Human Ecology, Vol. 15, No. 3, 1987

Ecological Stability and Community Diversity during Mormon Colonization of the Little Colorado River Basin

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By describing the ecological implications of Mormon settlement in the Little Colorado River Basin, the paper demonstrates: (1) the application of general ecological concepts in human ecology, (2) the ecological basis for the evolution of complex human communities, (3) the interactive, hierarchical relationship between community diversity and environmental stability, and (4) the positive contribution that human ecology can make to the general discussion of diversity and stability in ecological systems. The paper gives a brief description of Mormon colonization in the Little Colorado River Basin. Local differences in community development are then related to environmental variation within the basin and compared to general ecological research expectations. The implications of community development in this region for explaining the relationship between diversity and stability in ecological systems are discussed.

KEY WORDS: productivity; diversity; stability; maintenance costs.

INTRODUCTION

For several years, ecologists have debated the relationship between diversity and stability in ecological systems. MacArthur (1955) initially proposed the thesis that diversity caused stability in ecological communities due to the ability of complex food webs to regulate energy flow and to offset the destabilizing impact of environmental fluctuations. MacArthur's thesis soon

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0300-7839/87/0900-0317$05.00/0

achieved near universal acceptance among ecologists (Elton, 1958; Hutchinson, 1959; MacArthur and Connell, 1966; Margalef, 1968; Odum, 1971a). More recently, May (1973) concluded that no mathematical basis existed for this thesis, and, based on his observations of model ecosystems, he suggested that more complex systems were, in fact, less stable. However, he acknowledged the general empirical association between diversity and stability in ecological communities, and therefore proposed the alternative generalization that stability permits complexity. This thesis has found substantial empirical support (see Watt, 1964, 1965; Sanders, 1968; May, 1973, pp. 39, 173; Cody and Diamond, 1976). Sanders' (1968) comparative study of species diversity in benthic communities provides the clearest support for the notion that environmental stability underlay the evolution of community diversity. Sanders established that increased diversity was consistently associated with reduced seasonality. He also observed that species diversity was not only greater in more stable communities within similar climatic zones, but that communities in stable temperate environments exhibited greater species diversity than those in unstable tropical ecosystems. Thus, Sanders' research suggested that stability might even exceed productivity as the critical factor determining community diversity. Nonetheless, the most complex community observed by Sanders was the shallow water community in the Bay of Bengal, a productive *and* stable tropical benthic ecocystem.

Studies of community stability within human ecology have largely comprised neofunctional analyses of human environmental relations using cybernetic ecosystem models (Vayda and McCay, 1975; Bates and Lees, 1979; Moran, 1984). In addition, many researchers have merely used ecological concepts as heuristic metaphors (Barth, 1956; Hawley, 1971; Diener, 1980). Few have analyzed specific human environmental relations in terms of testable predictions derived from general ecological principles.

The present paper examines the relationship between diversity and stability in human communities from an explicit general ecological perspective. Differences in community development during Mormon colonization of the Little Colorado River Basin of northeastern Arizona are compared with expectations derived from comparative ecological research. As predicted by ecological theory, the largest populations and the most diverse community organizations were found among those settlements which were: (1) the most productive and stable and (2) located in the most productive and stable habitats for agriculture. However, by integrating diverse habitats into a unified system of resource redistribution, early Mormon settlements established a regional community organization sufficiently diverse to counteract local environmental variation and to maintain community stability.

MORMON COLONIZATION OF THE LITTLE COLORADO RIVER BASIN

Colonization of the Little Colorado River Basin was conducted largely under the direction and supervision of the Mormon Church (see Peterson, 1973). Establishing settlements in this remote region was part of the Church's larger geopolitical strategy to populate vast areas of the American West with self-sufficient Mormon farming communities that were socially and economically independent of American society (see Arrington, 1958). The first attempt to colonize the basin was in 1873 when over 100 pioneers were sent to the lower valley of the Little Colorado River (see McClintock, 1921, p. 135; Tanner and Richards, 1977, p. 12). This initial effort failed, however, and a second attempt began in 1876. This time, 500 settlers were organized into four companies and instructed by Church leaders to establish four separate settlements in the same general area chosen for the previous expedition. These settlements became known as Sunset, Brigham City, Obed, and St. Joseph (see Fig. 1). Additional settlements were soon founded upstream: along Silver Creek during 1877–1878, and along the upper Little Colorado River during 1879–1880. By the early 1880's, some 20 Mormon farming settlements had been established throughout the river basin.

A highly variable environment imposed considerable hardship on early settlers and undermined their efforts to establish self-sufficient farming communities. Annual agricultural productivity varied sharply due to recurring droughts, floods, frosts, high winds, hailstorms, and insect infestations. So variable were local environmental conditions that individual settlements often lost crops to several causes during a single agricultural season. The impact of climatic variability upon early Mormon agriculture is illustrated by the sequence of events at St. Joseph in 1876. First plowing was begun on March 25th, only two days after the first settlers had arrived. Surveying for the irrigation ditch began within two days and the first logs to be used in constructing the dam were cut on the third day. By April 3rd the first wheat had been sown, and farmers anxiously awaited the rains. No rain fell, however, for several months, forcing farmers at St. Joseph and the other early settlements to plant additional crops to replace those which were dying in the fields. Finally, on July 16th the first rains fell, and on the following day a torrential flood destroyed St. Joseph's dam and several others along the lower valley. On August 25th, a second flood destroyed what remained and what little had been reconstructed following the first flood. That year's harvest was a complete failure, forcing nearly 75% of the settlers to spend the winter in Utah. As a result of environmental variability, St. Joseph ex-

