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Author(s): Thomas K. Park
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Thomas K. Park
University of Arizona

Early Trends toward Class Stratification: Chaos, Common Property, and Flood Recession Agriculture

In societies based on flood recession agriculture in arid regions, economic stratification, institutionalized ways of sloughing off population, and common property are particularly valuable risk management options. Using ethnographic data from the Senegal River Basin and historical data from the Nile Valley, I argue that tendencies toward stratification were inherent in riverine societies practicing flood recession agriculture. Thus, early stratification occurred long before population pressure reached significant levels and well before regional trade, extensive storage capacity, or elaborate water-management infrastructure became economically significant. The article is intended to help explain why a number of civilizations developed in arid riverine contexts.

One puzzle that has been inadequately examined by theorists of the early state is why such states often developed in arid riverine contexts. In this article I address that issue through a reflection on chaotic weather in areas where water is a limiting agricultural resource, the ecological characteristics of standard flood recession agriculture in which crops are sown on the receding edge of floodwaters, and the theory of common property. My argument is intended as a contribution to the origins of economic stratification. I suggest a connection between unpredictable flooding, the economics of recession agriculture, and the advantages of group-level political response in the form of stratified systems. In addition, I use the Senegal River Basin case to illustrate an inherently hierarchical model of common property: one devoid of neoclassical assumptions of individual equality and associated tragedy-of-the-commons scenarios. I deal primarily with early forms of economic stratification (in terms of differential access to key productive resources) in the recession context, not stratification in general or developed forms of stratification such as are found in full-fledged states.

Anthropological studies of early stratification rarely discuss recession agriculture (Adams 1966; Béthemont 1982; Carneiro 1970; Flanagan 1989; Flannery 1972; Harner 1970; Orlove 1977, 1980; Renfrew 1986; Richards 1978; Smith 1984). Although a number of studies have mentioned riverine or recession ecology (Childe 1936; Hassan 1984; Netting 1977; Puleston and Puleston 1971; Sanders 1973; Trigger 1983, 1984), they spend little time on the specific characteristics of recession agriculture and do not link these characteristics directly to stratification. In some cases, such as Scudder's study of the Gwembe Tonga, recession agriculture plays a minor role in an environment that also supports various rainfed crops (1962).

The general lack of emphasis on recession, given the number of riverine civilizations, may be because few archeologists or anthropologists are familiar with living societies engaged in recession agriculture. This may be due to the success of recession regimes—many have developed into major civilizations using more intensive agricultural and water-management techniques (e.g., China, Indus, Mesopotamia, Nile, Olmec, coastal

Thomas K. Park is Assistant Professor, Department of Anthropology, University of Arizona, Tucson, AZ 85721.

Peru). Research has, understandably, focused on later stages of state building—along with irrigation, surplus production, storage, distribution, trade, war, and complex socio-political processes (Adams 1974; Lees 1973, 1974; Mitchell 1977; Wenke 1981, 1989; Wittfogel 1955, 1957; Wright 1977a, 1977b, 1986; Yoffee 1979). Many studies assume or imply that stratification first developed along with more complex social relations and more intensive economic strategies.

An extensive literature in anthropology deals with risk (Colson 1979; Cashdan 1990; Cancian 1980; Halstead and O'Shea 1989a, 1989b; Isbell 1978; Kent 1982; Legge 1989; Netting 1974; Sanders 1977; Smith 1988; Spooner 1982). Many of these authors begin by distinguishing risk, in effect gambling against given odds due to economic or environmental variability, from uncertainty, the paucity of knowledge available about the particular odds faced. This distinction makes particular sense if the variability in question reflects a simple random distribution (such as a normal distribution) making estimation of risk fairly easy. Most authors seem to assume, as well, that the levels of risk implied can be adequately compensated by such obvious risk-buffering responses as storage, trade, or mobility. The risk/uncertainty dichotomy is not a particularly valuable distinction in the flood recession case because estimation of risk is not possible in either the short or long term due to the chaotic quality of the flood (see below). I will argue that this type of unpredictability may require additional, and more intrinsically social, responses such as the development of common property, stratification, and institutionalized ways of adding and sloughing off population.

Ethnographic data from the Senegal River Basin help clarify the actual demographic relationship between early recession agriculture and alternative forms of production (foraging or pastoralism; depending on area and time). Kopytoff's (1987) model of the African Internal Frontier suggests that such demographic exchanges may have been typical in African societies. The details of the flood recession case support and complement Kopytoff's more general scenario. The pre-Aswan Nile Valley provides the basic test case for the flood recession model derived from the ethnographic data. While the flood recession model might appropriately be applied to other areas, such as Mesopotamia or Harappa, the African ethnographic material is most directly applicable to the early Nile.

The model I propose illuminates an early pre-state form of economic stratification. It provides a plausible linkage between early societies characterized by significant degrees of equality (Paynter 1989) and succeeding, more complex states in which both social and economic stratification are well developed. Explanations of the origins of the state (Claessen and Skalnik 1978a, 1978b, 1978c; Flanagan 1989; Tainter 1988:32; Yoffee 1979) are, generally, concerned with societies exhibiting far greater complexity than those considered here.

Initially, I look at the relationship between population, ecology, and production. I use ethnographic data on flood recession agriculture as the basis for a critique of an influential set of proposed relationships and the construction of a flood recession model for early economic stratification. Subsequently, I develop the model through an examination of unpredictability in both climate and flood patterns. Recent work in ecology has replaced traditional views of ecosystems in balance with the idea that many systems change chaotically and do not tend toward harmony (Worster 1990). Records of flood levels from the Senegal and the Nile rivers seem to fit this view better than they fit the traditional one. This change in perspective increases the significance of risk management as a response, and societal-level risk management becomes an integral part of the flood recession model for the early development of economic stratification. A final discussion section outlines the full model and puts it briefly into a broader context.

Demographic and Ecological Perspectives

Ester Boserup (1965, 1981) suggested that population pressure played a critical role in the adoption of agricultural techniques that increased returns per unit area cultivated.

In anthropology, Boserup's contribution led to improved ecological models based explicitly on the interaction between population and environmental dynamics (Netting 1981, 1982, 1990:37). Boserup's model included an influential, if slightly misleading, typology based on length of fallow. Boserup suggested that a key mechanism in the adoption of new technologies in response to population pressure was a decline in returns per unit of labor. Increasing population pressure led to the adoption of technologies that were more productive per hectare but less productive per unit of labor (Boserup 1965, 1981). This suggestion rested on the fairly persuasive claim that people would, given no constraints to do otherwise, choose the productive activities that gave greatest returns per unit of labor. Given no scarcity of the other productive inputs, and no particular reasons not to optimize in this fashion (*ceteris paribus* assumed), this seemed reasonable.

Boserup used a spectrum of intensification derived from a model of slash-and-burn agriculture to suggest that the periodicity of cropping and the returns per unit of labor were inversely correlated for agriculture in general. Going a step further, she implied that periodicity was itself an adequate proxy for returns per unit of labor. This methodological shortcut was in part motivated by pragmatism; returns per hectare and cropping periodicity are easier to measure than returns per unit of labor.

Useful as this shortcut may be as an initial approximation, it is still far from a general truth—as the flood recession case attests. The best returns per unit of labor (or, more precisely, per unit of energy input) seem to be in recession agriculture. In one of the few quantitative comparisons between recession, slash-and-burn, and irrigated rice cultures where most conditions are comparable, Hanks (1972:54–64) found that broadcast recession rice had the highest returns per unit of labor (38:1), followed by irrigated rice (23:1) and then swidden rice (17:1).[1] Hanks's Southeast Asia example differs most significantly from the arid riverine case in that the vastly moister climate imposes much higher labor requirements for clearing and weeding. Other authors have suggested that swidden fields can produce returns to labor as high as 29:1, while irrigated rice can vary from 11:1 up to a high of 54:1; labor on infrastructure does not seem to be included in this latter figure (Rappaport 1984:262, citing unpublished figures of M. Harris).

I suspect Hanks's swidden figures are unrealistically low. The rice swidden plots studied were monocropped to complement other productive activities and were not normal multicrop swiddens. Still, his study shows what one could expect for recession, which has an advantage over other forms of agriculture. Chibnik (1990:289) provides recent figures for flood recession rice grown in the Peruvian Amazon. Rice production on *barreales* (local floodplains owned as common property and reallocated annually) required an average of 79.25 days of labor per hectare and yielded two metric tons per hectare. Using 3,410 kcal/kg for rice, and 150 kcal (see Note 1) per hour of an eight-hour day, this would imply a 71.7:1 return on calories invested in flood recession agriculture.

