CHAPTER 15

DISCUSSION & CONCLUSIONS

The results of our simulations as laid out in Chapters 11-14 indicate that a wide range of factors played into the development of settlement in the Ancient Near East. These factors cannot be described as controlling variables, but rather as influences on the trajectories of development, sometimes acting in unison and sometimes in opposition. These factors include climate, soils, disease, conflict, labor availability, exchange and kin networks, transport systems, land management, availability of plow teams, perceptions of risk, swarms of locusts, and many others. One of the great values of agent-based models is that they enable the modeler to see, at least at the general level, how these factors interact with each other to produce outcomes that are not always obvious. However, the more generalizing models illustrated in Chapter 14 also play a role in understanding large scale processes such as urbanization; therefore, in this concluding chapter we discuss both classes of model.

THE NATURE OF THE MODELS

In his introduction to the volume *Complex Systems and Archaeology,* Alex Bentley compares agent-based models to 'generalizing mathematical models' to conclude that ABM is a 'more natural way to describe a social system because it replicates the actions of agents' (Bentley 2003: 21). Here we have taken the opportunity to illustrate both classes of models, with Chapters 11 and 12 presenting the key results of the ENKIMDU agent-based approach and Chapter 14 showcasing more generalizing mathematical approaches. Chapter 13 employs both generalizing mathematical models as well as ABM methods, so that decisions made by farmers (acting as agents) are taken from an agent-based method in which stochastic and process modeling are applied to allow for variations in soil salinity.

In reality, however, the modeling frameworks employed in Chapters 11, 12, and 13 are all hybrid because they incorporate both generalizing mathematical models and ABM methods. For example, as discussed in Chapter 10, certain domain behaviors are represented by means of well-established models that include weather and climate, hydrology, vegetation and soil models, such as those of the U.S. Department of Agriculture's Soil and Water Assessment Tool (SWAT) model (Arnold *et al.* 1998).

The models can also be classified according to their complexity. At a meeting on the uses of models held in Durham in 2007, the economist Paul Ormerod pointed out that one could broadly categorize the wide range of models in operation into 'high- and low-dimensional' models. The former were based upon ABM[1] and included a large number of inputs, whereas 'low-dimensional models' tended to be streamlined into a relatively small number of fundamental variables. In the high-dimensional models it was often, though not always, difficult to determine how a variation in any one input variable resulted in a change in any specific output. In contrast, when using low-dimensional models, establishing a relationship between the cause and effect from inputs and outputs was relatively straightforward because of the small number of variables. Although some modelers therefore favor the low-dimensional models because of the ease of relating inputs to outputs, the high dimension models (such as ENKIMDU) have the advantage of sensitively and realistically capturing a wide range of human behaviors.

In the present volume it is evident that the models which incorporate more generalizing approaches or a lower number of variables also exhibit more straightforward relationships. This is evident from the lower scatters of data points (see, for example, the scatter of points for the salinization models in Chapter 13). In contrast, the

[1] Of course, not all agent-based models incorporate large numbers of inputs; nevertheless, this is frequently the case.

outputs from the ENKIMDU simulations tend to be 'noisy', with a wide scatter of data points (see, for example, those illustrated in Chapter 11 relating to localized exchange systems). Such 'noisy' relationships are probably more representative of real-world behaviors, and we are probably deluding ourselves if we always expect to see distinct correlations between variables. It is therefore probably more realistic to suggest that human societies occupy a 'low-correlation world', in which both human behaviors and random factors, including factors that are more difficult to capture, operate to create a very wide range of outcomes. Therefore, if more variables were added, for example, to the salinization models, would we witness an increasing scatter in the data points as the number of variables is increased?

However, despite their complexity and the potentially ‘noisy’ appearance of some of the output, the agent-based models do present interpretable results, as presented below.
The conundrum facing the modeler is well illustrated by the comments of Michael Batty *et al.* (2012: 4) who argue that:

> '....ABMs break the basic rule of science that theory must be parsimonious – as simple as possible – and that a theory or model is better than any other if it performs equally well but is simpler; this is Occam's razor. In fact the argument for ABMs is quite the opposite. For many systems, we have plausible but non-testable hypotheses about how we think the system works, and if we exclude these simply because we cannot test them against data, then we are guilty of distorting our theory simply due to the expediency of not being able to test using classical means: against independent data. This is of enormous significance for it throws into doubt the whole process of developing and testing models of geographical systems, indeed of testing and validating or falsifying any theory.'

In addition to the ABMs and generalizing mathematical models, the MASS project also incorporated a number of qualitative models, namely imaginary representations of physical or cultural systems, which were expressed in symbols other than mathematics or computer language. It is useful to contrast the 'static' model derived from the Beydar data (Chapter 4) with the more dynamic model behaviors supplied via ENKIMDU: whereas the Beydar model provides a view of the state of the agricultural hinterland of Beydar at one point in time, probably its maximum extent, the agent-based approach allows one to assess how the local community may have got to that state. For example, a dynamic aspect of ABM is illustrated by the maps generated by Jeoviewer: these illustrate the spatial heterogeneity of the model outputs and how different agricultural activities can be going on in different locations at the same time, something that is difficult to capture using conventional methods of landscape analysis. Although the degree of agreement in the Beydar model resulting from the landscape and text based approaches (Chapter 4) is encouraging, it must be appreciated that the estimates of cultivated area derived from the landscape approach are generalizations that can only relate to a very broad period of time within the mid-third millennium BC. By way of contrast, the qualitative model developed for southern Mesopotamia is rather different because it allows for a dynamic range of behaviors, some of which are captured by the models illustrated in Chapters 13 and 14, and all of which sketch how cities in southern Mesopotamia may develop and grow. This 'baggy trousers' model (discussed below) therefore provides the potential framework for a future range of simulations.

Although it might be easy to dismiss the qualitative models as simplistic and worthy of that ultimate insult, 'functionalist', we point out that some of the seemingly arbitrary decisions that are made suggest that the agents are operating a degree of choice – they do not behave as automatons (e.g. Billy373 in Chapter 11).

ENVIRONMENTAL FACTORS

Because climate data can be quantified and arranged into fine-grained chronological sequences, there has been a tendency for scholars to focus on relationships between, for example, climate and society, rather than say locust swarms or plagues, which are difficult to quantify. Furthermore, it is more difficult to quantify the behaviors of the human populations themselves, and hence there is a tendency to see precisely dated palaeo-environmental proxy records being compared with much less well-dated (and quantified) cultural records (Bell 2012: 44). In opposition to those who see climate change as a 'driver' of social-demographic change are those who argue that a distinct pattern of climatic determinism is emerging (see the debates regarding abrupt climatic change and societal collapse (Weiss *et al.* 1993; Zettler 2003; McMahon 2012)). Although the members of the MASS team recognize the importance of the environment in everyday human and institutional lives we do question whether, for example, it is a 'driver' of societal development. For example, although a case can be made for associating dry periods with declines in agricultural (and pastoral production), the simulations demonstrate that when stresses are imposed on a community a large number of factors spring into action to mitigate some of the adverse effects.[2] Not only are there many more factors than rainfall which affect crop and pastoral productivity (Widell 2007); some factors alone can have an effect that is equal in magnitude to any known climatic stress. For example sharing of plow teams (as discussed in Chapter 11) can result in a total breakdown of settlement cohesion to such a point that the simulated communities can experience a significant decline in population (Chapter 11).

This does not mean that climate is not important. It is clearly a major factor in the agricultural productivity and health of ancient communities. Nevertheless, it should be seen as just one variable out of several. In the case of plow teams, a decline in rainfall can decrease the availability of fodder for the draft animals, which makes them more expensive to maintain. Consequently many households will find it more expedient to share plow teams rather than own draft animals, with the result that there will be an increase in the number of households sharing any one team. This would then result in problems of coordination of plow teams so that, ultimately, the tipping point illustrated in Chapter 11 will be reached. In this case, although climate may have created the need for more plow animals to be shared, it is likely that other factors (such as lack of breeding stock, the demands of tribute payments, marriage patterns, or general poverty) could also account for the tendency of households to increasing their sharing of plow teams.

In Chapter 11 we presented the results of a five-year drought on the model community. Not only did this result in the extension of the total field area to so that lower yields could be compensated for by a greater area; perhaps more significantly in terms of human behavior, we saw a growth in the number of exchanges of, for example, sheep and goats for badly needed grain. This scenario illustrates how an environmental impact may translate into an economic impact and be mediated and perhaps absorbed via the social networks. In other words, the climate does have a significant impact, but its effect is absorbed and dispersed through the social fabric; although, in some cases it is also amplified. Therefore in specific instances some households will become enriched at the expense of others. Consequently the climatic event will have an impact, but a non-linear one.

There is a tendency for environmental debates to polarize around certain questions, such as: is the climate a major influence upon economic activity, *or* do humans diminish the capacity of the soils, resulting in their erosion or a loss of productive capacity? However, it is also necessary to ask: what happens when both factors act together so that long-term nutrient loss occurs at the same time as a phase of climatic drying?

In the case of Upper Mesopotamia, Altaweel's modeling of the impacts of nutrient loss in the Assur region of northern Iraq demonstrated that the decline in barley production was in the range of 37-38% over a century-long simulation (Altaweel 2008: 826-27). This compares with a roughly 52% decline in the Soreq Cave proxy climate record (Bar-Matthews & Ayalon 2011). Although the climate curve shows a significantly higher decline than that of the crop yields around Assur, it is important to appreciate that if the two factors (soil depletion and climate) are combined the effects could be considerable. Moreover, the nutrient decline represents a long-term change, unless actions are taken to mitigate it. On the other hand, if climate change and nutrient decline act in opposition (say a dry phase when soils are more productive, or a wet phase when soil quality is diminished) the effects will tend to counteract each other, although a decline (or increase) in productivity may still be experienced. If such complexities are combined with other factors (such as exchange relationships, presence or otherwise of sufficient labor or draft animals) then it is clear that the relationship between climate and the

[2] Here we note the large and increasing literature on resilience, which examines the role of social connectivity and social mitigation strategies on communities under stress. See essays in Norberg & Cumming (2008); Fisher, Brett Hill & Feinman (2009), Gunderson & Holling (2002); Costanza, Graumlich & Steffen (2011)..

community's well-being will not be linear. Hence the overall number of households and population of a small community may not experience much of a decline even during a persistent dry phase. Moreover, because social and public institutions and storage were in place such adverse effects might be expected to be mitigated. Here, Postgate's reference to the role of the temple as a 'wealthy neighbour' is significant. For example, the temple could supply interest-free loans to individuals in times of duress, thereby illustrating how stress could be absorbed by communities (Postgate 1994: 135-36). Such factors, taken together with evidence that some famines resulted from political circumstances, siege or war (Postgate 1994: 194) means that food shortages were, as they are today, a result of a complex mix of environmental, economic and political factors, complicated further by a range of social behaviors and technologies.