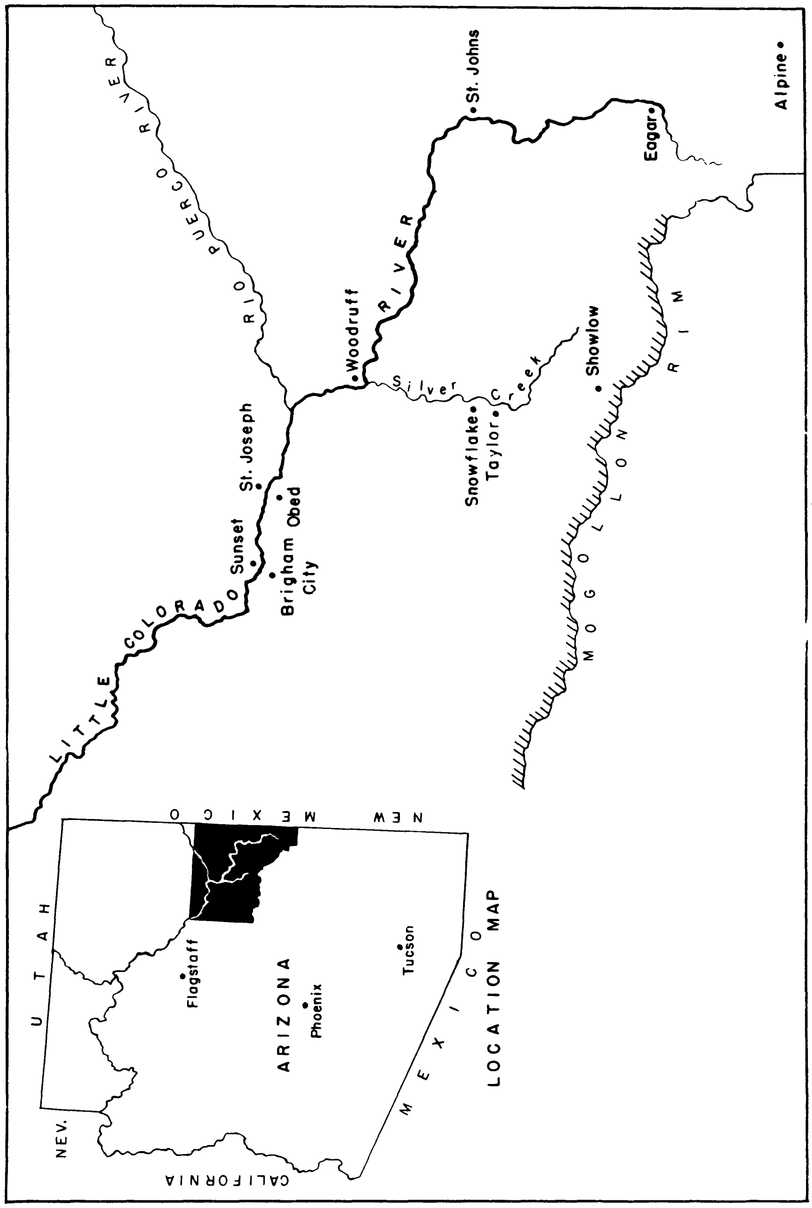

Fig. 1. Little Coloraldo River Basin–Mormon settlements.

perienced complete crop failures during 3 of 7 years beginning in 1876. Sunset, which produced an abundant harvest in 1879, was abandoned in 1883 following 3 years of poor harvests. Brigham City failed to produce a single adequate harvest and was dissolved in 1881. Available records indicate that either poor harvests or complete crop failures prevailed throughout the basin during half the years between 1880–1900. Successful colonization depended early on subsidies from Church headquarters in Salt Lake City, and, later on, a complex system of resource redistribution which connected every Mormon settlement in the basin was developed (see Arrington, 1958; Leone, 1979; Abruzzi, 1981, n.d.).

Most Mormon settlements in the region remained economically marginal throughout the nineteenth century and failed to become the prosperous, diversified farming communities intended. However, important local developmental differences did occur. Tithing records demonstrate that substantial variation in agricultural productivity existed within and between settlements (see Table I). Because cash was not readily available, most tithing collected among the Little Colorado settlements was paid in kind. Items were tithed as they became available, and local variation in tithing stocks reflected local differences in agricultural production. Consequently, tithing data provide a reliable indice of community productivity. Annual tithing collected at Snowflake and St. Johns during 1887–1905, for example, averaged over six times that received at either Showlow or Alpine during the same years, but was only about half as variable. Similarly, population size and stability varied several hundred percent among settlements in the region. Considerable local differences also existed in the diversity of occupations, the variety of businesses, and the complexity of Church organization. The Mormon Church is divided administratively into stakes and wards, which may be compared to diocese and parishes, respectively, in the Roman Catholic Church. Each of these administrative levels is composed of different organizations which perform distinct functions. During the nineteenth century, each settlement contained one ward, and, by the close of the century, two stakes had been established in the region, one at Snowflake and the other at St. Johns.

