Chapter 9
Simulating Land Use of Prehistoric Wetland Settlements: Did Excessive Resource Use Necessitate a Highly Dynamic Settlement System?

Tilman Baum

9.1 Introduction

From the archaeological investigation of findings in peat-bog and lake-shore sediments in the North-Western pre-alpine forelands, it is known that people built their wooden houses in these locations from the 5th to the first Millennium BC (Menotti 2004). In more than 150 years of interdisciplinary research, detailed knowledge has been gained from the excavations and analyses of the oxygen-depleted layers and the remains of wooden houses. However, a remarkable gap exists between highly resolved knowledge on certain issues, and some very fundamental, yet unsolved questions. Thus, it is known exactly which plant and animal species have been consumed (Jacomet 2009), but the husbandry and land use methods are contradictory discussed (Ehrmann et al. 2009; Bogaard 2002).

Evidence is for a highly dynamic settlement system and a short occupation time of many sites, yet the reasons are as unclear as the feedback mechanisms inside of the system (Ebersbach 2010). One reason for this disparity might be conditioned by the biased distribution of evidence that is concentrated in waterlogged locations. Inside of the sites, a lot of condensed information is stored, and in many cases, settlement structure, house architecture and consumption or production modes can directly be assessed from the excavations (e.g. de Capitani et al. 2002; Jacomet et al. 2004; Dieckmann et al. 2006; Schlichtherle et al. 2010). Yet the actions performed in the environment of the sites—and thus emergence of cultural landscapes—may only be inferred from the relevant findings in the sites, accompanied by sparse and punctual paleo-environmental information such as pollen profiles. Therefore, I present an approach to simulate landscape development around wetland sites as caused by the relevant anthropogenic and environmental processes.

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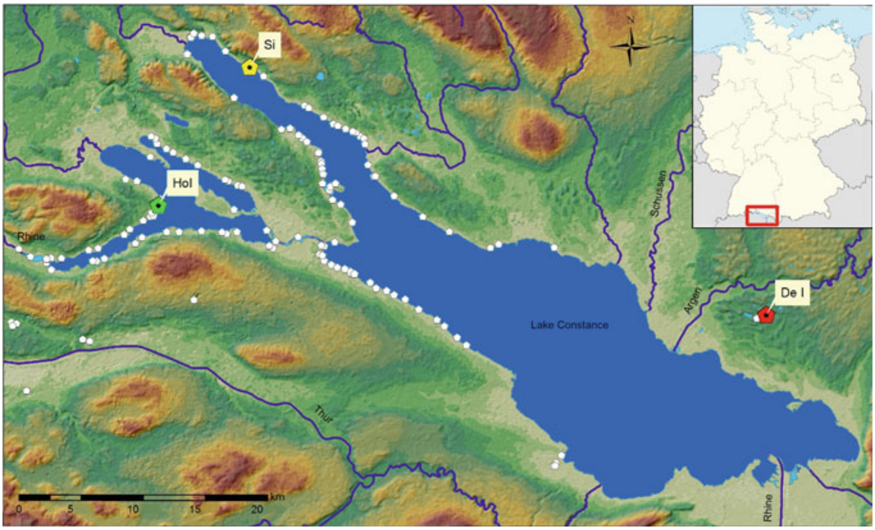

Fig. 9.1 Prehistoric pile dwellings around Lake Constance (not complete). The sites Ho I, Si and De I in *green*, *yellow* and *red* are discussed in the text (after Baum 2014, Fig. 1)

I mainly use GIS and ABM to integrate spatial, (paleo-) environmental and archaeological evidence with different competing models of land use in the wetland sites. The resulting scenarios are located in a hypothetical setting in order to underline the model character of WELASSIMO. To this aim, I chose a real landscape where no archaeological evidence is known, reconstructed a hypothetical natural environment integrating modern and paleo-environmental data, and simulated land-use activities in it as they have been reconstructed for the sites highlighted in Fig. 9.1, that were occupied in the early 4th Millennium BC. Thus it is possible to investigate the different pathways of landscape development and the systemic implications of certain hypotheses. The demand in non-finite resources such as livestock pasture, crop fields or suitable timber and their spatially and temporally varying availability can be assessed. In a second step, these hypothetical scenarios may be applied to specific archaeological sites integrating the local conditions, contributing to the understanding of the evolution of the earliest sedentary societies in this region.