One aspect of climate-change that the MASS group did not model was high-amplitude rare events, such as periods of extreme drought or extreme rainfall and associated flooding. Increasingly such events are regarded as of significance both in terms of landscape change and the sustainability of human communities (Bell 2012: 46), and because these can readily lend themselves to computer simulations they are well worth tackling in future modeling exercises.

SOCIAL FACTORS

Exchange mechanisms

The importance of loans and mechanisms of local exchange (grain and wheat, as well as an extended range of products in the case of the nomad-sedentary models of Chapter 12) is evident in Chapter 11. This is also a key factor in the Village Ecodynamics Project (VEP) models established by Tim Kohler and colleagues (see Kobti 2012).

In every case the imposition of a shock results in increased levels of exchange between the households, such as different types of loans and gifts. It is essential to point out that this may also result, in part, from how the models have been set up to specifically include exchange mechanisms. As a result, when a stress is imposed, changes in exchange provide an obvious mechanism of stress release. Here though, agents do also have choice and in this case choice driven by preferences with specific types of exchange that are dynamic or variable within the modeled system.

Although the role of markets and market exchange in the ancient Near East is disputed because of the lack of clear evidence in texts (Postgate 1994: 79) the MASS simulations imply that the stresses imposed on these smaller scale communities (and some of medium-large scale as well) are likely to have found a release through local patterns of exchange, which, when scaled up or formalized, could manifest themselves as markets (Widell 2005). If theory is a way of sketching possibilities, then the models imply that there existed a very real (albeit textually invisible) probability of the existence of markets in the fifth, fourth and third millennia BC. Hence the huge site complex to the south of Hamoukar (Khirbet al-Fukar: al-Quntar *et al.* 2012), being situated at a nodal point where WNW-ESE routes cross a topographically guided route from the obsidian sources of eastern Anatolia, may well have operated as some form of exchange complex for obsidian (Khalidi *et al*. 2009; al-Quntar *et al.* 2012). Similarly for the lapis lazuli trade, Klengel (1992: 26) has argued that the emergence of long-distance trade routes, entailed the integration into an inter-regional exchange system that enabled some Syrian centres to flourish and accelerate their development from small settlements into urban centres, protected by fortification walls, administrated centrally and with a market inside the wall.[3] Although the presence of such nodes of exchange may simply be explained as a result of their fortuitous location within a network, it is necessary to speculate that small-scale social networks may have played a significant role in their development.

It is important to emphasize that the role of the local exchange systems goes beyond that of economic exchange; such patterns of reciprocity and advantage also manifest themselves in terms of social obligations, status and

[3] This echoes the arguments of a number of other near eastern scholars (e.g. Algaze 1999). The resultant urban centers described by Klengel are the 'citadel cities' discussed in Chapter 3.

power (Hodder 1987: 106; Adams 2001: 350). Therefore if increased exchange activity was initially precipitated by adverse climatic conditions then the impact of this climatic event will be even more far reaching in terms of the social standing and power relationships within a community (see also Chapter 12). However, these impacts will not be one-way because the power and status of individual households will also put them in an advantageous position during times of climatic stress.

Processes of exchange at the household level also form a key part of the Village Ecodynamics Project (VEP: Kohler & Varien 2012):

'A key hypothesis by Timothy Kohler and Carla Van West (1996) argues that Pueblo I villages in the northern [American] Southwest in particular are organizations that formed in order to make their exchanges efficient. Trading efficiency naturally leads to a better quality of life for village inhabitants, and from the perspective of the model it enables an underlying social support system essential for survival.' Kobti 2012: 165.

In the case of the VEP simulations there appears to have been a tendency for certain exchange partners to be preferred because previous exchanges were successful. In a similar way, Paulette and Altaweel's pastoral-sedentary model in Chapter 12 sees the development through time of certain households as preferred partners or even exchange 'hubs'. Just as the MASS simulations suggest that the inclusion of local exchange networks bestows a certain resilience on the communities during times of stress, this also was the case of the VEP models (Kobti 2012: 171). Conversely, if the number of kinship connections diminished through time, then even minor crises could result in the migration of individuals or agents (out of the model) (Christiansen & Altaweel 2005: 24).

In the case of MASS simulations, although those households with the strongest and most extensive social networks did grow at the expense of others, our models have not proceeded sufficiently to demonstrate whether such exchange hubs developed to produce the most successful settlements and ultimately settlement hierarchies.

Here it is important to acknowledge the complexity of possible pathways within ancient households and their social networks. For example, patrimonial households, with their large number of relatives within the community, would likely benefit from a large exchange network at times of stress. Moreover, such consanguineous marriages also provide economic and social advantages because they result in the retention of wealth within the family (Bates & Rassam 2001: 213-215). However, such practices might also be expected to lead to adverse effects because of the inheritance of certain genetic diseases (Bittles *et al.* 1991). Consequently, within ancient communities such as those being modeled, there would have been a tension between these various factors, which would play out in numerous ways. Although undoubtedly these can be modeled, complexities of dealing with stress take us a long way from the straightforward models of climatic stress bringing on social collapse.[4]

Development of Social Inequality

The anthropological, historical and archaeological dimensions of social inequality can be regarded as one of the 'grand challenges' of the modern world and the topic has received considerable attention from archaeologists in recent years (Flannery & Marcus 2012; Smith 2012). Even within the relatively short time spans of the simulations (60 - 100 years) we are seeing the early stages of the development of significant differentiation of household wealth between households (see Chapter 11). Rich-get-richer effects (also known as the Matthew Effect: Adams 2001: 354), are clearly visible in the sedentary-pastoral simulations where certain favored households show evidence that they benefitted from increased wealth at the expense of others. However, the simulations have not extended for sufficient duration for structural change to be evident; nevertheless, social inequality may represent the logical next step in these scenarios.

[4] The discussion of marriage patterns and their effects is a vast topic and beyond the remit of this chapter. But questions to be asked in future include: what is the effect on the model community when a man (agent) takes on several wives thereby enlarging the social network, or alternatively, marries outside the lineage and therefore enlarges the social network further?

As noted above, the Sedentary-Nomad simulation (Chapter 12), indicates that certain families in the sedentary community started to function as economic (and social?) hubs by dominating the local exchange systems. Moreover, the generalizing models of Chapter 14 demonstrate these processes at a regional level. Outcomes include a differential flow of goods which result in some areas prospering while others do not (e.g., Fujita & Krugman 1995). Therefore even though the model framework is very different from the agent-based models discussed in Chapters 11 and 12, and the role of agency and bottom up process is minimal, the mathematics is capable of capturing some of the positive feedbacks that may have prevailed in the development of ancient urbanization.

Whereas models of the sedentary community do not always demonstrate the differential accumulation of possessions such as livestock and grain, such differential accumulation was more evident where sedentary-nomadic interactions were in operation (Chapter 12). For example, in the baseline scenario (in which there were no interactions with nomadic communities), although one of the sedentary households did control some fifteen per cent of the total textiles, no household was in a position to control ownership of any other commodities. In other words, the variation of wealth in these households was limited (Chapter 12).

On the other hand, when nomads entered the mix and interactions were allowed between both sedentary and nomadic groups there was a significant shift so that there were concentrations of wealth in the villages. This resulted in a much more limited range of households owning the livestock, textiles, and silver, as was the case when the nomadic groups arrived in either the spring or the early summer (Chapter 12).

The accumulation of wealth in the form of livestock or commodities was quite evident in the sedentary villages (early summer arrival of nomads) where one household (Household #29), owned 17% of the silver, 10% of the textiles, and 44% of the livestock in the settlement. This acutely uneven distribution of resources was even more extreme in the case of the spring arrival of nomads, when for Year 100, Household 66 owned 68% of the textiles, 56% of the livestock, and 22% of the silver in the village (Chapter 12, fig. 12). This suggests that not only might wealth differentiation occur quickly under appropriate circumstances, but that some fortunate families can amass very large holdings of sheep and goat which might then exceed the capacity of the village pastures to provide sufficient feed. At such times, it would be likely that steps would be taken for those families with abundant sheep and goats to make arrangements for them to be pastured elsewhere. Such large accumulations of sheep are known to have occurred in the state of Ebla around the middle of the third millennium BC, as well as in many other parts of southern Mesopotamia, and these flocks are thought to have contributed to the growth of the textile 'industry' of the period (McCorriston 1997; Wilkinson *et al.* 2012).

Moreover, 'exchange hubs' appear also to have emerged within the communities. In such cases, nomad agents show evidence of learning, so that by the end of the simulation their exchanges had become restricted to fewer sedentary and nomadic households: specifically, the more affluent ones who had resources to exchange. This emergence of exchange hubs might ultimately lead to the development of institutions or settlements whose economies were structured much more towards economic activities than traditional settlements.

The Role of Labor

The significance of labor in the rural economy of northern (Upper) Mesopotamia has been emphasized by Liverani (1994: 508), because without sufficient labor the land in Mesopotamia could not be cultivated.[5] According to Liverani:

> 'Now, in ancient periods land is generally an overabundant resource, labor and seed being the scarce resources which are carefully evaluated and recorded in the administrative archives of the early states. For example, the Late Assyrian "Harran census" (Fales 1973) provides a picture of the western Jazira in which only part of the available land is actually cultivated and the cultivated percentage seems to

[5] For more on the significance of access to land, see biennial fallow regimes in Chapter 11.