Differences in local church organization are important for understanding the evolution of community complexity among these early settlements. The local church organization provided the near-exclusive governmental apparatus through which the temporal affairs of these communities were administered. Local church leaders presided over such matters as land distribution, dam construction and maintenance, property disputes, distribution of tithing, and punishment for such local offenses as theft and adultery. The full complement of ward and stake organizations were not established simultaneously. Rather, specific organizations were formed as

Table I. Population, Productivity, Stability, and Functional Diversity among Little Colorado Mormon Settlements (1887–1905)[a]

Town	Toal tithing (1887–1900)		Per capita tithing (1887–1900)		Population size (1807–1905		Number of occupations (1900)	Number of businesses (1905)	Number of business categories (1905)
	$\overline{X}^b$	V	$\overline{X}$	V	$\overline{X}$	V			
St. Johns	3561	.230	7.09	.179	506	.201	22	34	22
Snowflake	3025	.195	7.58	.203	404	.148	16	24	20
Eagar	1810	.180	5.15	.157	310	.231	8	20	14
Taylor	1463	.217	4.75	.169	308	.111	8	3	3
St. Joseph	1124	.435	8.49	.349	118	.269	5	3	3
Woodruff	915	.389	5.44	.358	153	.265	12	8	6
Alpine	449	.327	4.54	.419	105	.302	3	2	2
Showlow	431	.335	2.40	.323	182	.261	7	6	6

[a]Source: Abruzzi (1981, pp. 98-108, n.d.).
[b]$\overline{X}$ = mean (in dollar values), and V = coefficient of variation.

resources, most notably manpower, were available to perform their specific functions. Differences in the complexity of church organization, thus, reflect local differences in the availability of administrative resources. Some settlements were clearly larger, more productive, more stable and more functionally diverse than others.

In order to explain these differences, eight settlements were compared regarding the extent of productivity, population size, stability, and functional diversity achieved between 1887–1905. Gross and net community productivity are defined by total and per capita annual tithing collected, respectively. Community stability is defined by the coefficient of variation associated with productivity and population size, and community diversity is calculated from the number of occupations, businesses, and business categories registered for each town at the close of the settlement period. These same settlements were also compared with regard to local physical environmental factors related to agricultural production. Four settlements, Snowflake, Taylor, St. Johns, and Eagar, consistently ranked highest on the indices of community development examined, while two settlements, Showlow and Alpine, repeatedly ranked lowest. The remaining two settlements, St. Joseph and Woodruff, generally displayed a medial ranking.

An apparent subregional variation in community development existed: the lowest ranking settlements were the southernmost towns, the intermediate ranking settlements were located along the northern margin of the region, and highest ranking settlements were all situated in river valleys between these two extremes. In order to understand this variation, it is necessary to examine the physical environment of the Little Colorado River Basin and its implications for community development among nineteenth-century agricultural settlements.

THE LITTLE COLORADO RIVER BASIN

The Little Colorado River Basin is an arid to semi-arid region in northeastern Arizona located along the southern periphery of the Colorado Plateau. Average elevation varies from 5000 feet in the north to 8000 feet in the south, with several peaks exceeding to 10,000 feet clustered in the southeast. Environmental characteristics display significant spatial variation, due largely to differences in elevation. The most important of these for understanding differential community development among early Mormon settlements are precipitation, length of the growing season, soil quality, and the availability of suitable water for irrigation.

Precipitation enters the basin through the action of two independent storm systems and occurs primarily during the months of December–March and July–September. The remaining months provide little, if any, precipitation. Annual precipitation increases with elevation and ranges from 9 inches in the north to over 25 inches in the south. Consequently, the predominant desert vegetation along the lower valley of the Little Colorado River is succeeded southward by grassland, juniper-piñon woodland, and montane forest communities, with alpine meadows prevailing at elevations above 9000 feet. Due to the combined arid climate and gradual topographic slope at lower elevations, grasslands constitute the largest vegetative community in the region, comprising more than 40% of the total land surface (Little Colorado River Plateau Resource Conservation and Development Project, 1971; Abruzzi, 1981, p. 123). Significantly, bare soil accounts for 55–65% of the surface cover in the grassland community (Dames and Moore, 1973, Section 4, p. 201).

In contrast to amount of precipitation, length of the growing season varies inversely with elevation. The average annual number of frost-free days ranges from nearly 180 in the north to less than 90 in the extreme south. Growing season variability also increases with elevation. This inverse spatial distribution between precipitation and the length and reliability of the growing season has rendered dry farming a marginal adaptive strategy in the basin (see Harrell and Eckel, 1939, p. 32). All substantial early Mormon farming enterprises were, therefore, restricted to river valleys below 6000 feet. Only in river valleys at lower elevations could adequate growing seasons be combined with surface water exploitation to circumvent climatic limitations.

Although an arid climate made irrigation a prerequisite for the development of early Mormon farming communities, surface water provided, at best, an imperfect agricultural resource. Most waterways in the basin are ephemeral and flow primarily in direct response to precipitation. Consequently, surface water availability fluctuates in conjunction with the highly variable precipitation cycle, and most stream beds are dry during the spring (April–June) when 45% of annual irrigation requirements must be applied (see Bureau of Reclamation, 1947, p. 72).