In the Senegal River Basin itself, sorghum yields vary normally between 300 kg/ha and 1,000 kg/ha. In some areas Senegalese sorghums produce as much as 2,000 kg/ha (Etasse and Laurent 1971:7). Some Senegalese sorghum varieties have both exceptionally high yield potential and brief growing seasons (e.g., variety 63-18 with a 70-day growing cycle and 4,500 kg/ha potential yield and variety 50-59 with a 58-day growing cycle and 4,000 kg/ha potential yield [Etasse and Laurent 1971:16–17]). In 1986, flood recession yields in long-fallow Lake Rkiz averaged as high as 1,250 kg/ha in some areas (Baro 1987).

Although no explicit studies of human energy expenditure in flood recession sorghum are available, the crop requires at most an average of about three hours a day of moderate labor, weeding requirements are slight on average because little grows in the off season, and the main weeding is finished early in the agricultural season. Using 300–1,000 kg/ha as typical for a range of soils in good years, a 100-day labor season, and 3,420 kcal/kg of sorghum, the returns per calorie of input in flood recession agriculture would range from 22.8:1 to 76:1. Optimal soils producing 2,000 kg/ha could provide returns to labor of 152:1.[2]

Comparable figures for predynastic Egyptian wheat and barley flood-recession agriculture are less certain. The range in yields may have been comparable; figures cited for various periods in Egyptian history range from 2 *ardeb* (120 kg) per *feddan* (2.38 *feddan* = 1 ha) to 10 *ardeb* per *feddan*, although modern 1977 yields have reached 19 *ardeb* per *feddan* (Hassan 1984:62–63). Authors providing these figures do not consistently make clear whether they refer to average returns or returns on the best soils and generally refer to flood agriculture with water-retaining infrastructure, which would necessitate some extra labor for maintenance. Fekri Hassan (1984:62) suggests that in predynastic times the crop involved little if any labor during the growing season. Even using modern labor assumptions comparable to the sorghum case, yet including the longer maturation period of wheat (185 days), the 2–10 *ardeb* figures (equivalent to 571–2,855 kg/ha), and 3,320 kcal/kg for wheat, the returns to labor would be in a range from 23:1 to 113:1.

These figures, particularly those based on thorough studies of flood recession sorghum, underline the potential advantages of flood recession agriculture. Given few demands for intensive labor after the initial planting and weeding period following the flood, and provision of both fertilization and irrigation by nature, it is clear that returns per unit of labor can vary dramatically and that top-quality soils in good years can yield superlative returns per unit of labor as well as per hectare. Local knowledge of the differential productivity and optimal moisture requirements of each soil type and sorghum variety is widespread (Tabor and Djiby 1987). It is significant both that returns are variable yet can be very high and that labor inputs in flood recession agriculture can be more easily modified to fit expected yields than with other forms of agriculture. Significant adjustments are possible because soil quality and length of inundation (which determines soil moisture and hence the density of crop likely to be sustained) are known in advance.

Unfortunately for Boserup's typology of cropping periodicity, floods generally occur on an annual basis, and this is why Boserup could not fit recession into her scheme (Boserup 1965:17). Had she focused her attention on returns per unit of labor (instead of average returns per hectare) as defining levels of intensification, recession agriculture would have been seen to fit in nicely as an annual version of full fallowing, comparable in this respect to forest fallow. The flood recession case demonstrates that returns per unit of labor vary according to many factors other than the periodicity of cropping. The focus on periodicity of cropping, even though it is a useful first approximation, has done much to distract attention from the high returns to labor in flood recession agriculture.[3]

Flood Recession Tenure and Stratification

The recent Mauritanian land tenure legislation (Ordinance No. 83.127 of June 5, 1983, and Decree No. 84.009 of January 19, 1984) was intended to facilitate economic development in the Senegal River Valley (Fleming, Gannett, Corddry, and Carpenter 1980; OMVS 1985); this was the only viable agricultural area in Mauritania during the drought years after 1970.[4] This legislation dichotomized property rights into private holdings and collective holdings. The latter were defined as holdings in which all members of the collective had equal rights and duties. The legislation was written in the Ministry of Justice by jurists who had ethnic backgrounds in pastoralism. The proposed form of collective tenure fit nicely with the pastoral situation, in which hierarchy in wealth and power, although pronounced, shows up primarily in the numbers of livestock owned rather than in nominal access to land or obligations to maintain it (Bates 1972; Irons and Dyson-Hudson 1979; Bourgeot 1975, 1979).

The tragedy-of-the-commons scenario proposed by Hardin (1968; Hardin and Baden 1977) suggested that common property tended to degrade because the immediate cost of overuse to an individual was small (one individual causes only a minor amount of degradation), while the benefit to an individual for overexploitation was great. Hardin concluded that individual tenure was the best solution to such problems. This simple calculus of costs and benefits was based on neoclassical ideas of equal access and equal

rights. Research in Mauritania in 1984–86, and my realization that hierarchy was very pronounced among Saharan and Sahelian pastoralists, led me to a critical view of the legislation and of the more general conclusions implicit in Hardin's analysis of common property.[5]

Livestock management attempts to adapt Sahelian pastoralism to the modern world through various forms of privatization (i.e., fencing, boreholes, etc.) failed spectacularly (Nyerges 1982). The failures of the livestock management efforts were more dramatic than anything prior to the application of Hardin's ideas. This suggests that, if privatization in arid lands accelerated environmental destruction, the traditional hierarchical common tenure systems, by implication, might have provided better responses to risk.

Hierarchy prioritized access such that the pastoral economy could shed human population in an orderly way in times of stress, and add population of client or subservient status in times of prosperity (Barth 1973). Poor pastoralists sometimes had to leave the pastoral sector, but could in better times succeed in reentering it as clients of wealthier pastoralists. The start-up costs were high, so that those without adequate capital could begin with loans of livestock from those with abundant capital. The rights of access of new or returning pastoralists were in practice secondary to those higher in the socioeconomic hierarchy (Barth 1973; Krader 1978; Nelson 1973; Salzman 1980). The system worked precisely because there was hierarchy. Thus, hierarchy might well have been more characteristic of some common property systems than equality. Although common property theorists have cast numerous doubts on Hardin's thesis (McCay and Acheson 1987a, 1987b; Crowe 1977; Hunt 1986, 1990; Ostrom 1977, 1987; Runge 1984, 1986; Townsend and Wilson 1987), and even partially rejected his conclusions, the cases of pastoralism and recession cultivation suggest the need for a more radical critique.

For the sake of exposition, I focus on the Pulaar-speakers of the Middle Senegal River Valley, although the situation is broadly comparable throughout the valley. Among this ethnic group, extended families or minimal lineages *(liniol)* hold land in common property and reallocate land to their members on an annual basis. Landholding lineages crosscut, and are quite distinct from, residence units (villages). Lineages hold a portfolio of lands distributed in a variety of ecozones around the floodplain (Boutillier et al. 1962; Boutillier and Schmitz 1987; Lericollais and Diallo 1980; Minvielle 1977; Ngaido 1986; Park 1985, 1986, 1988a, 1988b; Schmitz 1986). Usually, a portfolio consists of several geographically separated units that are themselves part or the whole of well-defined topographic areas (referred to as *collade*, sing. = *collengal*).

Free access to these lands is limited to core lineage members, while more peripheral lineage members have inheritable rights but pay tithes as well; outsiders have access only through contractual arrangements with lineage members. Core members may also obtain access to additional lands in a lineage portfolio by making usually seasonal contractual arrangements with the core members having excess rights to viable land. In such cases a portion of the tithe paid for access will go to the core member contracting out the land, while another portion will go into lineage coffers managed by lineage administrators. The annual reallocation, based on communal consensus, takes place as the floodwaters recede and it becomes clear which lands are best suited for agriculture, given the year's flood pattern and the portfolio's current soil types. Sharp tenure distinctions are made between riverbank lands *(falo)*, higher, rarely flooded lands *(fonde)*, basic floodplain *(waalo)*, and lands *(jeeri)* on which only rainfed agriculture is possible. Within these general categories, important distinctions are also drawn based on soil type and length of inundation; because of their varying rates of absorption, different soil types are optimal depending on the duration of the flood.

In general, reallocation is more complex than the preceding paragraph suggests. Lineages hold land for reallocation to household heads according to inherited shares. Other lands may be redistributed by an official either to core households whose members are short of land or to noncore families in return for tithes paid into the lineage coffers. Such officials generally receive a portion of tithes collected as their own revenues. The

exact pattern of administration, the payment of tithes, and the amounts of lands available for lineage reallocation vary enormously along the Middle Senegal Valley. Harvests of lineage lands are done simultaneously in a given area by consensus to facilitate the opening of the harvested fields to grazing, even though this decision always somewhat hurts those whose lands were planted last.