> decrease in proceeding from towns and rivers to the open countryside.' (Liverani 1994: 508 in Wilkinson 1994)

The catastrophic effect of the withdrawal of labor should therefore be seen in this light; in the corvée scenario (Chapter 11) the loss of the labor force for a significant part of the year must have seriously impacted the sustenance of the community.

SETTLEMENT AND URBANIZATION

Models of Urbanization

Although our modeling program aspired to simulate urban-scale settlements, in the case of the northern model this was only achieved at the heuristic level whereby field results from the Iraqi North Jazira provided the framework for a hierarchy of settlements as illustrated in Chapter 10 (Fig. 10.3). In terms of household behaviors it proved only possible to simulate a relatively minor settlement in which populations ranged between roughly 500 and 700; this is equivalent to a population that would be housed on a site of between 2 and 7ha, depending upon population density. Because the simulations clearly demonstrate that exchanges between households are stimulated by environmental, political or social 'stress events' it is tempting to simply scale up such models by substituting settlements for households, for example. In other words, any given stress event could then be seen as stimulating increased exchange of grain and animals between settlements, therefore leading to a growing network of exchanges and perhaps even the growth of hubs. Although such a simplistic scaling up may work for the exchange of precious goods or animals, the exchange of bulk goods such as cereals would be clearly inhibited by the 'frictional affect' of overland transport. In other words, stress events may increase exchange flows between settlements, but only for certain readily transportable commodities. Of course, in Southern Mesopotamia, where the frictional effect of overland transport was less pervasive, stress events might trigger increased exchange of bulk cereals as well as discussed below.

Chapter 14 takes modeling in a very different direction by building upon and developing a range of mathematical models, which were initially conceived during the period of the New Geography but are now much more sophisticated. Specifically, these 'entropy maximizing models' (Wilson 1970), which adopt the mathematical framework of economics[6], might therefore be dismissed as generalizing or 'top-down' models. Nevertheless, they are capable of handling the more large-scale behaviors which are difficult to capture by simply scaling up household-level agent-based models. Because the most recent generation of such models incorporate agent-based behaviors as well (Dearden & Wilson 2012: 708), future simulations should be capable of incorporating both generalizing and agent-based approaches.

Altaweel's model in Chapter 14 explores how, for example, transportation – specifically the 'low friction' channels of southern Mesopotamia – stimulate positive feedback effects stemming from a sites 'attractiveness' thereby contributing to the development and growth of southern Mesopotamian cities. This approach to modeling is very different from those of agent-based models, as such behaviors are generalized and simplified to such a degree that factors such as 'site attractiveness' or importance remain deliberately undefined.[7] Although such low-dimensional models may appear to neglect or ignore the rich complexity of the 'real world' so successfully captured by agent-based models, they do enable the modeler to recognize emergent properties and patterns of developed settlement structure and hierarchy without having to take a full account of all relevant inputs.

A key factor in the development of urbanization is that settlements may have grown larger where the settlement and population density was high and because of the proximity of settlements to other settlements (Chapter 3; Boserup 1981: 63-75; Drennan & Peterson 2012: 74). This relation is also borne out by the simulations of

[6] That is what Dearden and Wilson (2012) refer to as archetypal Boltzmann-Lotka-Volterra type models.
[7] 'Attractiveness' should not simply be seen in terms of economics, it could, for example, relate to the presence of shrines, temples, or the residence of charismatic kings.

urbanization discussed in Chapter 14. The evidence from archaeological surveys also suggests that this pattern is particular evident in northern Syria and Iraq where Late Chalcolithic (fourth millennium BC) cities developed within a relatively dense matrix of settlement. Where population densities are high not only are the 'costs' of interaction lower because there are more people to interact with, but also the networks of information flow and exchange are more likely to operate at a higher level therefore promoting the development of urban hubs (Wilkinson *et al*. forthcoming). Such loci of high settlement density are also likely to maintain more complex technologies and skills thereby making the growing towns centers of attraction (Kohler 2012: 258). In addition to such positive returns, in both northern and southern Mesopotamia the introduction of the plow would not only enable larger areas to be cultivated, but would also have required larger labor forces, which themselves would result in immigration to the growing towns. Positive returns would be even greater in the irrigated south where large labor forces would be necessary to dig and maintain canals as well as to operate the labor-intensive irrigation systems. Significantly, if the survey data for population density presented in Chapter 3 are at least approximately correct (which as pointed out is uncertain), Late Chalcolithic urbanization in Upper Mesopotamia appears to have developed in a more densely populated countryside than was the case in the irrigated south. If this was the case, then it is possible that whereas urbanization in the north was an outcome of increased settlement density and the associated factors mentioned above, in the south urbanization was able to develop at lower ambient population densities precisely because of the advantages of the network of channels that increased connectivity and allowed for the convenient transport of bulk goods from place to place (Algaze 2008).

Overall, these patterns of population density, network effects (connectivity) and positive returns provide the context for the urbanization models developed by Altaweel in Chapter 14. This is specifically the case for the positive feedbacks that surround the attractiveness of sites. This phenomenon, where growth concentrates in a small number of attractive locations whereas smaller settlements diminish in population and size, can be compared with the short-term history of households as modeled by ENKIMDU, in which the small or weak get smaller and the more affluent households get stronger and grow. Not only does this echo the 'Matthew effect' discussed above, it also hints that similar processes operated at different scales.

The entropy-maximizing models suggest that network effects and trade contributed to early settlement growth. Scenario 3 in Chapter 14 demonstrates that settlements with powerful ties to trade networks as well as with external contacts, can grow to dominate the settlement hierarchy, a situation that can be maintained as a result of increased resilience resulting from a favorable geographical location and access to transport routes.

The scenarios discussed in the entropy maximizing model echo the more general arguments of Ester Boserup (1981: 67-71) who not only pointed out the fundamental role of networks of water transport to the growth of cities, but also, drawing on the work of Adams and Nissen, was able to suggest how the growth of large centres was at the expense of the small and medium size communities (see also Algaze 2008). However, the models presented in Chapter 14, demonstrate this mathematically so that variations in the key variables make it evident how city size may change and the smaller settlements decline. By providing a clear relationship between the controlling variables and inputs and the outcome, namely changes in city size, these models are good examples of low dimensional models. However, they are not able to, and do not claim to be, capable of creating emergent cities that grow and develop out of small-scale processes at the household and community scale.

The high population densities discussed above not only encourage interaction, but also conflict, a perspective which, in turn, conforms to models of state development in which aggressive chiefs or kings enlarge political units (Carneiro 1970; Flannery 1999). Particularly relevant is that recent evidence for mass graves at both Brak and Hamoukar in northeastern Syria, which may result from such conflicts (Reichel 2006-07; Lawler 2006; McMahon *et al*. 2011; Algaze 2008: 70), are therefore particularly relevant to our models. Unfortunately the relationship between conflict and population density is somewhat ambiguous (Keeley 1996: 114). Nevertheless, its role in polity development and everyday life has been underplayed in the MASS models, in part because our simulations were primarily focussed upon a single settlement. This under-representation of conflict was also the case during the early stages of the Village Ecodynamics Project:

'The Village Simulation (....) is a model of functional regularity. Agents never so much as argue with each other. To bash someone on the head, or steal a wife or some maize, is quite literally unthinkable.' Cole 2012: 197.

The agents in the MASS simulations were similarly mild-mannered functionalists,[8] although the corvée scenario (Chapter 11) dealt with a situation that could encompass the male population going off to war. Although the VEP simulations did not explicitly include conflict, a later aspect of their research included Sarah Coles' testing of the Turchin-Korotayev (T-K) model in which conflict can be seen to be directly proportional to population until a point is reached where the amount of conflict leads to a population decline, ultimately spiralling towards an equilibrium point (Cole 2012: 200). However, because the T-K model specifically deals with internal conflict (i.e., within or between culturally similar groups) the exogenous forms of warfare are not relevant. Hence, in the case of the MASS Project, the corvée model, although developed to reflect a demand for corvée labor by a local political power, rather than a war, could be seen as equivalent to recruitment to fight a war. This therefore suggests that they have potential utility for using the T-K model in future.

Small Settlements and Path Dependency

In his volume *Cities and Complexity* Michael Batty suggests that cities are usually long-lived affairs, and that they persist until there is a major transition, usually as a result of some innovation in transport (Batty 2005: 356). In the MASS simulations it was not possible to test this assertion, although conventional archaeological studies are fully capable of comparing the life cycles of such cities as Nineveh (long life) with Samarra (short). In the ENKIMDU simulations the model settlements were all of relatively modest size, attaining, at most some 500-700 people, and at this scale we can get some idea of the factors that might structure long versus short duration. Depending upon the prevailing population density, such settlements would occupy some two-seven hectares. This is relatively modest in scale for Early Bronze Age settlements of northern Mesopotamia which usually attain some 100-120ha (Chapter 3). However, because sites of less than five hectares are numerically the commonest class of site in the region, the MASS models should be seen as being representative of a huge number of settlements. Here it is necessary to caution that because we have only run simulations for a single settlement without surrounding sites to interact with, the results cannot be taken as entirely representative of complex settlement patterns. Nevertheless, a few patterns emerge that relate to the significance of small sites (see also Schwartz & Falconer 1994 for a broader perspective).

In the 1960s, Robert MacArthur suggested that all else being equal, the 'time to extinction' of small populations (i.e., those with less than 150 people) was very short (Zubrow & Robinson 1999: 133). However, using stochastic numerical modeling Zubrow and Robinson demonstrate that village extinction was actually much more unusual than suggested in the literature (1999: 144). For large numbers of small villages over long periods, chance alone is not sufficient to cause extinction. Once a village attains a population of around 100 there is a greater likelihood that they will persist, and increase or decrease in numbers, rather than becoming extinct. The resilience of such communities is highlighted by the arguments that repetitive patterns of feast and famine, although causing hardship, do not necessarily cause extinction. Therefore in conclusion, Zubrow and Robinson considered that village extinction is more likely to be a result of cultural reasons, disease or warfare rather than any 'law of small numbers' (Zubrow & Robinson 1999: 144).