Only two fully perennial streams exist in the region, Silver Creek and the Little Colorado River above St. Johns, both of which are maintained by seeps which discharge water from groundwater sources. However, even these streams exhibit significant monthly, seasonal, and annual variation. In addition to adversely affecting agricultural production, intense surface water variation placed an inordinate stress on the infrastructure of early Mormon agricultural systems. Dramatic increases in surface water volume and velocity accompanied both spring snowmelt and summer storms and frequently produced floods that destroyed dams, buildings, and crops (see Abruzzi, 1981, pp. 165-196).

Although streamflow variability occurs throughout the river basin, it is greatest along the lower valley of the Little Colorado River where the largest surface area is drained. Mean monthly streamflow in the Little Colorado River near St. Joseph varies, for example, from less than 1000 acre-feet during May to over 37,000 acre-feet during August (see Abruzzi, 1985, p. 246). Similarly, annual streamflow at the same location between 1950–1969 ranged from less than 15,000 to nearly 200,000 acre-feet (Abruzzi, 1985, p. 248).

The most reliable local surface water source in the region is Silver Creek near Snowflake and Taylor. Silver Creek originates from Silver Creek Spring, located about 10 miles southeast of these two towns. The discharge of Silver Creek Spring is remarkably stable, and no record exists of it ever failing, even during the longest drought in the region (see Harrell and Eckel, 1939, p. 30; Bureau of Relcamation, 1947, pp. 50, 87). Thus, while annual discharge in the Little Colorado River near Woodruff varied 30-fold between 1930–1944, annual discharge in Silver Creek near Snowflake and Taylor during the same period differed by little more than a factor of two (see Abruzzi, 1981, p. 149).

Local surface water quality also varies considerably within the basin, generally decreasing with descending elevation (see Abruzzi, 1981, p. 149, Fig. 5.4). While Silver Creek and the Little Colorado River provide potable water for considerable distances downstream from their points of origin, both accumulate increasing concentrations of suspended and dissolved solids (particularly soluble salts) as they flow through high salt-bearing formations at lower elevations. They also receive increasing water from tributaries originating in these saline strata.

Sediment concentrations in streams at lower elevations increase during the summer rainy season, due to the prevalence there of alkaline soils and of insufficient vegetation to inhibit soil erosion. Thus, the lowest quality surface water is found in the Little Colorado River below St. Johns, where sediment load frequently approaches 20% of streamflow and where the water is considered unsuitable for irrigation (Bureau of Reclamation, 1950, pp. 3, 10). Two examples illustrate the degree of silt concentration in the Little Colorado River at lower elevations. The first concerns a story retold about the initial pioneers:

> A 7-gallon kettle was filled when they camped for the night with water from this stream and set by for use the next morning after it had "settled"...there was about an inch at the top of the kettle of fairly "clear" water; but soluble matter in the water was still so much in solution that the water was of poor quality (Porter, n.d., pp. 7–9).

The second concerns Zion Reservoir which was constructed above Hunt on the Little Colorado River between 1902–1905. This reservoir contained an initial storage capacity of 12,896 acre-feet. However, by 1952, over 22,700 acre-feet of silt had accumulated behind the dam reducing the reservoirs storage capacity to a mere 760 acre-feet (Akers, 1964, pp. 8–9).

Local variation in surface water quantity and quality had especially negative implications for agriculture and community development in the lower valley of the Little Colorado River. Without suitable reservoir sites, settlements in the lower valley could only construct diversion dams. They were, therefore, unable to circumvent the substantial streamflow variability that characterized this portion of the basin. In particular, lower valley settlements remained highly susceptible to the seasonal decline in surface water that occurred during the early growing season. In addition, as Mormon settlements expanded and more storage reservoirs were constructed upstream, less water was available at lower elevations in the Little Colorado River and Silver Creek during dry periods. Because a greater proportion of the remaining water originated from northern tributaries, surface water quality in the lower valley declined with time.

The increased impounding of surface water upstream had negative consequences for settlements in the lower valley during periods of abundant streamflow as well. Under the pressure of sharply increased surface water flow, such as normally accompanies spring snowmelt and the advent of summer storms, dams at higher elevations occasionally burst, aggravating the destructive power of already swollen streams. Dams at lower elevations were, therefore, frequently destroyed in chain reactions produced by dam failures upstream. Consequently, the incidence of dam failures followed an inverse distribution to elevation. St. Joseph lost 13 dams and Woodruff ten dams between 1876–1900, compared to three at Snowflake and Taylor, two at St. Johns, one at Showlow, and none at either Eagar or Alpine (see Abruzzi, 1981, p. 191).

Local differences in agriculture productivity also resulted from dissimilar soil quality. The basin contains a diverse variety of soils due to its complex geological history (see Kester *et al.*, 1964; Miller and Larsen, 1975). Although most soils in the basin are thin and loamy, deeper soils exist along the floodplain of the Little Colorado River and in the dense forests of the southern highlands. Lower valley soils are alluvial in origin and occasionally exceed 60 inches in depth. However, because of their predominant silt and clay composition, these soils possess low permeability and are highly susceptible to flooding during the summer rains. In addition, they contain little organic matter and are deficient in nitrogen and phosphorus due to the prevailing arid climate in the northern portion of the basin. Because of the parent material from which these soils derive, they also contain high concentrations of alkali salts, a condition quickly aggravated by irrigation.