Recession-based agricultural production in the Senegal River Valley varies both directly in relation to maximum flood levels (discussed above) and, also, in relation to the duration of the flood in particular parts of the valley. The latter depends on rains in the Guinea highlands (the headwaters of the Bafing-Faleme, a main branch of the Senegal) or in the watershed of the Sahel tributaries of the Senegal, located to the east, and on local rainfall. If properly inundated, the high clay soils support agriculture for a full growing season without more water. When the soil is under water too long, beneficial aerobic bacteria are killed off, or there is not enough time for crops to mature before the heat of summer. Too brief an inundation renders the land marginal, in varying degrees, depending on soil type and unpredictable subsequent climatic conditions. Local watersheds sometimes complement the Senegal's flood; if properly harvested, these local floods can prolong the period of inundation for high-lying lands that would be marginal if only flooded briefly by the Senegal itself. Sometimes local floods are redundant, in that they coincide with the main flood and so provide no significant improvement in the productivity of high-lying lands; this too is unpredictable. The Senegal River Valley, though fairly flat in its floodplain, displays a series of micro-variations in elevation such that floods of a given level may not cover all areas of lower elevation because of intervening higher lands. A slight increase in flood elevation may allow the flood to surpass some intervening areas and reach broad areas of lower elevation. In addition, the silt deposits of the flood regularly remake the micro-variations of the floodplain and redistribute the best soils. This multiplies the unpredictability of recession cultivation.

From an ecological perspective, reallocating land from common property on an annual basis is an adaptation to risk. An individual will, each year, receive a proportion of the common lands suitable for agriculture rather than run the risk of owning a specific parcel that is simply not suitable for cultivation in a given year. At the group level, reallocation also maintains the hierarchical status quo. Common ownership of a portfolio of lands distributed around the floodplain carries this process one step further by increasing the likelihood that the corporate group has suitable lands despite the unpredictable flood.

In the Senegal River Basin, stratification involves both ownership of land and a system of tithes and obligations. State systems using the lands of the Senegal River Valley are known from the middle of the 1st millennium A.D. (Ajayi and Crowder 1972; Levtzion 1973, 1978; Swanson 1978). Historically, in some periods elites and even pastoral groups controlled substantial areas put under cultivation by slaves. A movement against slavery (Shuur Bubbe) developed from 1644 to 1774, leading to an Islamic revolution in 1776. The current distributions of holdings to a significant degree date to this time. Complicated systems of tithes are still found throughout the Senegal River Valley (Boutillier et al. 1962; Ngaido 1986). Thus, elite classes receive tithes from lower strata, and lineage administrators, senior sublineage members, and landholders in general receive tithes from sharecroppers or other inferiors. In some areas the tithes stop locally, while in other areas part of the tithes are passed up to traditional political leaders of regional status.

The standard term for the tithe among Pulaar-speakers, *assakal,* is assimilated, in indigenous conceptions, to the Islamic obligation to provide for the poor *(zakat).* This obligation is a direct payment to the poor, by those who can afford it, of one-tenth of revenues. The payment of *assakal,* by contrast, is a payment from the bottom of the social hierarchy to the top. Though nominally a reversal of *zakat,* it involves an explicit obligation on the part of the recipient of the tithe to use those receipts to help the community in general and the poor in particular. In this sense, *assakal* is another form of security against risk. It institutionalizes the storage of a surplus against times of scarcity while simultaneously supporting elite classes.

This spectrum of land quality corresponds to a spectrum of tenure rights. Different categories of people have higher or lower priority rights accompanied by lower or higher obligations in tithes. In virtually all years, the common lands of a *liniol* would be cultivated by the following categories of people listed in order of decreasing priority: (a) descendants of the putative original settlers, (b) descendants of early but not original settlers, (c) descendants of people with special claims to high status other than priority on the land, (d) descendants of people who came at various subsequent periods, (e) descendants of people who had in living memory sedentarized or immigrated into the area (with varying levels of status), (f) descendants of free but servile groups and castes, (g) descendants of slaves, and (h) slaves. The primary basis for classification is the association between claims to descent from original settlers and high status that is common throughout Africa (Kopytoff 1987:52–61).

Virtually all of these groups have rights of some sort, and generally these are heritable. These rights vary from numerous shares in the common lands to sharecroppers' access to the lower-quality lands. Many people have claims in lands of other lineages as well. Thus, in a given year they try to activate their most propitious rights. Even a complete stranger can, in a good year, get easy access to lineage common property because in good years lands are in excess of the available labor because of the long-term riskiness of agriculture in the Senegal River Valley. (This is implicit in the large gap between the two curves of Figure 2, discussed below.) The same stranger can, if good years hold up long enough, become assimilated into the hierarchy and acquire heritable rights. This potential for assimilation is reflected in the current system of social stratification, which exhibits layers of social strata that to a degree reflect historical priority.

The rights held by these different groups are both clearly prioritized and equally legitimate. A family with inherited rights to cultivate subject to a tithe can, in turn, lease out lands to sharecroppers and even have, on some family lands, regular sharecroppers whose claims have solidified into inherited ones. To ask simplistically who owns what land is inappropriate, because tenure involves a bundle of rights and obligations rather than one simple right of ownership. In an annual reallocation, individuals get land in proportion to their inherited shares, in proportion to their inherited usufruct rights, and, in some measure, in proportion to their individual status in the corporate group. Some individuals have land to farm or rent within a single *collengal* from all three bases.

One of the basic claims of this paper is that common property in the flood recession case is intrinsically hierarchical and does not involve individuals having equal rights; imputation of the tragedy-of-the-commons scenario to this case would be a misapplication of 19th- and 20th-century economic liberalism. I would suggest that the role of common property is to add another level of stability to this system. Once hierarchy is introduced, justifications for stratification benefit from its institutionalization. The different interrelated spectrums of rights, land, obligations, and status add up to a sophisticated form of risk management integrally linked to common property and social stratification. Although the analysis has focused on Pulaar society in the Middle Senegal River Valley, the model is more generally applicable. All the historical societies and states of the Senegal River Valley have been stratified; the Wolof and Soninke states have also been either caste or slave-owning societies.

The flood recession form of common property, which includes rights of exclusion of outsiders and significant control over insiders, is based neither on equal rights or duties nor on simple divisions between those with rights and those without them.[6] It is a model of common property in which hierarchy and inequality are fundamental. Tenure involves a spectrum of rights ranging theoretically from those incorporated in the concept of ownership "in fee simple" all the way to usufruct rights for specific purposes and brief periods without automatic rights to renew, and accompanied by some form of payment.

The number of people with rights in a particular piece of common property responds to short- or long-term environmental and political risk through a system of prioritization or economic stratification. This form of common property is typically a form of risk man-

agement linked to economic stratification rather than a response by individuals to the short-term cost of privatization. It is not the cost of fencing, but the nonviability of a small holding that makes privatization prohibitive.

Although one could still cast this in terms of the individual cost of privatization, to do so would be misleading on several counts; in a hierarchical society all individuals are not equal and more particularly are not equally responsible for decision making (despite the frequency of consensus-type decision making for core lineage members). It is misleading to suggest that the decisions made are individual choices because this abstraction of the decisions from their social context underplays the most significant characteristics of stratification.

The portfolio of lands is reallocated annually, not on the basis of what plots were cultivated in past years by which members, but rather by lineage consensus as conditioned by hierarchy. Reallocation is thus based on current flood patterns and the proportional shares going to each family. Tithes and communal obligations go hand in hand and the room for individual strategizing activity is more than complemented by the social constraints imposed by hierarchical common tenure. These responses to risk are intrinsically political: the response at a group level to a chaotic weather system and a weather-dependent agricultural system. To focus attention on the individually perceived cost of privatization adds nothing to the explanation other than to suggest an origin for the system in some form of individual negotiation (Lukes 1974). Such reductionism is not persuasive, since differential returns and the advantages of collective portfolios would be present before population levels rose to the point that significant stratification became necessary. Although all responses can be reduced to individual behavior, the critical causality, in this case, is political and environmental rather than maximization at the individual level.