The modeling exercise of Zubrow and Robinson aligns, not only with the field evidence from Upper Mesopotamia, where small sites of 0.5-5ha are numerically dominant in the Early Bronze Age (Wilkinson *et al.* 2012), but also the arguments of Dunbar (2003) who posits that 150 people approximates to the optimum size for social interaction (the actually Dunbar number being around 150 people; see Chapter 3). In other words, rather than being rare and demographically unstable, small settlements are extremely common, often, but not necessarily of long duration, and also exhibit a social cohesion that perhaps makes them potentially long-lived. Of course, anyone who has lived in or witnessed small communities will be aware that they can be riven by

[8] That said, our seminars at the Oriental Institute, did argue for the incorporation of a range of a wide range of additional behaviors which could be included in future simulations.

conflict, and in extreme cases such conflicts can lead to such communities dissolving. However, the MASS simulations demonstrate that kin and social relationships are crucial to the survival of small communities, especially during times of crisis. Furthermore, such communities may well have been small patrimonial communities, with closely integrated kinship networks. As argued for southern Mesopotamian cities, residential neighborhoods may approximate the size of villages (Stone 1995: 240; Chapter 3), implying that the social behaviors within cities may have mimicked these smaller settlements (see Schloen 2001: 108-12).[9] The MASS results, be they relating to social networks, plow teams, or response to times of stress, are therefore relevant to a much wider range of settlement types.

As note above, such small-scale communities also give the impression of being occupied for relatively long durations. Here the concept of path dependency (Adams (2001: 352) is crucial, in part because it injects a major role for history in the development of social groups and their settlements. In other words, once a small community attains the form of a tell, it not only has 'place value' (Chapman 1997), but it also becomes visibly part of the landscape, so that even if people do depart for a period, that place can be re-settled as a result of claims that can be backed up by material evidence (such as the graves of ancestors) or by manifest tradition. Therefore what may be seen as a settlement that was sustainable for social or ecological reasons, may simply have persisted because of its location in the landscape or because of cultural traditions. As Zubrow and Robinson suggest, even episodes of famine may not cause extinction, a conclusion that is echoed by the MASS simulations which sketch out the ebb and flow of population within such small settlements. This is especially evident in the case of environmental shocks, which hardly dent the demographic trajectory of small settlements (Fig. 15.1: the imposed drought occurred from years 8 to 12).

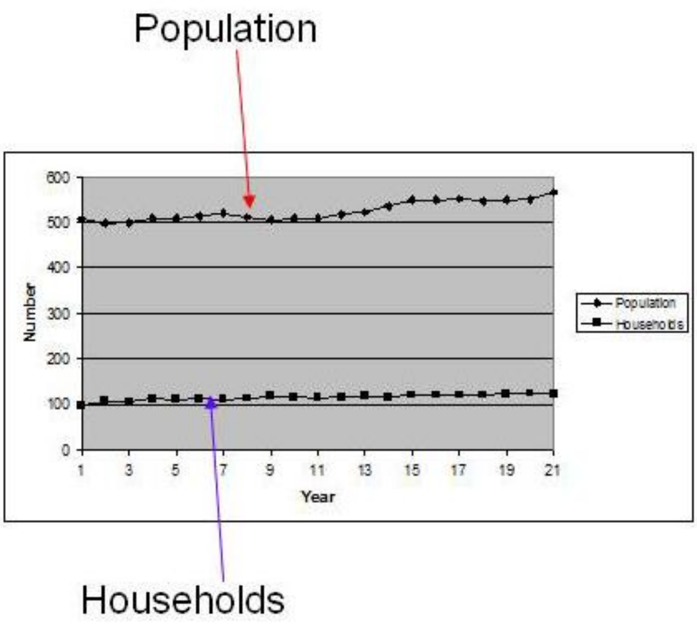

Fig. 15.1 Output from the imposed drought scenario (Chapter 11) showing how the population and households remain stable despite the high variation of inputs. The imposed drought occurred from years 8 to 12.

DEMOGRAPHY

One of the more insightful outcomes of the MASS Project was that it provided valuable perspectives on what might be called micro-demographics, in other words snapshots of how a society might grow (or otherwise)

[9] How households scale up to form residential neighborhoods, and the cultural logic behind such processes is discussed in detail by Schloen, and forms a fundamental aspect of the patrimonial model.

under specific circumstances. But how did the demographic estimates compare with estimates established from field data?

This is not as straightforward as it might seem, because demographic estimates from both skeletal evidence and from archaeological surveys are approximate, at best (Paine 1997). Overall, the MASS-derived population growth rates fall within the rates estimated from archaeological surveys, either from the Basin of Mexico Survey (Feinman *et al*. 1985; Dumond 1997: 186-88), or from North Mesopotamian surveys re-analyzed as part of the Fragile Crescent Project (Table 15.1; Fig. 15.2). Although the highest growth rates in the simulations presented in Chapter 11 exceed most estimates for the Basin of Mexico (i.e., 0.66% versus 0.2% growth per annum) the Oaxaca results were occasionally as high as 1.4% suggesting that demographic growth can be very variable (Feinman *et al*. 1985: table 2). Moreover, the Stability and Change scenario is not typical of the simulation outputs which, in general, are equivalent or significantly less than those of the Basin of Mexico examples.

On the other hand, the MASS estimates are significantly greater than those from the Fragile Crescent Project which have been calculated from long-term settlement trends (expressed as aggregate site areas per km^2; e.g. Wilkinson *et al.* 2012 & forthcoming). These survey-derived figures, which consistently fall within the range of 0.05 to 0.064% per annum, are rather low, but sit between estimates for long-term growth rates for 10,000 BC (0.008% p.a.) and 1 BC (0.037% p.a.) published by Livi-Bacci (1992: 31). The only deviation from the survey-derived figures are those from the growth phase of the site of Titriş Höyük in southern Turkey, which is more characteristic of the explosive growth of citadel cities, rather than that of the general population. This difference is because such citadel cities appear to have grown by sucking in populations from outlying areas, so that they can hardly be regarded as typical of the period. Of course, the above figures are all dwarfed by the global growth rates for the modern era during which range between 1.73 and 2.06 % per annum (Cohen 1995: table 4.2).

Overall, the rates expressed by the MASS models appear to be relatively realistic when compared with other estimates. Nevertheless, the interest lies in the details. That is when are population levels maintained during periods of socio-economic or environmental stress, or when are there specific declines as a result of demographic crises such as diseases or the dysfunctional sharing of plow teams (Chapter 11)?

Table 15.1 Population growth rates from archaeological examples.

Location	**% Growth Rate Per Annum**
Example: Basin Mexico (Feinman et al. 1985)	0.20 (range -0.17 to 1.4)
Example: Basin Mexico (Dumond)	0.33
MASS 1: Stability & Change.1	0.66
MASS 1: Stability & Change.2	0.1287
MASS 2: Plow teams (app.)	0.1479
MASS 3: Disease: baseline	0.338
MASS 3: Disease outbreak	-0.2279
FCP: Mid Euph. KHS-TS	0.064
FCP: Mid Euph. KHS-TS: max	0.062
FCP:LCP: 4400BC-LBA peak	0.05
FCP: KHS-TS: to Roman peak	0.0516
Titriş Höyük: 3100-2500BC	0.36

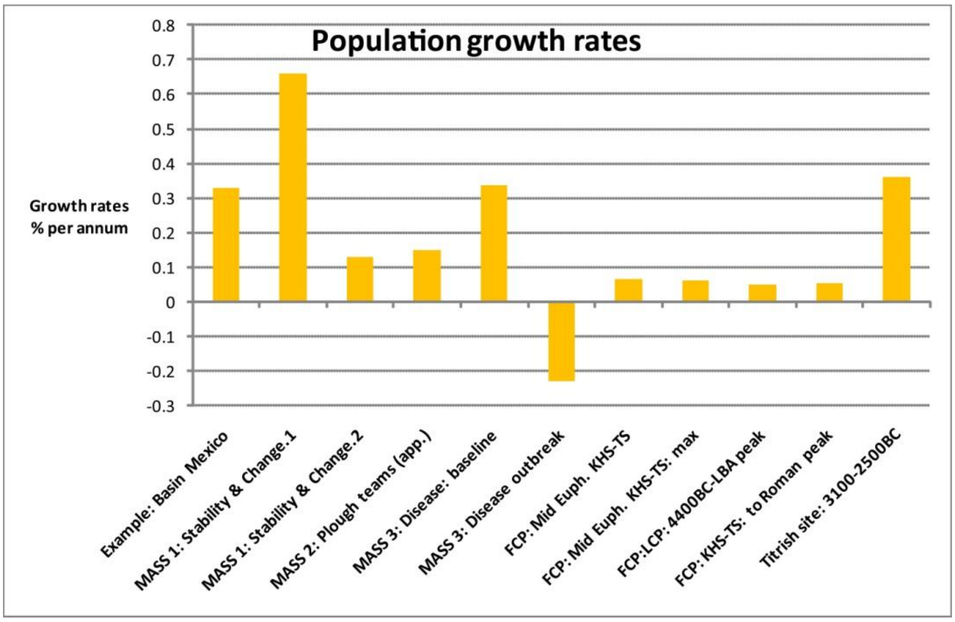

Fig. 15.2 Population growth rates based on Table 15.1

THE ROLE OF NETWORKS

Although we have dedicated a full chapter in this volume to the role of networks, the formal analysis of networks (Strogatz 2001; Newman & Watts 2006; Knappett *et al*. 2008) was not undertaken as part of the MASS project. This omission is unfortunate, although the emergence and operation of social and kin group networks is very evident as discussed above and in Chapter 11. At a completely different scale, there is abundant field and remote sensing evidence for the existence and operation of a remarkable network of Bronze Age hollow ways for which we now have a considerable amount of information (Chapters 4 and 9, plus references). However, the challenge is how to 'scale up' from the small-scale interactions within the community to larger-scale networks which entail the inhabitants of the central community a) traveling to reach their fields, b) delivering their flocks to the outlying pastures c) getting to neighboring communities and d) crossing the landscape from one region to another.