Outside of the Little Colorado floodplain, soil depth and fertility generally increase to the south due to increasing precipitation and vegetation density. Soils within the forest of the southern highlands average 18–20 inches in depth and are high in organic matter. They are also well drained, possess a high water-holding capacity, and are classified as moderately fertile.

However, soils in the highest valleys, including Bush Valley where Alpine is located, tend to be poorly drained, susceptible to flooding and slightly acidic.

Soils in most valleys located between the lower Little Colorado River and the southern highlands range in depth from about 9–15 inches and derive primarily from sandstone, limestone, basalt, and quartzite. They are, therefore, generally well drained and possess a moderate to high permeability and water-holding capacity. However, important local differences exist. Soils in parts of Round Valley in the southeast possess a low water-holding capacity. Consequently, several irrigated areas near Eagar experience temporary flooding during the growing season. Also, soils to the east near both Eagar and St. Johns are classified as moderately alkaline. By comparison, the soils near Snowflake and Taylor are noticeably free from any harmful accumulations of soluble salts, even after 100 years of continuous irrigation (Salt River Project, 1974, Section 3, p. 78). Significantly, these latter soils have been classified as among the most fertile and productive soils in the entire region (Kester *et al.,* 1964, p. 11).

DISCUSSION

Ecological communities, be they multiple or single species communities, evolve to the extent that the individuals within them convert available potential energy into productivity, biomass (population), and, ultimately, functional diversity. Multispecies communities contain organisms of widely varying size. Therefore, population size is not an appropriate measure of the organic matter maintained within such communities. However, simple population numbers present an adequate measure of biomass in human communities since only one species is involved. Thus, the use of population figures facilitates data collection and analysis without introducing serious distortions into the investigation. Community evolution represents an incessant developmental process resulting in the most diverse community structure supportable by local resources (see Margalef, 1968; Odum, 1971b; Whittaker, 1975). Consequently, a fundamental task of ecological analysis at the community level has been to identify those factors which inhibit or advance the developmental process.

Although the specific physical factors which influence community development are numerous and differ locally in their relative importance and effect (Odum, 1971a, pp. 43-53, 106-136), certain general considerations prevail. The most complex ecological communities evolve in environments that are both productive and stable. Other factors are also important to the evolution of complex ecological communities, including habitat diversity (see Levins, 1968, pp. 10-38; Vandermeer, 1972, pp. 114-116) and exploitation (see Margalef, 1968, pp. 37-39). However, because these are not directly related to differences in community development among the Little Colorado Mormon settlements, they are not discussed here. Although environmental productivity has generally been considered the *a priori* condition needed for the evolution of complex ecological communities, research has shown that the developmental benefits of high productivity may be either compromised or completely negated by environmental instability (Sanders, 1968). Consequently, the most complex ecological communities occur in ecosystems characterized by high productivity, predictability, and low variability (Slobodkin and Sanders, 1969). This simple set of considerations substantially explains the differential development of nineteenth-century Mormon settlements in the Little Colorado River Basin.

Ecology and Mormon Colonization

For the purpose of examining agricultural community development, the Little Colorado River Basin may be divided into three broad subregions: (1) the southern highlands, (2) the lower valley of the Little Colorado River, and (3) intermediate territories. Each subregion is distinct with regard both to its defining physical characteristics and to the pattern of community development exhibited by the early Mormon settlements within it. Of the settlements investigated in detail, two (Showlow and Alpine) were located in the southern highlands, two (St. Joseph and Woodruff) were situated in the lower valley, and four (Snowflake, Taylor, St. Johns, and Eagar) existed in river valleys at intermediate elevations.

Located above 6000 feet, settlements in the southern highlands generally enjoyed sufficient water for irrigation. However, they had the shortest and most variable growing seasons in the entire basin. The number of frost-free days experienced throughout the southern highlands was generally too low for the cultivation of some crops and too variable for a reliable harvest of others. Highland settlements were also located in relatively narrow valleys with limited potential for the expansion of agriculture. In addition, the more highly situated settlements in this subregion had to contend with soils that were both poorly drained and slightly acidic. Consequently, community productivity and population size among settlements in the southern highlands remained among the smallest and most variable in the basin. Furthermore, the highest settlements recorded the largest proportion of dependents working in farming operations, suggesting that a high per capita labor investment was needed to sustain the limited agricultural productivity achieved by these towns (see Abruzzi, 1981, p. 296).

In the language of general ecology, low environmental productivity and stability resulted in a low and highly variable aggregate community productivity among southern highland communities. Environmental instability also imposed high maintenance costs, which resulted in low net community productivity. As anticipated by ecological theory, settlements in the southern highlands possessed the least functionally diverse community organizations in the basin.

In contrast to settlements in the southern highlands, those in the lower valley benefitted from a more than adequate growing season. Lower valley settlements also farmed larger areas. They therefore had the potential for supporting larger populations and achieving greater community diversity than settlements in the southern highlands. However, lower valley settlements experienced high summer temperatures, dust storms, and a recurring spring dry season, all of which reduced agricultural productivity and increased the frequency of crop failures. In addition, lower valley settlements irrigated the least fertile soils with the poorest quality surface water in the basin, and both soil and water quality deteriorated steadily throughout the nineteenth century. The lower valley settlements also experienced greater surface water variability than any other settlements in the region, and this variability not only reduced annual agricultural productivity, it also increased the cost of farming in this subregion. With the highest incidence of dam failures occurring among some of the smallest populations, lower valley settlements easily bore the highest per capita maintenance costs in the basin.