Chaotic Output and Chaos Theory

The study of weather systems, turbulence, and nonlinear (complex) dynamic systems has been revolutionized by the approaches developed in the new science of chaos. A key conclusion of chaos research is that nonlinear dynamic systems may exhibit such great sensitivity to initial conditions that deterministic predictability is impossible.[7]

While classical physics suggests that science is predictive, chaos research replaces that belief with a realization that arbitrarily small changes in many complex dynamic systems can, and normally do, lead to major qualitative changes (Gleick 1987; Schaffer 1986; Schaffer and Kot 1985). At the root of chaos theory is the idea of "strange attractors." Rather than having data centered around a mean and scattered stochastically around a normal or other simple distribution mean, a "strange attractor" is a range to which the data, of a particular complex dynamic system, is attracted. While all the data-points end up in the range, each succeeding datum may fall anywhere within the range.

While few social scientists believe in the fundamental long-term predictability of the world, there has clearly been a tendency to view unpredictability and stochastic processes in terms of a model of a *normal* distribution (or some alternative simple distribution) with a definable mean around which data are distributed. This distribution has then regularly been viewed as the appropriate basis for decision making. From this perspective, responses to environmental or economic risk are viewed much as insurance policies intended to deal with relatively infrequent problems (Cashdan 1990:3). When humans must respond to chaotic inputs to their productive system, risk management becomes more than conservative behavior based on an expected mean and expected infrequent deviations from that mean. The flood recession model is intended as a description of one such risk management response.

Weather systems are currently seen as chaotic or inherently unpredictable beyond the immediate short term (Faure, Faure, and Diop 1986; Lorenz 1963, 1964; Lamb and Peppler 1990; Pestiaux, Duplessy, and Berger 1987). If, for example, rainfall is quantified for a long period, something peculiar shows up. There is, of course, an average for the entire

period, but, if the span is divided into smaller units, the submeans do not cluster around the overall mean. There may be long periods of high rainfall followed by periods of very low rainfall. This chaotic quality may show up at any scale; at the level of days, years, decades, centuries, or millennia. This type of unpredictability is not particularly significant where virtually all levels of rainfall are enough for rainfed agriculture, but in recession agriculture (especially in arid lands) it is quite another matter (Noy-Meir 1973:31–33). While weather systems may exhibit a limited number of easily describable elements, including quasi-cycles, the period and amplitude of such quasi-cycles may be chaotic. It helps human buffering strategies only a little to know that terrestrial history has included a series of times when glaciers have waxed and waned. If the periodicity and amplitude of such changes is intrinsically unpredictable they are not adequately described as cyclical. The same can be said for recurring periods of high and low flood.

Terminology such as "metastable equilibrium with threshold switches" (Butzer 1980), that is, levels at which qualitative change occurs, needlessly complicates matters. Chaos theory would suggest that there may be no such switches. A change from decades or centuries of adequate rainfall to a regime of drought no longer requires a cause of comparable magnitude and scope; rather, it may be a result of inherently chaotic behavior by the relevant weather system based on arbitrarily small changes in input conditions at any level of rainfall.

The output of chaotic systems is not unpatterned, and some research focuses precisely on the patterns and uniformities in "chaotic" output. Nor is the causality in the system itself chaotic; some systems with chaotic output have a simple deterministic causality (weather, mathematical functions); others may involve normal human causality (chaotic stock-market prices). While there may be long-term coherence to the system, it is quite impossible to predict successive states from measurement of initial (or current) conditions. Knowing the range of the flood does not allow one to predict any given future flood level—other than that it can be expected to be within the range. This unpredictability implies, in general, that characteristics of given conditions (e.g., a mean or other statistic or datum) are not reliable bases for predicting particular future conditions—even if the basic structure of the system is well understood. The next section, which examines the chaotic characteristics of the Senegal River flood, provides the basis for an evaluation of the Nile case and the more general model.

The Pre-Manantali Senegal River Flood Pattern

The Senegal River case has general relevance both because recession agriculture is a current contender for one of the earliest forms of agriculture (Hopf 1983; Bar-Yosef 1986a, 1986b) and because the natural regime of the Senegal Valley is similar to that of the Nile (Butzer 1976:19). Nevertheless, the climatological data for the Senegal River from earlier centuries is sparse (Olivry and Chastanet 1986).

In the western Sahel, a number of earlier periods were clearly wetter overall than the 20th century. In particular, Nicholson (1980) suggests that during the late 19th century, and from the 16th to 17th centuries, climate was significantly moister in most of the Sahel. Figure 1 records the maximum flood at Bakel, a town on the eastern edge of the main floodplain. Recording began in 1903; in 1986 the Diama Dam went on-line, followed in 1987 by the Manantali Dam. Thus, the period 1903 to 1985 is the full period for which an undisturbed natural record is available. The flood is measured more accurately in terms of cubic meters per second than in terms of height. Figure 1 depicts a large range in flood levels; from a virtually dry maximum of 899 cubic meters per second to 9,340 cubic meters per second. This more than tenfold range reflects several periods of Sahelian drought: around 1913, 1944, and from 1968 to 1985. On this scale, adequate flood levels are actually in the upper two-thirds of the graph—in the 4,000-cubic-meter-and-above range—and only the highest levels (6,000 m^3 and above) come close to flooding the entire available floodplain.

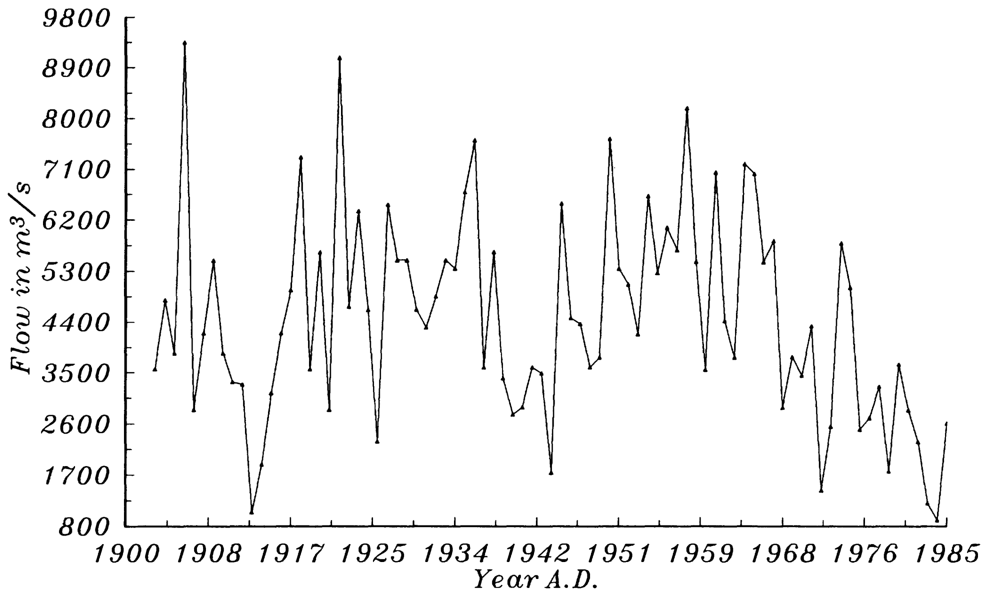

Figure 1
Annual maximum of Senegal River at Bakel, 1903–1985. (Source: OMVS 1985.)

From 1968 to 1985 the Sahel experienced drought conditions and, despite over 50% of the Senegal flood coming from the wet Fuuta Jalon highlands, the drought conditions have shown up clearly in the post-1968 flood conditions (Palutikof, Lough, and Farmer 1981). The river was dry much of the year and the floods inundated only a fraction of the floodplain in all except two years (1974 and 1975). Nevertheless, as the rest of Figure 1 indicates, these low levels also occurred, though for briefer periods, in the two earlier 20th-century droughts.

Figure 2 plots both area inundated and area cultivated against the quantity of the flood (in cubic meters per second). The few data available are enough to sketch out the general picture. The area inundated rises rapidly at first and then much more slowly. This has a simple volumetric explanation; the higher the flood rises in the valley, the greater area each additional quantity of water must cover—hence the leveling off of the curve. Area cultivated rises rapidly at flood levels above 1,500 and then rises slowly after about 3,500 m^3 per second. The total area inundated is greater than the area cultivated for at least the following reasons: (a) it includes land that is not adequately inundated or is otherwise of marginal quality, (b) the probability of high flood levels is so low that there is not normally adequate population present in the valley to take full advantage, (c) in the modern situation many people have emigrated out of the agricultural area, (d) some inundated areas are in long forest fallow, and (e) prevailing agricultural prices and free food aid discouraged production during much of the 20th century.

