salt water is in the open oceans, and brackish water is at the interface between fresh and salt. Other local water characteristics such as temperature, dissolved oxygen, turbidity, etc., may further limit crop choices [31]. Although many aquacultural systems involve releasing plants or animals into the environment for part of the life cycle, almost all systems require confinement in ponds or cages at some point in the production process.

As shown in Table 5, aquatic harvested crops have included fish, shellfish, bullfrog, and aquatic plants. Crop species that have been selected for commercial production have tended to be prolific in reproduction, high in early survival,

Table 5. Potential Physical Habitats and Crops in Each Salinity of Water

Water Salinity	*Potential Physical Habitats*	*Finfish*	*Shellfish, Other Animals*	*Plants*	*Ecosystem Byproducts*	*References*
Fresh	Pond, Lake, Impounded Rice Field, Swamp, Marsh, Bog, Stream, River	Catfish, Trout, Bass, Minnow, Tilapia, Buffalofish, Perch, Pike, Bluegill, Crappie, Sunfish, Goldenshiner	Crayfish, Shrimp, Crab, Bullfrog, Duck, Goose	Cranberry, Duckweed, Cattail, Bulrush, Sagittaria, Rice, Water Hyacinth, Water-Cress	Water Quantity, Water Quality, Species Preservation	Ackefors & Rosen, 1979 [30] Bardach, et al., 1972 [31] Lovell, 1979 [32] Newton, 1979 [33]
Brackish	Estuary, Tidal Marsh	Bass, Flounder, Pompano, Mullet, Tilapia, Trout, Eel	Oyster, Mussel, Clam, Quahog, Shrimp, Crab, Scallop, Snail		Water Quantity, Water Quality, Species Preservation	Ackefors & Rosen, 1979 [30] Bardach, et al., 1972 [31]
Salt	Estuary, Inlet, Bay, Fjord, Harbor, Open Ocean	Salmon, Sturgeon, Milkfish	All Brackish Shellfish, plus Prawn, Lobster, Abalone, Conch	Kelp, Seaweed, Algae, Eelgrass, Seashore Mallow, Saltgrass, Glasswort	Water Quantity, Water Quality, Species Preservation	Bardach, et al., 1972 [31]

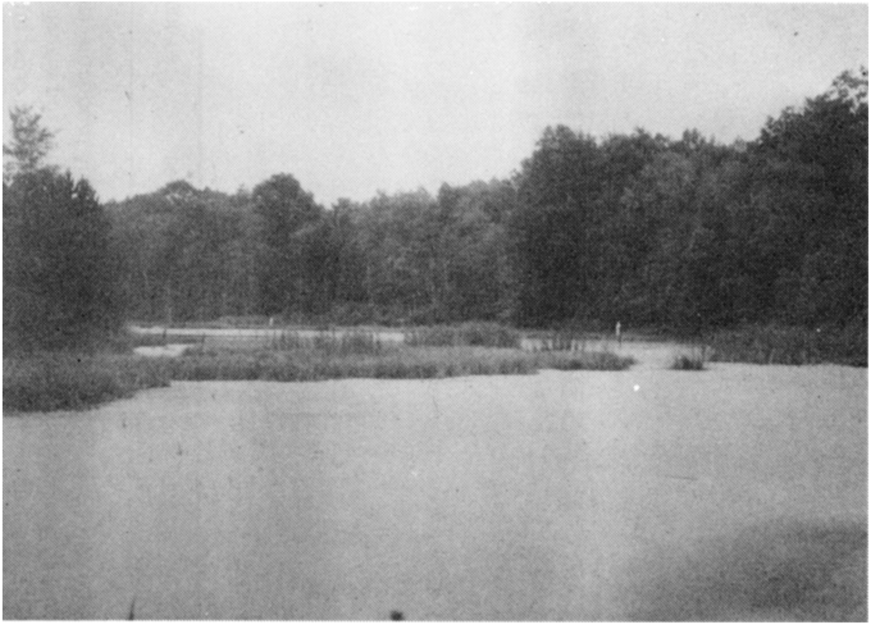

Figure 7. Aquatic production: a managed wetland in a glaciated part of Pennsylvania. The water level and vegetation are maintained for waterfowl such as ducks and egrets.

efficient in protein conversion, and adaptable to crowding [31]. Products from aquatic harvested crops have included food for human consumption, animal feed, pearls, and, in the case of water hyacinth, input to biogas digesters. Currently fin-fish are two-thirds of world aquatic harvest, shellfish about one-sixth, and plants about one-sixth [30].

Aquatic areas are also used to produce the ecosystem byproducts of water and species preservation. Wetlands, most frequently, have been designated as maintainors of water quality and species diversity.

DISCUSSION

Our attempt at an overview of bioproductive systems can ease and accelerate the systematic planning of productive areas. We have attempted to arrange the systems along lines that combine the structures and the functions of systems. There are other dimensions along which bioproductive systems could be arrayed.