When comparing the irrigated south with the rain-fed north, there is a marked contrast in both the morphology of transportation networks and how they contributed to the development and growth of settlements. Although route networks in the north are primarily radial, and tend to service the local agricultural territories, many settlements are linked by routes and the presence of inter-regional hollow ways suggests that there was considerable interconnectedness and therefore regional integration (Ur 2003: 112). This may be because communities needed to be more connected when they ceased to be self-sufficient. In other words, when a settlement grew to a size that exceeded the capacity of its fields to support it, it had to import food from neighboring places to make up the deficit (either by taxation, force or mutually agreed arrangements). Consequently, increases in size above a key threshold (probably around 10-20ha; Chapters 3 & 4; Wilkinson 1994: 501-02) must have resulted in increased connectivity between those settlements. On the other hand, when the percentage of hollow ways connecting sites to other sites is compared to the size of settlement, it appears that, if anything, the smaller sites are more connected to other Bronze Age settlements than was the case with larger sites (Smith 2008:27). However, this may result because these connections were primarily to larger sites in the settlement system to which they were tied.

Just as increased social and kinship links within the community enabled individual households to cope with stress and food shortages, settlements may have required more links with neighboring communities for the exchange of essential items during times of stress, or because they exceeded a key sustainability threshold.

Smaller sites were also more likely to be linked to other settlements, especially larger ones, because they would have been contributing products in terms of tax, tribute or share-cropping to larger ones. Although it might be expected for larger sites to develop more hollow ways, and therefore to act as hubs in networks, the relationship is hardly strong, with a correlation coefficient of 0.44 for a limited sample of sites (Smith 2008: 19-20). Overall, the Early Bronze Age route networks of northern Mesopotamia are nodal, but with a significant number of cross country connections. A significant contribution to hollow way formation was a result of the passage of flocks of sheep, goats and traction animals (Wilkinson *et al*. 2010), all of which can be regarded as 'self transporting', with the result that the frictional effect of overland transport could be partly mitigated by the large-scale movements of animals at both the local and inter-regional levels. By way of contrast, for the fourth and third millennia BC, the transport of bulk crops such as cereals was mainly constrained to the local arena, namely the site territory and the neighboring communities.

In contrast, the pattern of movement in southern Mesopotamia, as argued by Algaze (2008; see also Chapter 3), must have been dominated by the network of rivers and larger channels. In fact, because the characteristic herringbone field patterns were *functionally* linked to the major channels, there was a natural integration of food supply and low-friction transport networks. However, because the main channels were anastamozing networks along which settlements were oriented,[10] there were considerable biases in connectivity, with settlements positioned along any single channel being highly connected. On the other hand, in contrast to connections along the channel network, settlements on different channels could be remote (as the fish swims) from their neighbors on other channels, even if these were geographically close (Wilkinson 2003: fig. 10.1). Moreover, the movement of sheep and goats across the land, although no more nor less as efficient as in the south, was relatively less efficient than the transport of bulk food stuffs.[11]

Overall therefore, the networked landscape of the south was much more economically efficient than that in the north, although differential access to different river systems must have meant that there was a significant difference in the connectivity of settlements in the south.

Also indicative of the operation of networks is the settlement pattern itself. Specifically, it has been noted that in those parts of the north away from the broad plains of the Khabur, small settlements, with only occasional larger sites were the norm (Chapter 3). These settlement patterns show very skewed distributions with usually a single dominant centre and a long 'tail' of smaller sites of 1-5ha area. Such non-Gaussian distributions skewed towards a long tail are classic examples of scale-free networks (Bentley 2003) as well as more generally the operation of network effects (Ormerod 2012: 163-67). Therefore even where the networks themselves are not evident, their operation might be inferred from the distribution of settlement sizes.

COMBINED MODELS

Southern Mesopotamia and the 'Baggy Trousers Model'

As outlined in Chapter 2, the network of channel systems and marshes that criss-cross alluvial Southern Mesopotamia created a mosaic of opportunities for pre-Bronze Age agriculturalists. By using simple techniques such as initially levee breaks or eventually sluices to control the flow of water to fields the prehistoric inhabitants may have created the formative stages for irrigation. A gradual shift from the reliance on natural anastomosing branches to increasingly artificially created and manipulated channels with their characteristic linear settlement patterns appears to have fully developed by the late third or second millennium BC.
During the initial stages of the MASS project we developed a simple qualitative model that sketched the physical factors that allowed for, but also constrained, the development of third millennium and later patterns of

[10] At least those of the third millennium BC and later (see also Chapter 3)
[11] Note, however, that sheep and goats were transported on boats in the south. Even oxen and donkeys are attested to have been loaded onto boats which then were pulled up the rivers/canals by humans! See Englund (2010: 106) regarding the lack of evidence for animals towing boats.

settlement (Fig. 15.3). The basic modules that structure this model consisted of a series of settlements positioned at regular intervals along low, sinuous levees (Chapters 2-4). The populations of these settlements would have been supported by the products of palm gardens along the levee crests and secondary channels and cultivated fields on the levee slopes that led down to flood basins beyond (Fig. 15.3). Beyond, the agricultural land, desert steppe, often saline, supplied intermittent pasture for larger flocks of sheep and goat, as well as refuges for wild animals. Marshlands were also important (Cole 1994) and the procurement of marshland and riverine resources must have formed a significant component of the local economy especially in the far south of the plains (Pournelle 2003).

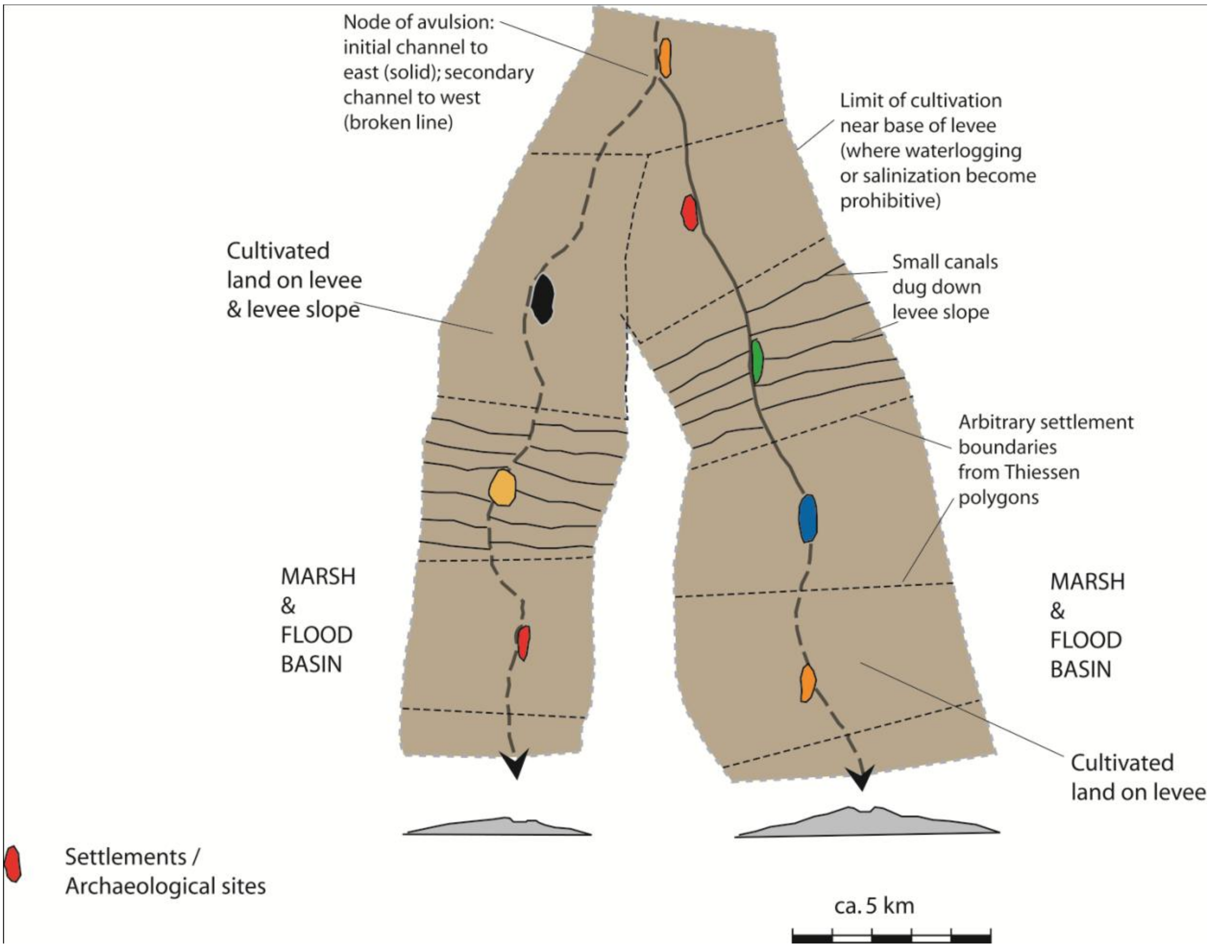

Fig. 15.3 The 'Baggy Trousers Model' for southern Mesopotamia illustrating factors that allow (stimulate) or constrain growth within a levee-based irrigation system (other types of irrigation system are not included).

The heuristic 'baggy trousers' model therefore employs a limited number of assumptions (Figure 15.3):

- Avulsion results in the bifurcation of channels, which can either lead to settlement abandonment along the dry channel or an increase in settlement and irrigation opportunities if flow and settlement continues along both channels (i.e., a partial avulsion).
- Settlements are arranged at roughly regular intervals along the main channels and/or levees. Of these, at least the larger towns or cities, would tend to remain in place for long periods because of manifest tradition or because they acted as religious centers.
- For contemporaneous settlements aligned along the crest of a channel levee, the mutual territorial boundaries are positioned normal to the main channels and half-way between settlements (estimated using Thiessen polygons).