Recurring crop failures and dam losses produced low, variable, and sometimes negative net community productivity. This resulted, in turn, in the most unstable populations in the basin. Indeed, so great were the maintenance costs relative to productivity, that only two of the six settlements established in this subregion survived. As already indicated, Brigham City and Sunset were abandoned in the early 1880's following successive crop failures. Obed was abandoned in 1877 due to a persistent illness attributed at the time to that town's location near a marsh of the same name. A sixth settlement was established along the Little Colorado River as well. Known later as "Old Taylor to distinguish it from the subsequent settlement on Silver Creek bearing the same name, this town was located about 5 miles downstream from St. Joseph and contained about 15 families. Founded in 1878, the town lost five dams in 5 months and was abandoned the same year. Those who left the town formed the core of the population which settled Snowflake and Taylor to the south.

From the perspective of general ecology, the lower valley settlements were located in highly unstable habitats, possessing only moderate productivity and imposing what were clearly the highest community maintenance costs in the region. Moderate environmental productivity in the face of low environmental stability and notably high maintenance costs resulted in only limited aggregate and net community productivity. As anticipated by ecological theory, lower valley settlements contained among the smallest and most variable populations in the region and achieved a functional diversity not significantly greater than that found among settlements in the southern highlands.

Intermediate settlements did not experience the inadequate growing seasons that limited community development in the southern highlands nor the high surface water variability that plagued towns in the lower valley. They all enjoyed average growing seasons of between 130–160 days and were located adjacent to perennial streams and in proximity to suitable reservoir sites. Intermediate settlements were also situated in relatively large valleys containing fertile, well-drained, and relatively alkaline-free soils, and were able to irrigate these soils with largely silt-free water. Significantly, the contiguous valleys in which Snowflake and Taylor are located possess the best soils and among the purest and most reliable surface water in the region. With access to dependable water resources and adequate growing seasons, intermediate settlements were not as vulnerable to climate instability as towns located in either the lower valley or the southern highlands.

From the perspective of general ecology, large valleys, good soils, and abundant, superior quality surface water yielded high environmental productivity for intermediate settlements. At the same time, reliable growing seasons combined with stable surface water sources (made even more stable through the construction of storage reservoirs) produced high environmental stability with regard to critical resources for agriculture. High environmental productivity and stability combined to produce the highest and least variable community productivities of any settlements in the region. Furthermore, because intermediate settlements did not suffer the frequency of dam failures experienced in the lower valley, and because they contained the largest populations in the basin with which to undertake dam reconstruction, they also sustained the lowest per capita maintenance costs of any settlements in the region. They therefore yielded the highest net productivity and were able to support the largest and most stable populations in the basin. As predicted by ecological theory, intermediate settlements evolved a greater functional diversity than any other Mormon settlements in the region.

Ecological theory thus explains the substantial subregional differences in community development that accompanied Mormon colonization in the basin. The smallest and least developed communities were located in the southern highlands where both environmental productivity and stability were low and where maintenance costs were high. The largest, most productive, and most complex communities occurred in river valleys at intermediate ele-

Table II. Rank-Order of Mormon Settlements (1887–1905)[a,b]

Settlement	Composite population, productivity, and stability rank-order	Composite diversity rank-order
Intermediate settlements		
Snowflake/Taylor	1	1
St. Johns	2	2
Eagar	3	3
Lower valley settlements		
St. Joseph	4	6
Woodruff	5.5	4
Mountain settlements		
Showlow	5.5	5
Alpine	7	7

[a]Source: Abruzzi (1981, 269).
[b]$r_s = .884, p < .01$.

vations where both high environmental productivity and stability prevailed and where relatively low maintenance costs were the rule. Settlements in the lower valley displayed an intermediate ranking because the relative advantages of moderate environmental productivity were negated by low environmental stability and by the especially high maintenance costs that environmental variability imposed.

Local differences in community development also conform to general ecological expectations. A significant rank-order correlation was achieved comparing individual settlements according to composite indices of population, productivity, and stability on the one hand, and functional diversity on the other (see Table II). Snowflake and Taylor are treated as a single community in the calculations performed in Table II. Unlike the other towns, which were more or less isolated, these two settlements were located within 3 miles of each other. Consequently, they jointly constructed and maintained a single irrigation system, employing the same dam and the same network of irrigation ditches. Their spatial proximity also resulted in their complete economic integration. Most of the businesses serving these two towns were established in Snowflake, however, due to its larger population and the larger valley within which it was located. Furthermore, developmental differences within subregions conform to the criteria used to explain the differences between subregions. Alpine, the lowest ranking settlement, is situated at the highest elevation. It experienced most acutely the environmental conditions that constrained community development throughout the southern highlands. Similarly, Eagar, which was the lowest ranking intermediate settlement, is situated at a higher elevation than any other settlement in this subregion.