Although measuring the flood at Bakel in cubic meters per second is perhaps the best single measure for the flood, it is only a single statistic. The points for 1924 and 1964 in Figure 2 illustrate one problem with the measure: a fast-moving pulse without much water behind it (1964) may register a high maximum but may be absorbed by upper reaches of the river and not inundate as much land as a lesser pulse (1924) backed by more water.

In the better periods a typical range of variation would have been around 4,500 m^3 per second. Transposing this figure to the X-axis of Figure 2, it is clear that half that distance down from the average would bring one to around the 1,200 mark—at which point hardly

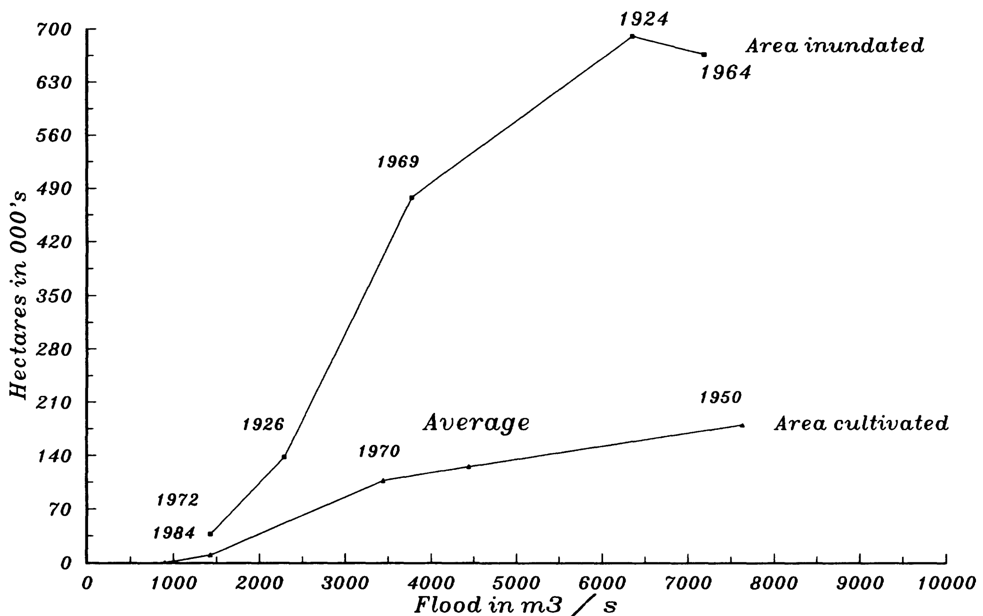

Figure 2
Area inundated and cultivated related to size of flood, Middle Senegal River Valley. (Sources: Fleming, Gannett, Corddry, and Carpenter 1980; Ba and Crousse 1988; Lericollais and Diallo 1980.)

any land is cultivated. This expectable range, then, spells the difference between miniscule floods and quite healthy ones, with both occurring frequently in the better periods of the 20th century. The 20th-century record gives no reason to conclude that the Senegal floods reflected a normal distribution about a mean, nor does the record suggest any other simple distribution. Rather, it suggests chaotic weather producing random floods within certain limits. The predictable elements include rough estimates of the range and little else.

In an attempt to analyze the data, Olivry (1983) concludes that the examination of the available time series does not permit one to attribute a periodicity to the cyclic variations nor to provide a physical explanation of the persistence of the drought. The complete inaccuracy of Faure and Gac's (1981) prediction of a 1985 end to the drought was due to the attribution of cycles to a phenomenon that might better be characterized as quasi-cyclical and intrinsically nonlinear (Palutikof, Lough, and Farmer 1981; Pestiaux, Duplessy, and Berger 1987). Climatologists working on the Sahel are making progress understanding the various components of Sahelian climate, but currently are in no position to do more than hope for future modest success in prediction, especially at the few-month level (Lamb and Peppler 1990).

Long-Term Flood Variability

Although we have flood records for the Senegal River only for the 20th century, we have long-term records for the Nile, which had, prior to the Aswan Dam, a very similar regime (Butzer 1976:19, 86). The records from the Nile flood have been admirably collected, analyzed, and reconciled by various specialists. I have relied primarily on Popper's data for the Nile from A.D. 641 to A.D. 1890 (Popper 1951) and for dynastic Egypt on Bell's synthesis (1970, 1971, 1975) of various years for which there are records.

Mandelbrot and Wallis have shown that Nile flood data exhibit chaotic behavior, in the mathematical sense, both in the short and long term (1968, 1969). Their work is based on Hurst's (1951, 1956) work, which showed the insuperable problems involved in designing an optimal dam for long-term Nile flows: optimal in the sense that it (a) would not overflow in periods of high floods, (b) could release a steady optimal flow, and (c) would be of minimum size to do (a) and (b). Mandelbrot and Wallis show that the difficulties are due to the intrinsically chaotic quality of the flood levels.

Although Mandelbrot and Wallis have made the case for the long-term chaotic nature of Nile floods, and one could extrapolate their conclusions to the Senegal floods, there are a number of reasons for closely examining records for both the Nile and the Senegal rivers. Data from both cases will support two claims: (a) that the variability was such as to have a major impact on production and the amount of optimal lands and (b) that the regular range of the flood covered a spectrum from floods inundating little if any land to floods inundating more land than could be cultivated by a long-term resident population without large-scale storage or trade in foodstuffs. This has significant implications for demographic dynamics and the development of early economic stratification. These claims seem justified for the 20th-century Senegal, but the model will be much stronger if they also hold for the known record of the Nile. Flood records are not available for all years, so I have chosen the periods with best available data for examination.

The Pre-Aswan Nile River

The Nile, as it appears in most dynastic records, is a reliable and regular source of water. Indeed, scholars have suggested that it is "a more regular source of water than any other of the world's great rivers where valleys are used for irrigation farming" (Baines and Málek 1980:14). This conception does not conflict with the idea of a chaotic flood distribution, for the latter has no intrinsic implications of frequent catastrophe: it simply implies a distribution randomly covering a range, rather than a normal distribution in which most floods hover around the mean. Nevertheless, the regularity of the Nile in dynastic times seems, from the data available and examined below, to have consisted primarily in that the Nile flooded regularly, not in that it flooded approximately the same amount each year, and secondarily in that truly catastrophic floods were relatively rare except at the beginning of the Early Dynastic period and in the Middle Kingdom period (Hassan 1985:95). With good storage facilities, low floods are less catastrophic than high floods, which destroy infrastructure.

At the scale of millennia, the range of Nile flood levels varied frequently but irregularly. There is general agreement that by the Middle Pleistocene the Nile had basically modern (pre-Aswan) hydrographic conditions (Brice 1978; Butzer and Hansen 1968; De Heinzelin and Paepe 1965; Grove 1980), though some would place this further back in time (Berry and Whiteman 1968). From the Middle Pleistocene, records of African lake levels suggest major changes in climate and Nile flood levels. From 18,000 B.C. on we find roughly the following changes: much drier from 18,000 B.C. to 10,000 B.C., then moister to 6000 B.C., then much drier for a millennium until 5000 B.C. (Talbot 1980). There were relatively moist conditions between 5000 B.C. and 3000 B.C. followed by more arid conditions approaching the modern climate. This was followed by a moister period from 1850 B.C. to 1200 B.C. (Butzer 1976:32).

This general picture was no doubt complemented by brief opposite trends and extreme examples, though we can currently document them only for the more recent millennia (Butzer 1978; Clark 1980). Floods were often particularly low (riverbed dry) between 2180 and 2130 B.C. as well as from 2000 to 1990 B.C., and extremely high from 1840 to 1770 B.C. (Bell 1970, 1971, 1975; Butzer 1976:29). There are indications of cultivated wheat in Egypt dating as early as 7000 B.C. (Germer 1985:210–214; Kemp 1989:14) and general agreement that wheat was cultivated in Egypt at least by 5000 B.C. (Wendorf, Schild, and Close 1984; Close 1987:9). Pastoralism may date to 7000 B.C. in the eastern

Sahara (Wendorf, Schild, and Close 1984). Early grain cultivating settlements, which date from 5000 B.C., are well established by 4000 B.C. (Stemler 1980:505). It is intriguing that sedentary population growth in the Nile seems to have begun very gradually around 5000 B.C. and then accelerated after 3000 B.C., when conditions apparently became more arid (Butzer 1976:85).

Using data from the Islamic period, we find that on average the Nile began to rise in Cairo around June 20, reached a maximum around August 15, and then began to recede, leaving the last of the inundated areas around October 15 (Popper 1951:191ff.). It is worth stressing that these dates are seasonal averages for the A.D. 641 to A.D. 1890 period; individual years and subsets of this period did not conform particularly closely to them. The annual maximum heights of the flood are the main data that have been preserved. Hassan has shown that high Nile floods in the historic period correlate well with both high rainfall in equatorial East Africa and with warmer climate in northern Europe (Hassan 1981; Hassan and Stucki 1987).