- At the distal end of the levees where soils are clay-rich, fine-grained, and with a propensity to waterlogging and salinization, crop yields decline until a point is reached where it is counterproductive to grow crops. Because crop yields on the levee slope will be a function of soil properties, water-logging, and salt content, this can be modeled by means of Altaweel's crop model to estimate a distal land use boundary as presented in Chapter 13. In addition to being a function of the soil parameters and groundwater, the area of cultivation may be constrained by the time taken to travel from the settlement on the levee crest as well as available labor and land.
- Rivers or artificial channels provide ideal conduits for the transport of staple goods, so that any shortfalls in production can be alleviated by importing grain by boat.
- Additional territorial boundaries can be estimated between settlements on different channel branches and parallel to the levee crest. In addition to the salinization boundary, these boundaries serve to constrain crop production which, in turn, *might* limit the overall growth of the settlement.

The above model is essentially that laid out in an earlier publication (Wilkinson *et al*. 2007b) and it is now appropriate to examine how the modeling results relate to elements of this model. First, of course, because most ENKIMDU simulations were focussed in northern Syria and Iraq, it is only possible to apply these results in the broadest comparative way. However, the model results from the South, as presented in Chapters 13 and 14, are directly relevant specifically to points D (salinization) and E (enhanced transport) laid out above. In addition:

- Irrigation produces both higher *and* more reliable yields than rain-fed agriculture.

- Shortfalls in the supply of bulk staples at any one center can be counteracted by imports from upstream or downstream communities.

- If population levels or city growth exceed a certain level, such production constraints would encourage the import of goods from upstream or downstream communities. This would occur as long as those areas are capable of generating a sufficient surplus, either as a result of coercion, taxation or trade, and as long as relationships between communities are not rendered dysfunctional by conflict. The operation of efficient water transport would entail surplus production being metaphorically sucked in from other areas along the same channel system.

- In other words, closed settlement/land-use modules with communities of modest size (2000-4000 people; occupying 10-40ha) would have been self-supporting under the conditions laid out on Figure 10.3.[12] However, once the community size exceeded a key threshold, they would no longer be self-sufficient and transport networks would then become the key driver of growth. These conditions then provide the ideal circumstances for increased transport and the associated rich-get-richer factors to prevail as laid out in Chapter 14.

- Moreover, as cities grew they also became more powerful, and thus created the required links to sustain the increased size (as shown in Chapter 4).

Within this admittedly rough model, individuals and social groups might have operated within the following framework: down-levee canals being relatively short (1-3km) could be organized by kin-groups as described for modern Iraq by Fernea (1970). Under most circumstances, the distribution of water in such irrigation modules, consisting of only 20-40 households (ca. 100-200 people), could be administered without recourse to the use of writing or water distribution logs. On the other hand, irrigation systems of significantly greater size and complexity may have exceeded the cognitive capacities of the groups and would have required a more complex set of administrative practices. With the herringbone system outlined above, it would have been relatively straightforward for a state to administer the main water supply as well as the distribution points along the trunk

[12] Significantly the figure of 40ha is the threshold chosen by Adams (1981: 138) for 'large urban'; see also Ur 2013 fig. 7.10). Our own figure was arrived at by the estimation of what size of population levee cultivation could support under a regime of biennial fallow.

channel, but to leave the basic water distribution along the down-levee canals to the social and kin-groups. In such a system, the king's command and those of tribal or kin groups would interleave, and if there was a break-down of the state, it would have been possible for the traditional methods of water management to continue. By analogy with the small-scale communities of the north modeled using ENKIMDU, local stresses and shortfalls in supply would have been satisfied by local exchanges between households in a similar manner as described in Chapter 11.

Therefore the irrigated landscape of southern Mesopotamia was not only different in terms of productivity from the north, it was also different structurally. Whereas a limitation on self sufficiency in the irrigated system could be readily met by the transport of bulk food stuffs by boat, in the rain-fed north, a similar threshold (in this case when sites attained some 10-20ha area) probably forced connectivity to increase (as discussed above), but because the required overland transport was significantly less efficient than in the south, urban growth faced a significant drag effect as a result of difficulties of transport. Constraints arising from the limited size of cultivated territories and the frictional effect of overland transport could only be over-ridden under the appropriate circumstances, as was the case during the later empires when the overall scale of the economies increased considerably. On the other hand, in the south the efficient distribution of bulk products along the trunk channels (i.e., the backbone of the herringbone system), like those of the post-Industrial revolution world, were capable of fuelling continuous growth so that cities developed to cover areas of at least 400ha. Overall, the southern landscapes must have been much 'busier' (and more labor intensive?) than those of the north, with many more activities going on both in the fields with more effort being expended on manuring, weeding, harvesting threshing etc. (Netting 1993: 131), but also more activity being involved in the administration of water distribution as well as tending the multiplicity of crops in the orchards.

Fragility or Sustainability

Discussions of early Mesopotamian settlement (both northern and southern) include the topics of sustainability and fragility. In the context of the agricultural economy the former refers to the propensity of production to continue to produce optimal yields in the medium or long-term. On the other hand, agricultural systems which are productive in the short term but are vulnerable to marked declines or even collapses in supply, may be regarded as brittle or fragile systems.[13] Such arguments have been used in the context of the 'violation of fallow' in both the south (Gibson 1974) and the north (Wilkinson 1994). Whereas in the south, the increased frequency of cropping which resulted in the violation of fallow, resulted in increased salinization and an eventual decline on crop yields (Gibson 1974; Chapter 13); in the north similar practices are thought to have contributed to reduced soil moisture and therefore reduced and less stable crop yields (Chapter 11).

By reviewing the settlement-agricultural system as a whole, it is, however, possible to suggest the overall context for such strategies as well as their long-term ramifications.

For example, in alluvial southern Mesopotamia, where fallow is violated (by increased food demand as resulting from increased population) salinization increases, especially in basin soils and the lower levee slopes. As demonstrated in Chapter 13, unless it was mitigated by good practices of soil management, salinization must have resulted in reduced yields. If population increased within the settlements on the levee, any shortfalls in production could have been met by a) extending cultivation (with fallow) lower down the levee slopes, even into the basin soils; b) 'violation of fallow' so that cereal crops were produced every year rather than every second year, as is the case with traditional biennial fallow; c) leaving the cultivation strategies as before, but arranging for any shortfalls in production to be compensated for by importing bulk products from neighboring polities by exchange, taxation or by force. Of these both a) and b) will result in salinization and reduced production, and only c) will avoid this problem.

[13] Complementary approaches, including the so-called 'adaptive cycle' as proposed by Gunderson, Holling and colleagues (2002), have been discussed in relation to archaeology by Redman *et al*. (2009: 22-26).

Population increase is not, however, the only problem: population concentration into growing cities (as discussed in Chapter 3) would become more of a challenge because the increased size of population centers would lead to increased demand for cereals from the immediate territories with the result that there would be a tendency for any (or all) of the strategies a) b) or c) to be initiated. The first two would encourage the violation of fallow as the local fields had to increase production or the spread of cultivation into areas prone to salinization. However, this could be mitigated if more food supplies could be imported from elsewhere by boat (strategy c). On the other hand, the 'perfect storm' would result if an area with a high percentage of urban population was in conflict with neighboring polities so that such food imports were impossible.[14] This might then result in increased demands from local agriculture, violation of fallow and a decline in yields. The overall decline in rural settlement that occurred during the period of maximum urbanization in the late Early Dynastic period (ca. 2500 BC: Adams 1981; Ur 2013: 149-50) must also have created sustainability problems. This is because although smaller settlements along levees or their distributary canals would have been able to maintain biennial fallow, taxation demands from the city would have strained their own production systems and pushed them towards violation of fallow or the extension of cultivation in to areas prone to salinization. Overall, urbanization not only imposed strains on agricultural production, it also pushed the systems towards a state of fragility, as argued by Adams (1978: 332). Conversely, those periods with higher percentages of rural settlement, which are thought to have prevailed in the Uruk period as well as the Old Babylonian and Kassite periods, are less likely to have experienced these problems, and could have been more sustainable. Again, the models demonstrate the crucial role of good agricultural husbandry: under appropriate circumstances proper crop management could even enable larger settlement structures to persist in southern Mesopotamia. For example, the simulations demonstrate that in scenarios where increased aridity prevailed, the situation became difficult to manage effectively, whereas alternatively, over irrigation could be mitigated with only minor increases in fallowing.

Similarly in the north, under the appropriate circumstances, violation of fallow could have resulted in reduced soil moisture and less stable yields as discussed in Chapter 11. Again, the push factor behind the shift from biennial fallow to annual cropping might have been growing population, increased population in large settlements, or, increased taxation demands from the prime cities in the region.

Although violation of fallow appears to have resulted in significant declines in crop yields in both the rain-fed north and the irrigated south, the circumstances in the south that result in salinization may have taken longer to reverse. On the other hand, because southern communities could benefit from 'low-friction' transport along canals and rivers to move bulk foods between cities (as discussed in Chapter 9) it would have been possible to address any shortfalls without recourse to violation of fallow. In other words, although the problems resulting from violation of fallow may have been more catastrophic in the south, the conditions were present to address shortfalls by the use of new technologies of transport.

SAMPLES OF SETTLEMENT GROWTH

Because the MASS Project only tackled part of the universe of everyday life, it is appropriate to illustrate which parts of these complex systems was actually modeled.