Consequently, several agriculturally important environmental characteristics at Eagar, most notably length of the growing season, fall midway between conditions found at other intermediate settlements and those present in the southern highlands. Significantly, the highest ranking community was that composed of neighboring Snowflake and Taylor. As a single community, these contiguous settlements farmed the largest area containing the most fertile soils, irrigated with the purest and most reliable surface water, suffered among the least frequent dam failures, maintained the largest functionally integrated population, and came closest to achieving the nineteenth-century Mormon ideal of stable, diversified farming communities (see Peterson, 1976). It is also important to note that all four of the extinct lower valley settlements were situated downstream from St. Joseph and Woodruff where they experienced even more intensely the stresses that environmental instability imposed on these remaining two towns.

An examination of Mormon colonization in the Little Colorado River Basin has thus far shown that physical environmental differences resulted in considerable local variation in community development. However, regional environmental diversity also provided early Mormon settlements with a unique opportunity for circumventing local environmental limitations. By adopting a multihabitat exploitative strategy, individual settlements could utilize the region's spatial diversity to counteract its temporal variability. Widely separated habitats experience distinct schedules of variation and are differentially affected by the same regional climatic events. Droughts, floods, and other catastrophes occurred at different locations during various years, while increases in temperature and precipitation had an opposite effect on agriculture at higher vs. lower elevations. To the extent that individual settlements integrated the productivity of multiple habitats into a single resource-flow system, they would have reduced their dependence on any single, variable habitat and increased community stability.

Two multihabitat, resource-flow systems emerged during Mormon colonization of the region. Both integrated several settlements into a single unified system of resource redistribution. However, the two systems were not equally successful as mechanisms for overcoming environmental variation and maintaining community stability. Their differential success bears directly on the issue of diversity and stability in ecological systems.

The first of the two multihabitat, resource-flow systems occurred among early lower valley settlements, and represented a conscious attempt to counterbalance the unstable environmental conditions that characterized this subregion. The system was based largely on the joint operation by these towns of a dairy, a tannery, and a lumber mill at higher elevations to the south (see Abruzzi, 1981, pp. 198-205, n.d.). these joint enterprises provided cheese, butter, meat, lumber, and other products not readily produced along the Little

Colorado which supplemented the wheat, corn, barley, sorghum, and garden vegetables raised there through irrigated farming.

Although the joint enterprises prospered at first, they eventually failed as mechanisms of environmental regulation because their productivity depended ultimately on environmental conditions in the lower valley. The term "regulation" has a problematic history in ecology because it has generally been used to imply the internalized maintenance of a balance between populations and resources in ecological systems (Odum, 1969; Margalef, 1968; Rappaport, 1968; Leone, 1979; Patten and Odum, 1981), a claim which has been shown to be both untrue and undemonstrable (see Engelberg and Boyarsky, 1979; Moran, 1984). However, the term is not used here to in any way imply the existence of homeostatic equilibrium in ecological systems. Rather it merely refers to the persistent processes through which the actions of populations positively influence the abundance and distribution of resources within a community. As such, the concept of regulation (like that of adaptation) is viewed here as an interactive process rather than as a state of affairs, or, as Skinner (1974, pp. 177-178) suggested in a different context, as a verb rather than as a noun. The joint enterprises were primarily summer operations which necessarily competed with farming for labor. They could only be developed to the extent that surplus labor existed during this time of the year. However, as lower valley settlements sustained recurring droughts, floods, and dam failures, their populations decreased and their ability to provide manpower to operate the joint enterprises declined. Furthermore, because the lower valley settlements were all situated in neighboring habitats, they experienced similar schedules of environmental variation. They also frequently suffered simultaneous dam failures. Consequently, during the very years when the productivity of joint enterprises was most needed, an acute labor shortage existed throughout the lower valley settlements which precluded their investment in these supplementary activities.

Thus, for the same reasons that environmental instability limited community development in the lower valley, it precluded the establishment of a viable multihabitat, resource-flow system by settlements in this subregion. High maintenance costs in farming reduced their ability to fully exploit habitats geographically removed from the lower valley. The system of joint enterprises, therefore, failed to achieve sufficient diversity to operate as an effective mechanism of multihabitat resource redistribution. Ultimately, dependent on environmental conditions in the lower valley, the joint enterprises were unable to provide the redundant energy flows needed to maintain community stability in this subregion.

A second multihabitat, resource-flow system evolved among nineteenth-century Mormon settlements following the demise of the joint enterprises. This later system was based on the redistribution of tithing collected in towns throughout the region (see Abruzzi, 1981, pp. 210-221, n.d.). Local church leaders were granted considerable discretion by authorities in Salt Lake City regarding the use of the tithing they collected, and largely applied these resources to offset local poor harvests or to assure the completion of projects approved by the Church. Although tithing stocks were regularly exchanged between towns in order to equalize the local availability of specific commodities, the critical role of tithing redistribution in maintaining community stability occurred in relation to dam failures.

In most cases, a dam failure placed a local community in serious jeopardy, especially if it occurred during the growing season. The loss of a dam frequently left a settlement without food for the year. In addition, its prompt reconstruction was beyond the resources of most towns. Through tithing redistribution, a destitute settlement often received sufficient produce and supplies to sustain it until the next harvest. In addition, tithing resources were used to hire labor to help a town complete the reconstruction of its dam. Individuals were also allowed to offset their tithing obligation to the Church by donating labor on a dam, and calls were frequently issued throughout the basin for help in dam reconstruction.