Over the course of centuries, silt deposition raised the bed of the Nile and the level of the surrounding agricultural land. This deposition occurred at different rates in different periods. Accurate data are available for the rise in the bed of the Nile during the Islamic period as well as for flood minima and maxima (Popper 1951:243, and various tables). For the pre-Islamic period, even flood maximum levels are not regularly available, though flood maximums for a fair number of individual years and a few reliable, if short, sequences of flood maximums are available.

A simple use of maximum flood levels is misleading because, even if measurements are comparable, the bed of the river rises over a sequence of centuries such that a given height of flood in one century may have quite different agricultural or climatological implications than the same height centuries later. One alternative is to use the amount of increase from low flood levels. This is not particularly desirable because the amount of increase also reflects how low the river fell in the low season; dry winters will make a subsequent flood appear higher. There is in fact no correlation between annual lows and annual highs (Popper 1951:214). The alternative I have chosen is to use the maximums adjusted by the amount of rise in the riverbed for each period for which data are available (Popper 1951:243). In the graphics for the Islamic period, the data for rise in the Nile bed, which are available broken into periods, have been spread out over the decades within each period.

Figure 3 plots the available early dynastic data, although it should be stressed that it represents only a fraction of the years in the period plotted (3050 B.C. to 2450 B.C.). Some scholars use a rough estimate of the sedimentation rate of 10 cm per century, but I have not modified the data in Figure 3 since this value is merely a guess.

The data from the first through the fifth dynasty (plotted sequentially but without exact dates in Figure 3), clearly show the more arid period following 3000 B.C. If the rise in the riverbed were known and were included it would only reveal the later periods to be even more arid. The zero level of the nilometer in use is unrecoverable, hence absolute levels cannot be compared with those in the other figures, but we may assume that the range recorded included the critical range for agriculture. In the early Islamic period (Figure 4), Arabic sources indicate that a 14-cubit flood would water only a fraction of the lands, a 15–16-cubit flood was an adequate flood, and a 17–18-cubit flood would inundate all the lands. Damage actually began at 18 cubits and a 20-cubit flood would cause severe damage. The cubit referred to was a 0.463-meter or 18.2-inch cubit (Popper 1951:79, 105).

Assuming similar topography in the Dynastic period, the range depicted in Figure 3 (roughly 160 inches or 4 meters) reflects fairly frequent extreme floods. If we take a 73-inch (1.85-meter) range as going from a very poor to a damagingly high flood, Figure 3 suggests that both extremes were reached in the early part of Dynasty I, but only the lower extreme would have been frequent in the latter part of Dynasty I and in Dynasties II through V. Although the data are extremely thin, the surviving fragments give se-

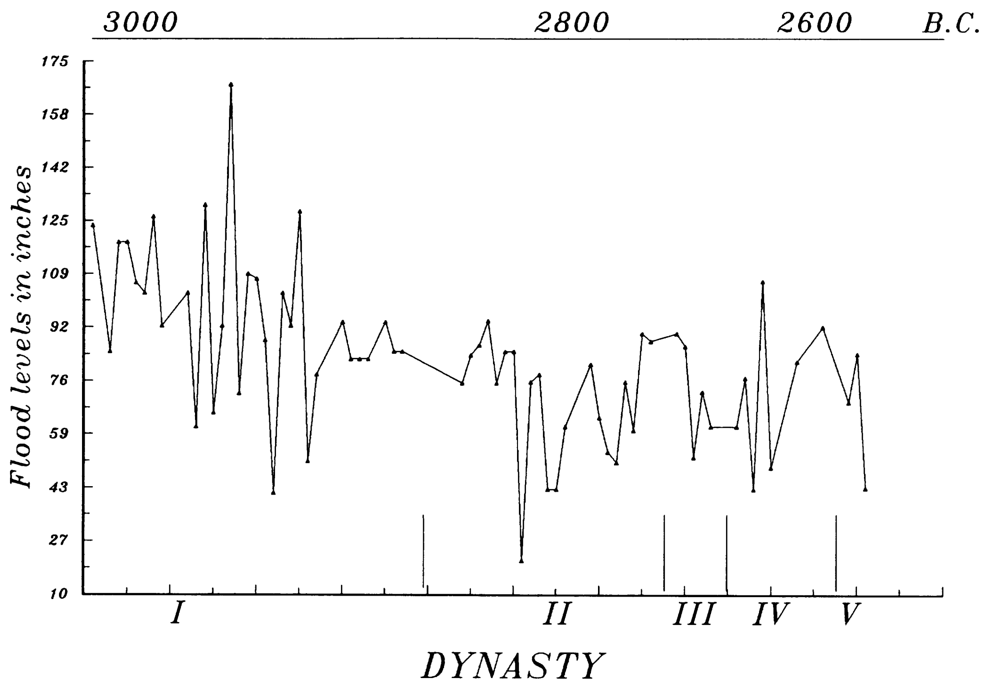

Figure 3
Early flood levels in Dynastic Egypt: 3050–2450. (Source: Bell 1990, personal communication, 1990.)

quences. The missing years are apparently due to failure of archeological preservation, not deliberate exclusion. This means we have no reason, a priori, to assume the missing data differ significantly from those that have been preserved. Further, those that have survived conform to what we know about general climatic conditions.

Figure 4 shows the decade averages from A.D. 650 to A.D. 1530. This is the Islamic period up to the Turkish conquest (A.D. 1522). Since these are decade averages they show a much narrower range of variation than the annual records of Figure 5. Nevertheless, a number of points are quite clear: (a) flood levels in one decade are of very little value in predicting flood levels in the following decade; (b) the amounts of land properly inundated no doubt varied dramatically from one decade to another, even with the substantial water-management infrastructure used in the Islamic period; (c) the decade averages do not conform nicely to the mean—they seem to alternate substantially above or below the mean far more than they hover around it.

The last point is quite significant because it reflects the chaotic behavior of the weather systems determining the flood levels. One might naively assume that, since the watershed of the Nile is immense, all fluctuations should nicely balance out and the flood levels should vary only slightly from year to year. This is not the case; even at the level of decade averages the chaotic fluctuations show up with great strength (Figure 4). The general regional climate during this period, moreover, was quite similar and showed no major changes (Butzer 1976:33).

Figure 5 depicts the annual variation for a subset of the years shown in Figure 4. As one would expect, the range of variation is far greater than that of the decade averages (about 100 inches versus 40 inches). Thus, behind the decade averages is an annual variation that covers both extremes of inundation. The decade of A.D. 1430 to 1439 is bracketed in Figure 5 for purposes of illustration because this is the peak decade showing up

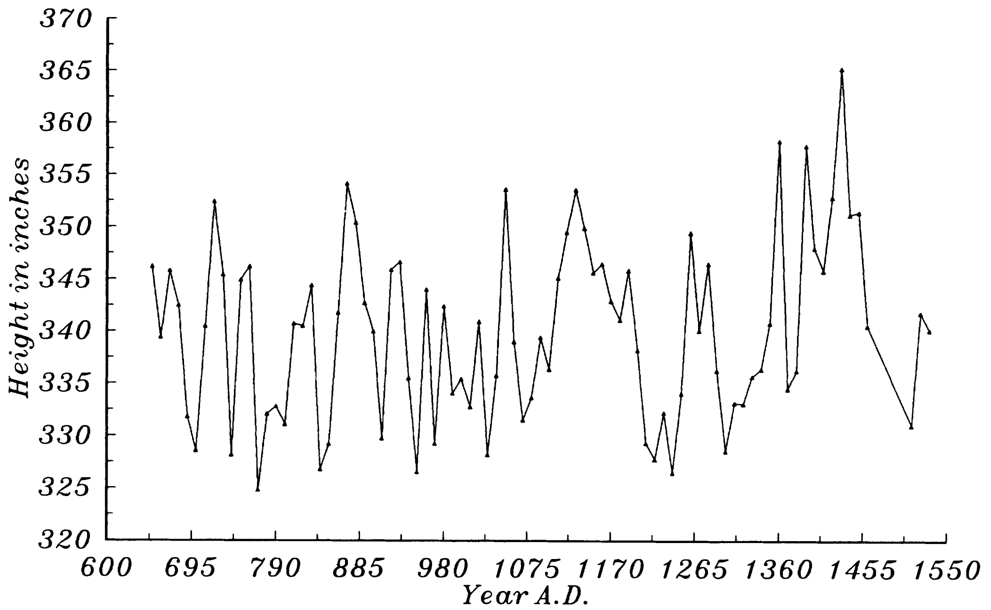

Figure 4
Nile flood by decade at Cairo: 650–1530. Average maximum minus rise due to sedimentation. (Source: Popper 1951.)