First, for the rain-fed North, Fig. 15.4 illustrates how smaller settlements (left-hand side) represent the most common class of site, and which represent an element of continuous occupation and slow demographic growth. These are the types of communities that were modeled by the MASS Project. On the other hand, the slow growth of such communities within a dense matrix of rural population into large sites such as Brak and Hawa was not achieved. Equally the rapid growth of select tells into citadel cities such as Titriş Höyük, Hamoukar, and Mozan, is not represented in this sector. Of these two scenarios, the slow growth into Late Chalcolithic centers might have been achievable through modeling because their growth probably relates, in part, to bottom-up processes and local circumstances of high settlement density, whereas the accelerated growth of citadel cities

[14] Of course, grain could be imported across the 'grain' of the landscape (that is from places on different channel systems) overland by pack animals and porters, if those areas were not in conflict. However, this would be laborious and expensive.

would have been more difficult to model at the scale of the local polity because their circumstances of growth probably related to economic and political conditions operating over a much larger area. Such a model, although feasible would require the introduction of sub-economies such as textiles, flow of precious items and metals, which would require a much larger and more complex model than was achieved by the MASS group. In Fig. 15.4 the background star-shaped shading represents mobile groups, which although poorly understood for the fourth and third millennium BC, probably represented a significant presence in the region and may well have contributed to the development of exchange systems and trade, especially in the more climatically marginal regions. However, as indicated by the lower arrows, many of these expanded cities (but by no means all) then became reduced in scale later in their life histories during the second and first millennium BC to return towards the left hand trajectory.

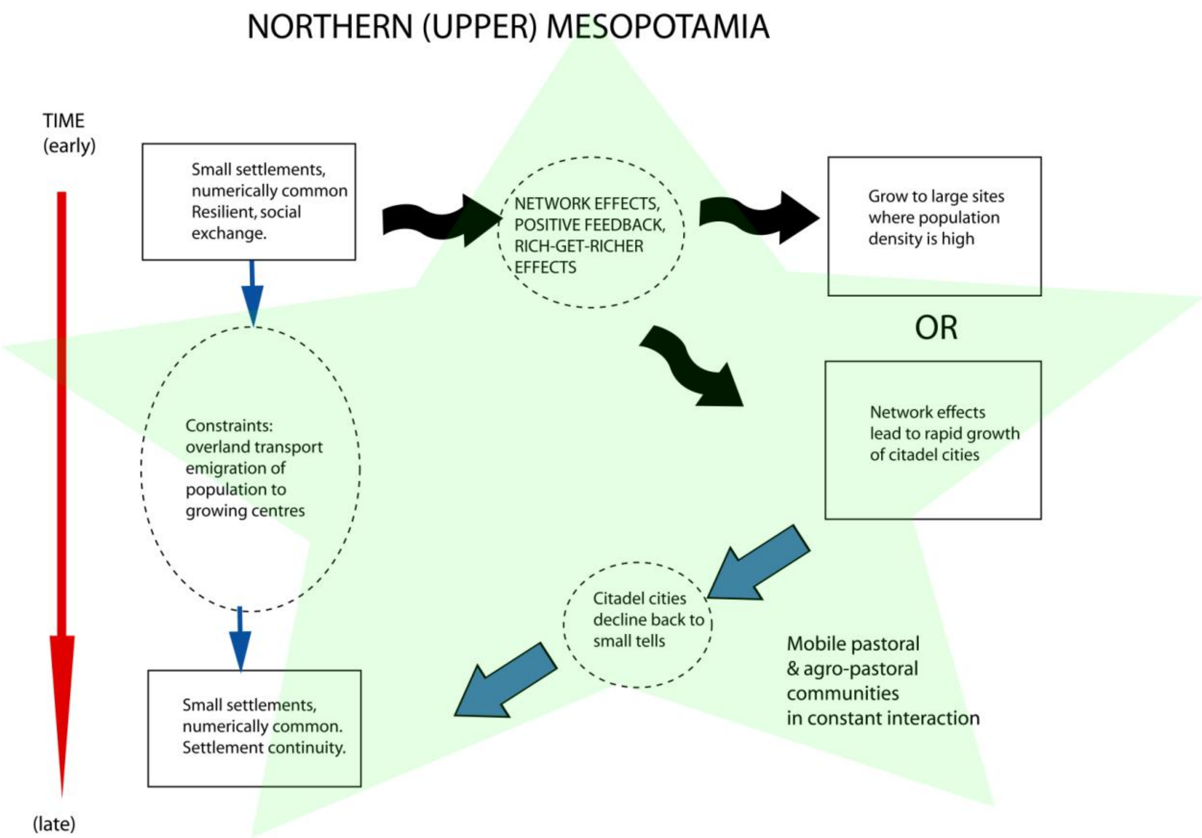

Fig. 15.4 Chronological diagram for northern (Upper) Mesopotamia showing which parts of the settlement development continuum were modeled (see text). The star-shaped shading implies the role of agro-pastoralists and mobile groups.

Just as the above flow diagram only represent a part of the settlement system, that for the south (Fig. 15.5), only serves to sketch some of the bare bones of settlement development that relates to our modeling. In this case, the diagram represents the operation of three broad technological stages:

First, the initial development of small-scale irrigation and settlements associated with wetlands during the prehistoric period; in this case, the smaller settlements which represent the formative stages of settlement history, have not been modeled.
Second, growth of larger scale settlements along levees. These both benefitted from the development of more extensive patterns of irrigated fields, but also were constrained by the diminished yields and salinization towards the base of the levees and the flood basins. The associated agricultural systems have been modeled by Altaweel, who, building upon earlier models demonstrate the degree of constraint provided by the soils and water tables (Chapter 13).

Third, illustrates the stage when in addition to the technologies of water distribution and irrigation, settlement grew to such an extent that it exceeded the capacity of the local agricultural production and the additional technologies of boat transport enabled city growth to be fuelled by extended networks of waterborne transport. Some aspects of urban development, specifically those related to the feedback effects associated with highly 'attractive' sites, have been modeled by Altaweel in Chapter 14. These suggest how network and rich-get-richer effects may have contributed to selective growth of favoured cities and the decline of others.

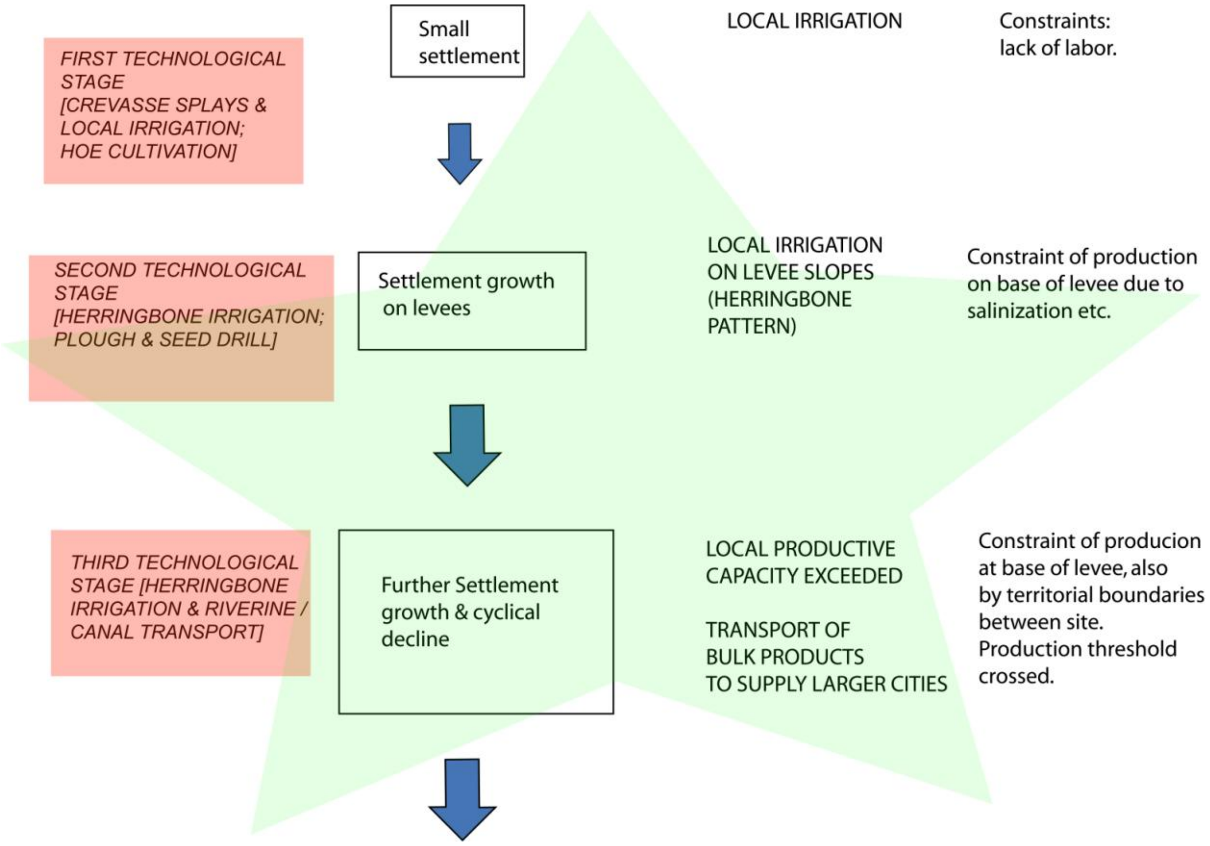

Fig. 15.5 Chronological diagram for southern (Lower) Mesopotamia showing the temporal settlement continuum. The star-shaped shading implies the role of agro-pastoralists and mobile groups.

The above sketches of how the modeling exercise fits into the broader patterns of settlement development highlights one of the central problems of applying agent-based and quantified models to complex societies: namely that is difficult to make them applicable to the complexity of daily life and all the activities that take place in any one location. Moreover, it is even more difficult to make them apply to broad technological stages where factors such as growth of textile industries, transport technologies and so on, must be introduced to cover huge geographical areas. If modeling is to be undertaken at such broad scales, it will be necessary either to scale-up the bottom-up models with commensurate increases in computing power, or, to make simplifications using elements of the system using the generalizing mathematical models illustrated in Chapter 14. Ideally, both approaches should be combined.

CRITIQUE AND RETROSPECTIVE

It would be easy after such a project as the MASS Project to project an evangelical narrative stating that the use of agent-based models are the best way forward for representing the complexities of ancient societies, and that researchers of the ancient world should immediately adopt such an approach. Here, it is therefore appropriate to examine more critically the overall outcome of the project and sketch aspects of the modeling that either need to be enhanced or modified.