One dimension that is frequently of concern in physical land planning is intensity of management. Some examples of operations at different levels of intensity are listed in Table 6. The lower levels are characterized by a relative

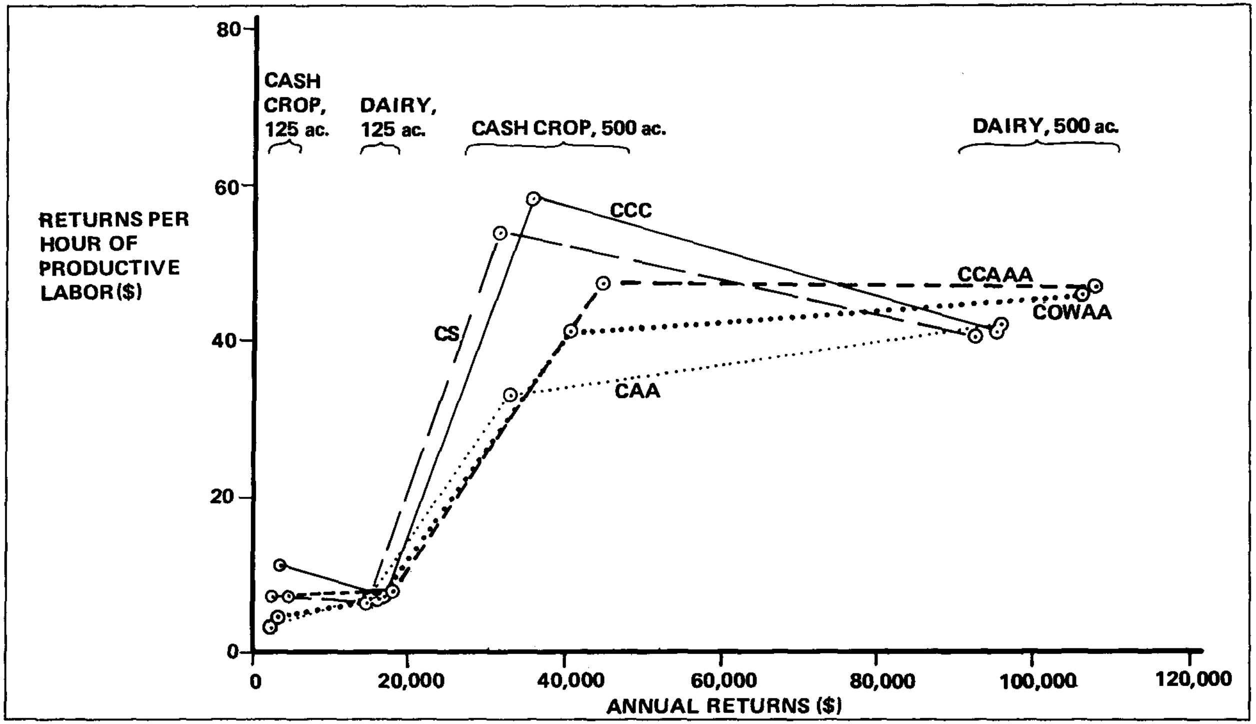

Figure 8. Annual and per-hour economic returns for cultivated (cash crop) and dairy systems on "highly productive land" in Pennsylvania, at two scales of operation and with alternative crop rotations. Returns are to operator's labor and management, after all other costs (including general farm overhead and hired labor, but not land costs) are subtracted from gross returns. (C = corn, S = soybean, A = alfalfa, W = wheat. After Lazarus, et al., (1980), Table 22.)

Table 6. Some Examples of Bioproductive Systems at Contrasting Levels of Intensity

Bioproductive System	*Lower Intensity*	*Higher Intensity*
Cultivated	(Not Applicable)	Intense Field Cultivation Hydroponics (Doyles, 1973); "Bioshelter" (New Alchemy Institute, 1981) [34]
Perennial-Plant	Picking of Wild Berries	Hydroponics, "Bioshelter"
Grassland	Successional Rangeland	Managed Pasture
Forest	Successional Forest	Short-Rotation Coppice
Terrestrial Animals	Game Management	"Animal Factory" (Mason and Singer, 1980) [35]
Aquatic	Aquatic Habitat Management (Bardach, et al., 1972)	"Fish Farm" (Ackefors and Rosen, 1979) [30]
Ecosystem Byproduct (Aquatic or Terrestrial)	Watershed, Airshed, Refuge	(Not Applicable)

dependence on the unmodified natural environment. The higher levels are characterized by artificial controls over the environment such as confined housing, artificial irrigation, and artificial fertilization.

Compatible types of systems are sometimes placed together on the same land. Animal grazing, particularly, tends to be adaptable as a secondary use in other systems. A common example is the grazing of cattle, sheep, or swine on perennial grass under the canopy of an orchard or forest plantation, making economic use of the spaces between plantation stems. Grazing geese are used to control weeds in cotton, strawberries, and some truck crops. Honeybees graze symbiotically on many flowering plants. Cultivated crops tend to be the least tolerant of combinations with other crops because of their necessarily high intensity.

Which systems are selected for implementation in a given situation can be one of the major determinants of the success of a plan for productive land. Figure 8 compares the economic returns from dairy and cultivated (cash crop) systems in Pennsylvania, under conventional intensity of management, and under alternative crop rotations and scales of operation. It is clear that the choice of system is highly relevant to the economic performance of the farm and the region – although which one is finally selected depends on whether one is interested more in annual returns or in returns per hour.

In addition to economic returns, the effects of alternative bioproductive systems reach out to energy, environmental and other non-economic issues that land planners are often concerned about. Some non-economic criteria that could be taken into account in selecting and laying out systems could include the following:

1. site suitability in terms of soil, slope, rainfall, temperature, etc.;
2. availability of labor, capital, energy, fertilizer, etc.;
3. regional infrastructure (markets, services, irrigation systems, roads, etc.);
4. environmental impacts such as soil erosion and nutrient water pollution;
5. minimum acreage necessary to realize economies of scale; and
6. the ways other objectives such as sewage disposal, energy conservation or land reclamation are fulfilled.

Such effects can come about through the crops' impacts on soil, their demands for energy and other inputs, and the overall composition of land uses in a region. To influence such effects, economic and non-economic, is certainly one of the tasks of land planners. It is one which the growing demands and controversies over productive land will make more prominent in coming years.

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