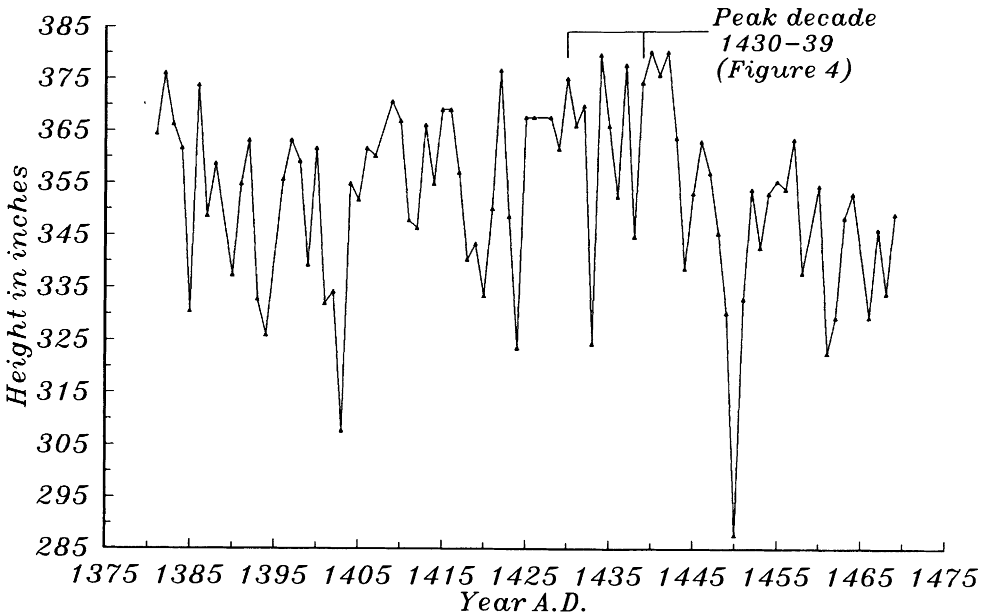

Figure 5
Annual Nile flood at Cairo: 1381–1469. Maximum minus rise due to sedimentation. (Source: Popper 1951.)

in Figure 4. Figure 5 indicates that even this excellent decade included floods differing as much as 50 inches in maximum height. Overall, Figure 5 suggests that a range of 55 inches was not unusual, while variations of 45 inches would have been normal. The point to stress is that a range of 45 inches implies major variations in cultivable area and, especially in the pre-infrastructure (dikes, canals, etc.) era, would imply both crucial differences in total area cultivable and a whole spectrum of lands varying in quality because of the length of time they were inundated.

The little we know about early land tenure in the Nile suggests that, in this respect, the Nile was also quite similar to the historical Senegal. Little is known in detail about general peasant-level tenure during the Dynastic periods, as the most detailed document, the Wilbour Papyrus (1142 B.C.), deals with less than 5% of the land in the regions it covers (Katary 1989:23). Though it is unlikely to cover significant amounts under normal peasant cultivation, it does show strong evidence that institutions had lands widely scattered around the valley and seems to make a distinction between riverbank land, used for cultivation of fruits, vegetables, and flax, and normal recession lands that were sown in grain (Katary 1989:245–247, 257–258). The Wilbour Papyrus also shows clearly that taxes were assessed on the basis of land quality, not just land area, and that the quality was closely tied to geographic location (Katary 1989:265). The last two points suggest that risk management and the explicit recognition of qualitative differences in flood lands were still important issues even for major landowning institutions in dynastic Egypt.

Even in Islamic times, in those areas where in earlier times distinctions had been made between land regularly inundated and land irregularly inundated (particularly important in Upper Egypt), land was owned collectively and reallocated at local levels after each flood (Popper 1951:76, citing Description de l'Egypt 1821–29:XI:488ff., XVII:195). After 1658, lands in Egypt were divided into three categories: (a) *kharājī* lands, which had two subdivisions, (i) *arḍ filāḥa* and (ii) *arḍ usiya;* (b) *rizq* or *waqf;* and (c) *itlāq* or *ṭalāq* ('Abd al-Rahim 1984:237). Subcategory (i) was the majority of the land in category (a), and the former was unquestionably the predominant part of the land overall. This dominant category was annually reallocated according to the flood and given to the peasants to cultivate ('Abd al-Rahim 1984:238). In historical Egypt, economic stratification was pronounced and the peasants were generally allocated only usufruct rights with tithes attached.

Although states in Egypt developed institutions to hold large portfolios of land, the ecological value of such portfolios would have been comparable to the less institutional lineage holdings found in the Senegal River Valley. The existence of village-level reallocation in Islamic Egypt, given its obvious ecological importance, suggests continuity rather than innovation. The following discussion develops a general flood recession model, and elaborates on some of its potential implications.

Discussion

The model outlined in this section is proposed as a contribution to the development of stratification in flood recession contexts and as a contribution to a hierarchical model of common property. I do not mean to suggest that hierarchy is as significant in all common property contexts as in the recession case. In some contexts it may not be particularly important, and hierarchical common property can arise for other reasons. Similarly, in some recession situations (Somalia's Jubba Valley, with its two rainy seasons, or the Zambezi, where recession is now not so critical, may be examples) neither common property nor economic stratification may be particularly significant (Scudder 1962; Cassanelli 1982).

A substantial number of the world's civilizations appear to have developed in riverine or flood recession contexts. Flood recession agriculture's potential for high returns per unit of labor may help to explain its presence at the dawn of agriculture. There is now evidence for early recession agriculture on alluvial fans along the margins of the Jordan Rift in the 9th millennium B.C. (Bar-Yosef 1986a, 1986b).

There are some readily available explanations for the difference in chronology between state formation in the Nile and the western Sahel. The relatively early chronology for the Nile owes something to proximity to the early Neolithic centers in Jordan and Southwest Asia, its greater capacity to support population, its access to the Mediterranean, and the early availability of suitable crops (soft wheats and barley), which do not grow well in the Sahel (Shaw 1981:627; Watson 1985:157). Significant state formation in the western Sahel dates from a few centuries before the Islamic era, though the major states (Ghana, Mali, Tekrur, and Songrai) were at their height between A.D. 800 and A.D. 1600. New varieties of high-yield and drought-resistant sorghum (S. Dhurra from India) and millet, which quickly came to dominate, seem to have arrived in the western Sahel a century or so before the Islamic period, circa A.D. 400–500 (Watson 1985:12). This would also fit the chronology for Bantu agricultural expansion in East Africa within a few centuries of the beginning of the Christian era. The economy of these western Sahelian states, at their height, seems to have been based on agriculture complemented by trade (Levtzion 1973:119), but Fage (1978:67) has suggested that interaction between pastoralists and farmers may have provided an initial stimulus to sociopolitical development.

The behavioral scenario suggested by the model is roughly as follows: Initially some people adopt flood recession agriculture for its high returns per unit of labor. When population rises to the point where locally available optimal lands are regularly in short supply, difficult annual decisions must be made. It is worth emphasizing that, because of the spectrum of arable lands, this will occur long before there is on average significant pressure on arable land per se. These difficult decisions may be resolved by giving priority to some people over others. In poor years there will not be enough viable land of any quality for all, while in somewhat better years the available land will only be sufficient if marginal lands (meaning lands that provide distinctly lower returns per unit of labor invested) are cultivated.

We might view the population engaged in flood recession as comparable to that engaged in pastoralism in historically later periods (Barth 1973). In times of stress, population from a stratified pastoral group is easily shed—the poorer segments become sedentary when their flocks are no longer viable. In better years those same segments may rejoin the pastoral sector as clients of wealthier pastoralists. Over time they may succeed in establishing themselves on their own. In the flood recession case the poorer segments would be sloughed off in extended periods of poor flood and would have to take up foraging activities (fishing, hunting, gathering) or (depending on the area and period) pastoralism until better times return. After an extended period of good times some of these segments of the regional population may fully reestablish themselves as full-time cultivators. In the meantime they may practice agriculture regularly, but primarily in better years. Even when established as full-time cultivators, they may for indefinite periods have to accept less optimal access rights (poorer land, less land, tax or corvée obligations).