First, we admit that there is a tendency for the agents to be programmed according to functionalist behaviors and concepts of rational choice. Consequently, the decisions taken are based upon the agents perceiving the full range of information available and taking appropriate measured and rational decisions. However, behavioral economists and anthropologists have cogently argued that given the plethora of information available, individuals do not simply sort through available information and make the 'best' decisions about calorific intake and other physiological requirements. As stated by Alex Bentley and colleagues (2010):

> 'Few behavioural choices can be explained exclusively in terms of individual costs and benefits involving calories, or energy, time or other currency. Even hunting, which is not the most reliable means of procuring protein—females can often supply it more reliably by gathering nuts, for example (Lee & DeVore 1976)—is simultaneously a crucial means for males to socialise and acquire prestige (Wiessner & Schiefenhövel 1997; Henrich & Gil-White 2001).' Bentley *et al.* 2010.

Although archaeologists and anthropologists have long been aware of this argument, there is a temptation to configure agent behaviors in such away that they obey rational rules alone. One of the easiest ways of adding more realistic behaviors is simply to provide more opportunities for copying behaviour, an approach that successfully captures how many individuals and social groups actually behave (Ormerod 2012: 193-228; Bentley & Shennan 2005; Bentley *et al*. 2010). Such behavior, according to the authors, more successfully accounts for the rich-get-richer affects than either rational choice or even network models. This process is particularly relevant to the modeling, because in traditional societies key bearers of knowledge form beacons of emulation. For example in traditional parts of southern Arabia it is common to find that one farmer is often recognized as the person with the greatest agrarian wisdom, with the result that other farmers tend to copy his planting program rather than individually taking decisions based upon the information available. This is basically the 'Baghdad traffic rule', namely that when driving through Baghdad, one is best advised to follow the predominant stream of traffic rather than attempting foolish things such as taking the most rational route or simply following signs. Such behaviors which also appear to work for sheep and goats (but not necessarily lemmings) need to be incorporated into our models. That said, it must be reiterated that our current models did create rich-get-richer outcomes which did not entail copying.

One aspect of human behavior captured by some of the models is risk. For example, in Chapter 13 the salinization scenarios included conservative farmers who incorporated fallow whereas others adopted more risk-taking strategies by employing shorter fallows. The parameter that controlled for such risk taking was incorporated into the model code, and the evident benefits of these alternative strategies are evident in Chapter 13.

However, the MASS simulations did not take sufficient heed of approaches that incorporated agent learning. Instead, our focus was more on how existing or perceived behaviors were thought to have affected landscapes or settlements. In contrast, more emphasis on agent learning would have allowed agents to completely derive such solutions as farming strategies or trade relationships on their own (i.e., without being programmed). However, this deficiency is more a result of the strategy chosen by the MASS group than any limitation in agent-based models.

Although our model structures did grow to include a larger region which approximated to the scale of a small city state (ca. 500km^2), we lacked the time and resources to run the model over such large areas. Therefore there is a need to increase the scale of ABMs to cover larger areas and to include neighboring communities. However, as noted above, this runs into the need for ever increasing computational power, which although soluble was not possible within the duration of the Project.

Ironically, although the project was based upon principles of bottom-up simulations, we were less successful at migrating the skills of agent-based modeling from the modeling group (Argonne National Laboratory, DIS division) to the Oriental Institute, Chicago, where the academic inputs were developed. This challenge was recognized early on, and although we did train the appropriate individuals from the Oriental Institute, the lead-time for such training was beyond the realistic life-span of the project. One solution, again adopted, was to develop a GUI (graphical user interface) which would enable the team members to run their own scenarios; although this was almost achieved, the final GUI required further technical work which could not or did not happen within the duration of the project. This was unfortunate, because by developing a GUI, it is possible for archaeologists, anthropologists and historians to 'take the controls' and run numerous scenarios themselves. That said, one must caution that a GUI must be sufficiently flexible to allow completely new scenarios to be developed otherwise these secondary modelers will be locked into a single modeling framework.

Here one necessarily must confront the major question, namely whether to adopt low or high dimensional models? The pros and cons have been discussed above, but they persist because for the potential modeler there is always the question: what are the driving variables? What should we include or exclude? One question that was put at a recent MASS workshop is that there is an assumption in much modeling that our models incorporate all the key variables; to what degree can such models be explanatory, if the key variable happens to have been omitted; how do we determine this? Certainly the best way of dealing with this is to be flexible and run as many different simulations with different input variables as possible, a strategy which is perhaps easier with low rather than high-dimensional models. Nevertheless, despite some of the stated disadvantages of high dimensional models, the case can be made for trying to include as many variables as is feasible in order to maximize the realism. Nevertheless, we acknowledge that a simple, streamlined approach with fewer inputs may be more effective in light of the difficulties of testing high resolution models. On the other hand, even at our final seminar,[15] ideas were being offered for the inclusion of further inputs and for adopting different model frameworks, a point which serves to underscore that modeling is never complete, but rather an ongoing process of error and refinement. Ideally this process should entail stripping out redundant inputs and processes, but in reality this may require the addition of new factors as well.

Although our models were realized within a spatial framework via JeoViewer and an object-oriented GIS with dynamic capabilities (Lurie *et al.* 2002), the spatial representation was not taken as far as it could be, and we often faced the dilemma of producing elegant and perhaps explanatory models that lacked a realistic spatial dimension. In general, the trajectory of the MASS Project was towards the exploration of social coping mechanisms of small-scale communities rather than grand schemes of ecological modeling.

Lest the above should seem to be overly pessimistic, we point out that the interdisciplinary seminars held by the MASS group were a major outcome of the project. This is because they resulted in enlightening and frank discussions of not only the very different nature of the types of evidence being gathered as input for the models, but also managed to illuminate innumerable aspects of daily life in past Mesopotamian societies within a much broader framework than would normally be possible. MASS meetings, which included specialists in cuneiform studies, archaeology and geoarchaeology, remote-sensing, anthropology and computational informatics, were honest, divergent, and sometimes hilarious. Not only did they break down boundaries, at the same time they enabled genuine breakthroughs to be made, specifically in our understanding of the morphology and development of irrigation systems.

SUMMARY AND CONCLUSIONS

The wide-ranging nature of the modeling exercise did enable the MASS Project to contribute to our understanding of Mesopotamian urbanization. It is now well known that in the fourth and third millennia BC, southern cities grew significantly larger than those in the north. This was thanks to a combination of higher crop productivity under irrigation and probably more important, the increased efficiency of transport along rivers and other channels (Algaze 2008). Not only were the herringbone patterns of levee-based field systems capable of sustaining rapid rates of population growth by the selective addition of fields, these systems were functionally linked directly into the main trunk rivers and channels. Here we recognize that the herringbone field systems were probably only one component of a much more complex landscape, which as stated by Adams for the

[15] At the Oriental Institute, Chicago, in March 2013 as part of the Robert Braidwood visiting scholars program.

province of Umma, would have also included extensive areas of open space between these arteries of high productivity (Adams 2008).

Settlement growth was not unrestricted, however, and constraints, in the form of salinization in flood basins, under most circumstances must have limited cultivation to the better drained levees (Altaweel: Chapter 13). If settlement and cultivation did spread off the levees into the lower plains and basins, fields in such locations would have been vulnerable to salinization and may therefore have been short-lived. Thanks to the arteries of movement along the main channels, growing centres that exceeded the productivity of their local areas, would have been able to either to import bulk food from up or downstream, either via taxation, exchange or by force.

In fact connectivity, a central platform of discussions in Mediterranean landscapes (Horden & Purcell 2000) was also a valuable concept in the various levels of models employed in the extended MASS Project. The value of connectivity between households, was key to household sustainability (as discussed in Chapter 11), but also inter-site connectivity must have enabled settlements to expand beyond the limitations of their environment as discussed above. Moreover, preferential location on networks of connectivity is also important in the development of urbanization as demonstrated in Chapter 14. Although logically these different systems of connectivity should themselves all connect, this was not possible to achieve, and to date we have not been able to scale up different levels of connectivity from household to city, although this should be technically feasible.

In the north, where settlement in the fourth and third millennium BC attained a growth ceiling which limited their size to some 100-120 hectares (Chapter 3), populations were probably limited to some 10,000 to 20,000 people. This was probably due to the challenge of moving bulk products such as cereals by land. Unfortunately the modeling project was unable to attain the scale necessary to test this level of constraint. Here, the models could usefully include the perspective of Roland Fletcher who argues for a range of scalar thresholds as well as social practices that constrained the size of ancient cities (Fletcher 2012).

Nevertheless, the model scenarios did demonstrate that small-scale communities of a few hundred people were rather resilient, and stresses caused by short-term droughts, loss of the labor force and so on were met by increased exchange activities by the agent-households. Because such small settlements were numerically the most common size class throughout both the north and south, this makes the model results of greater relevance than might be appreciated. The overall resilience of the modeled communities during times of stress not only suggests that such communities were unlikely to simply collapse under the action of 'normal' stresses, but also, the increased and asymmetrical patterns of exchange that resulted means that stress effects may have contributed to the development of social differentiation.

These rich-get-richer effects were evident both in the household diaries and in the sedentary pastoralist models (Chapters 11 & 12). When such results and principles are scaled up, as in the case of the southern cities' model (Chapter 14), then one can recognize how the better located (or simply 'more attractive' or more accessible) cities were capable of rapid growth at the expense of the other settlements in the region (Chapter 14). Equally, a king located in such an advantageous position could be the beneficiary of such growth, with his own city expanding accordingly. Such rapid growth must have been accelerated thanks to both the irrigated field systems as well as the efficiency of movement of bulk goods along the network of rivers and canals. Moreover, because the short canals on the levee slopes were capable of being administered by local social and kin-based groups, they had the potential to weather the rise and fall of states and kingdoms over long periods. Overall, probably one of the major contributions of the MASS Project is not at the grand scales of urbanization and state development, but more in the areas of understand how small-scale communities coped under stress. Scaling such communities up to city-size continues to present a challenge for future research.

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