Through tithing redistribution, local Church leaders channeled considerable resources into projects which enhanced community stability and advanced the colonization effort. Local crop failures were offset, dams were reconstructed, and several settlements which might have been abandoned survived. In contrast to the joint enterprises, the system of tithing redistribution succeeded because its organization and operation made it ecologically viable. Tithing redistribution functioned through a basinwide Church organization that included every Mormon settlement in the region. The hierarchical organization of the Mormon Church facilitated the concentration of sizable surpluses which were then readily distributed to meet local needs. The responsiveness and flexibility of the system was enhanced by: (1) a regional Board of Trade that made it economically advantageous for individuals to donate resources to the Church, (2) a network of Church-affiliated mercantile institutions that provided the storage, transportation, and credit arrangements needed for efficient resource redistribution, and (3) a system of quarterly conferences at which representatives from every settlement met to exchange information, assess local needs, and determine necessary resource allocations.

From the perspecitve of general ecology, the system of tithing redistribution differed in every important regard from that of the joint enterprises. By including every settlement in the basin, tithing redistribution effectively integrated the population and productivity of every occupied habitat in the region, in contrast to the joint enterprises which linked together only a limited population within a few closely related habitats. In the face of environmental variability, the system of tithing redistribution had a more dependable aggregate productivity. In addition, because tithing redistribution was based on the exploitation of diverse habitats by permanent and independent populations, it was less vulnerable to specific local environmental conditions than were the joint enterprises which were ultimately bound by climatic variability in the lower valley. Thus, the system of tithing redistribution was more diverse than that associated with the joint enterprises due to the greater productivity and stability of the resource base upon which it depended. At the same time, the increased redundancy of resource flows provided by its greater diversity made the system of tithing redistribution a more effective mechanism for maintaining community stability than that based on the joint enterprises.

CONCLUSION

This research has shown that differences in community development during Mormon colonization of the Little Colorado River Basin conformed to expectations derived from comparative ecological research. A clear positive association existed between community productivity and stability on the one hand, and community diversity on the other. In addition, the most complex community organizations occurred among settlements situated in the most productive and stable habitats for agriculture. These findings clearly support the proposition advanced by May (1973) and others (see Leigh, 1976; Cody and Diamond, 1976) that diversity derives from stability in ecological systems.

However, the paper also indicates that successful Mormon colonization of the basin resulted in large part from the development of an integrated system of resource redistribution which enabled individual settlements to withstand the impact of local environmental perturbations. In addition, it has shown that of the two distinct systems of resource redistribution initated, one based on joint resource exploitation and the other on tithing redistribution, only the latter succeeded, due to its greater diversity. The research, therefore, also provides support for the alternative thesis that stability drives from diversity within ecological communities (MacArthur, 1955; Odum, 1969; Margalef, 1968).

The research reported here suggests that the current controversy surrounding the relative priority of diversity and stability in ecological systems needs reconsideration. These competing theses may reflect processes operating at distinct levels in hierarchically organized ecological systems (see Alexander and Borgia, 1978; Abruzzi, 1982a, pp. 28-31). In complex multispecies communities, competition among diverse predators increases community stability through the control it exerts over prey species numbers and variety (Paine, 1966), as well as through the indirect effect it has on the abundance and diversity of the plant species consumed by those prey (Hairston, Smith, and Slobodkin, 1960). However, the control that predators exert in a community requires a continuous supply of resources. The existence of predators and of the effect they have on prey populations depends, therefore, on the availability of these same prey species as resources throughout the year. Consequently, the enhanced stability that results from community diversity derives ultimately from the productivity and stability of encompassing ecosystems. Thus, while complex ecological communities are capable of mitigating minor disturbances caused by environmental instability, they are highly vulnerable to major dislocations in resource availability.

An examination of Mormon colonization in the Little Colorado River Basin suggests that the relationship between diversity and stability in human communities may be viewed hierarchically as well. The system of tithing redistribution succeeded in maintaining community stability because its functional diversity provided the redundancy needed to offset local environmental variation. However, the diverse activities upon which tithing redistribution was based required substantial and reliable resources for their operaiton. Consequently, while the complex system of tithing redistribution was successful in counteracting the negative impact of local environmental variation, its success was, in turn, dependent upon the aggregate productivity and stability of the regional ecosystem within which it operated.

In conclusion, variation in community development among Little Colorado Mormon settlements provides support for current alternative views about the relative priority of diversity and stability in ecological systems. Evidence exists to substantiate the competing cliams that environmental stability leads to community diversity and that diversity enhances community stability. The suggestion here is that an important goal of ecological research, including that in human ecology, should be the development of a synthetic model of community evolution which accommodates existing divergent research conclusions within a hierarchical view of the organization of ecological systems (Abruzzi, 1982b).

ACKNOWLEDGMENTS

The research upon which this paper is based was supported by the National Science Foundation under Grant No. BNS 78 21488. The author wishes to express his appreciation to N.S.F. for its support. Appreciation is also expressed to Brian Foster, Fred Plog, Mike Little, Hal Koster, John Frazier, Mark Leone, and Charles Peterson for their valuable assistance during the research and to Mary Reith for the illustration which accompanies the text.

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