This dynamic process, through which economic classes get established in flood recession, requires only that people be able to leave foraging or pastoralism when better returns to labor are available in flood recession agriculture and, similarly, that people can leave the agricultural sector for some form of foraging or pastoralism in poor agricultural periods. Within the flood recession sector, each annual variation in the availability of optimally inundated lands can potentially reinforce the developing system of prioritization.

The model thus adds the following new ideas to the debate on the origin of stratification:

a. The flood recession context itself is characterized by an annually recurring spectrum of land such that decisions about who gets which lands are always required.

b. Common property provides the possibility for a larger portfolio of lands as a risk management device.

c. The combination of (a) and (b) suggest that the common property may soon involve hierarchy as its basic building block—not equality.

d. The spectrum of annually available land, because it is the basis of the economy and corresponds to significant differences in expected returns to labor, provides an opportunity for economic stratification and, later, the potential for further development of stratification in general.

e. Chaos theory may contribute to anthropology, in that risk in a chaotic system is improperly understood in terms of a "normal" (or other unimodal) distribution. If flood levels occurred with a normal distribution, one might defensibly argue that the extreme values were of minor societal significance. If we took the range representing 99% of the values, the central one-third might contain 90% of the values. By contrast, with a chaotic distribution this central one-third of the range would include only one-third of the values. The remaining "extreme" values would make up two-thirds of the values. It would clearly be difficult to argue that such "extreme" values were likely to be insignificant from a societal perspective.

f. If weather systems produce a chaotic pattern of floods, it is significantly more difficult to make fully adequate long-term provisions for storage than with a "normally" distributed pattern of floods. The chaotic quality of the flood and its regular range reinforce early prioritization or stratification in recession lands as well as the value of links to alternative means of production (foraging, pastoralism, or rainfed agriculture) for absorbing or providing population. The flood recession model supports current revisions to ecological theory (Worster 1990) that replace the model of harmonious and balanced ecosystems with one of continuously changing adaptations to a more chaotic environment. The next step may be to modify the vision of ancient Egypt as developing in a harmonious and balanced relationship with the Nile; this may go some way toward explaining ancient Egyptian concern with the duality of order and chaos (Kemp 1989).

The managerial and the internal conflict models common in the archeological literature (Haas 1982; Parsons 1974; Rathje 1971; Renfrew 1972; Service 1975; Webster 1975, 1977; Yoffee 1979) complement the model proposed here because they explain later forms of stratification as well as other factors contributing to stratification. The incipient class stratification I have associated with early flood recession precedes any regional organization. Only when annual variations of crucial local significance have been adequately dealt with can the polity begin to organize at a greater regional level; yet, by this time, I would argue, it would already be stratified. Agricultural technology and irrigation techniques, from water spreading to construction of major irrigation and storage infrastructure, must also be included in any full discussion of early riverine agriculture. The potential linkages between the flood recession model and other models for the development of stratification also need to be examined. The model is intended to explain no more than why societies developing in a flood recession context might be predisposed to further development of economic stratification in the direction of state formation. The latter most clearly has its own dynamic.

In the flood recession case there seems to be a relationship between Steward's culture core and the ecosystem (Steward 1955). Kopytoff (1987) makes a persuasive case that a number of the elements of this model (population exchanges between core and frontier areas and the role of priority in settlement) reflect more general African cultural dynamics. The specifically African and the specifically flood-recession-related elements cannot yet be adequately distinguished.

The flood recession model suggests a dialectical form of causality. It is the relation between the initial social relations of production and the economic base that gives rise over time to transformations in the social relations of production—the development of a significant degree of class stratification. Gradually, these transformations may facilitate transformations in the economic base in the direction of more intensive production systems. The collective responses are complemented by individual strategizing within the parameters established by the hierarchical common property system. The model is, in a sense, a political and ecological model placing individual risk management strategies within the context of a collective, and critically significant, response to chaotic flood lev-

els. The collective response is a political response because it does not primarily involve optimizing production but does involve resolving conflict. Rather than deriving the origin of stratification from individual competition (cf. Kemp 1989:32), the model suggests that stratification develops out of economic differentiation imposed by a chaotic recession context and takes a political form as it is institutionalized and legitimated. Other factors that may contribute to the development of stratification do not so specifically affect arid riverine contexts, though they clearly need to be included in any full discussion.

Notes

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[1]Hanks converted inputs and outputs to rice. The wet rice in question must be broadcast before the flood and harvested after the water recedes. In this it differs from sorghum and most crops, which do not grow in water and are planted when the water recedes, but in my view this is no reason to decide a different form of agriculture is involved. Hanks is very clear that the system is based on natural flooding, without reliance on irrigation infrastructure (Hanks 1972:37, 97), and this implies that the key elements of flood recession agriculture, natural provision of water and fertilizer, are present.

[2]A Food and Agriculture Organization table (FAO 1972:5) gives the caloric (kcal) content of whole grains: barley (3,270/kg), millet (3,320–3,410/kg), rice (3,410/kg), sorghum (3,420/kg), and wheat (3,320/kg). The estimate of three hours medium labor per day comes from colleagues (T. Frankenberger and M. Lynham, personal communication, 1990) in the Office of Arid Lands Studies, who have just completed a five-year (1986–90) study of flood recession sorghum and millet production in the Senegal River Basin, and from a Mauritanian doctoral student in anthropology (Mamadou Baro, personal communication, 1990) currently studying flood recession agriculture, who has calculated an average of 2.5 hours. Horowitz and Salem-Murdock (1991) provide a figure of 46 person-days per hectare, which works out, using a reasonable six-hour workday and a 100-day season, to 2.76 hours per day.

The figure of 150 calories expended above basal metabolism per hour is a deliberately conservative estimate derived from Rappaport (1984:appendix 5), who suggests 141 calories per hour for medium heavy labor, clearing underbrush and planting on steep slopes in New Guinea; this labor is heavier than could be the average in flood recession agriculture on the comparatively bare and level Senegal River floodplain. In Senegal River flood recession agriculture, only the initial, immediately post-recession, weeding and planting involve heavy labor; most of the year labor would have to be classified as light and nonstrenuous.

[3]Carneiro's (1970) model for the development of the state out of population pressure in circumscribed areas attributes a much greater causal role to population pressure than that required by the flood recession model. Carneiro's argument that population pressure in a circumscribed region (Carneiro 1970; Coe and Diehl 1980) can lead to stratification is based on Boserup (1965) but requires sufficiently high population densities to of themselves lead to stress and conflict. This has been a source of criticism, since it can be shown that stratification seems to precede population pressure in many cases examined (Brumfiel 1976; Butzer 1976; Hoffman 1982; Hoffman, Hamroush, and Allen 1986; Wenke 1989). Further, unlike Boserup's use of changes in the returns per unit of labor, Carneiro's model does not provide a clear reason or mechanism why initial stratification should develop in some areas of circumscribed high population pressure but not in others.

[4]Unfortunately, the legislation was in part responsible for the recent crisis in Mauritania, involving the dislocation of about 400,000 people and a great deal of violence (Park, Baro, and Ngaido 1990).

[5]I directed and conducted research from 1984 to 1986, under the auspices of the Land Tenure Center, University of Wisconsin, that was primarily intended to examine the relationship between land tenure and development in flood recession and irrigated agriculture in the Senegal River Basin. Three Mauritanian researchers (Tidiane Ngaido, Ely Salem, and Mohamed Lemine), one other American researcher (Glenn Rogers), and a number of Mauritanian assistants participated in components of the research.

[6]My edited volume, *Risk and Tenure in Arid Lands* (Park 1992) deals at length with the issue of common property in the Middle Senegal River Basin.

[7]A typical example would be the Verhulst population growth model used in ecological modeling, in which r is the rate of growth and X is the population level at points n and $n + 1$ in time:

$$X_{n+1} = f(X_n) = (1 + r)X_n - rX_n^2$$

The model reaches a stable population if the growth rates are small. Yet, if one sets the rate of growth (r) at 2.3 and initial population at 0.1 (implying one-tenth of the sustainable level), a few iterations will quickly reach a level where the population will oscillate between two levels; if r is set at 2.5 it will oscillate between 4 levels. As r is increased, this periodic doubling comes after increasingly small periods, until at 2.57 the process stops its periodic doubling and vacillates chaotically among an infinite number of values (within a well-defined range) without stabilizing. Minute changes in r thus determine qualitative changes in the range—from single-value ranges to multiple- and infinite-value ranges. In 1976 Feigenbaum showed that, for a multitude of functions in one variable, the ratio between the length of one period and the length of the next is 4.669201 . . .—a new constant in physics (Feigenbaum 1978). Despite entirely different functions (causality), each arrived at chaotic output along the same route.

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