9.2 Regional and Archaeological Setting

WELASSIMO is a tool to simulate the land-use of a hypothetical, idealized settlement, but I used data from several sites that have been excavated to a significant extent as a reference. Figure 9.1 shows the three main sites that were used to this aim. All sites are located in South-Western Germany in the vicinity of Lake

Constance. The larger Lake Constance area is shaped by the Würmian glaciation, as documented by numerous lakes of various sizes, kettle-hole peat-bogs, drumlin fields and wide areas of relatively fertile soils on glacial till. In the vicinity of Lake Constance, the sub-continental climatic conditions of the pre-alpine forelands are locally relatively favorable with moderate winters and mostly mild and humid summers. The site Ho1A (Hornstaad-Hörnle 1A, 3918—ca. 3905 BC) is located near the outlet of Lake Constance into the River Rhine. It was excavated to a large extent, and an impressive body of evidence is published on archaeological and ecological questions, e.g. Dieckmann et al. (2006), Matuschik (2011), Maier et al. (2001). Up to 45 houses were inhabited contemporaneously, each of which is interpreted by the authors as representing an individual economic unit. I use their interpretation for the sake of simplicity, despite new studies that demonstrate how the social system is likely to have been more complex than suggested by the equation house = household = nuclear family (Doppler et al. 2013). At the site Si (Sipplingen-Osthafen), up to 15 anthropogenic debris layers bear witness of frequent settlement activities from the 39th to the 24th century BC (Billamboz et al. 2010). Dendrotypological studies on the wooden house posts yield evidence of forest management systems, such as the use of primeval forest, the existence of coppiced forests, or intensive forest thinning (Billamboz and Köninger 2008; Billamboz 2014). For this project, I refer to the layers Si1 and Si2 (3919–3904 BC). The third settlement is De1A, which lies at the shores of Lake Degersee and was inhabited at the beginning of the 40th century BC for a few years only. It was partially excavated recently, and only preliminary results are published until now, e.g. (Maier et al. 2010).

9.3 The Economic System: Data and Hypotheses

The general properties of the socio-economic system of the wetland sites have been described by various authors in relative consistency, e.g. Menotti (2004), Jacomet (2009), Gross et al. (1990) and can thus be described as follows. The inhabitants of the wetland settlements lived on a mixed diet comprising of products from crop and livestock husbandry, hunting, gathering and fishing. The relative importance of these elements varied due to external and internal factors (e.g. Schibler and Jacomet 2010; Schibler 2006) but it is generally agreed on that cereals provided a large proportion of the calorie demand. Hypotheses on crop husbandry vary, but it is highly probable that the plough was not used during the 5th and the first half of the 4th millennium BC (Ebersbach 2002). People built elevated houses in close proximity to or directly in shallow lake areas or in peat bog. The average lifetime of the houses was only several years (Ebersbach 2010), and accordingly, the occupation time of many of the sites was short. Interpretation of published data by the individual authors with respect to the internal functioning of the subsystems, however, is not always consistent (e.g. Ehrmann et al. 2009; Bogaard 2002, 2004).

This is especially true for the crop husbandry system. The major hypotheses on crop husbandry systems are:

(1) Shifting Cultivation (SC). The main arguments for this hypothesis on crop husbandry and land-use is evidence for frequent large-scale fires and for an increase in scrubland vegetation dominated by hazel at the beginning of the 4th Millennium BC (Rösch et al. 2002; Rösch 2014), which is correlated with settlement activity (Lechterbeck et al. 2014). Several authors interpret these phenomena as a result of a land-use system that is based on ash fertilization of the crop fields, e.g. (Ehrmann et al. 2009; Schier 2009). In this system, high nutrient availability due to a burning procedure allows for high yields, while the high demand for wood for the burning and very intense weed growth in the second year after the fire necessitate an annual shifting of the fields. Based on experimental reconstruction of this system, I assume annually varying yields with a long-term average of 2700 kg/ha (100 % dry matter) for SC on soils of average quality (Ehrmann et al. 2009, p. 67). Annual variation of the yield due to weather conditions is accounted for in all simulated husbandry systems as described below. An important objection to this scenario is the evidence that backs the following hypothesis (IGC).

(2) Intensive Garden Cultivation (IGC). The weed content of well-preserved crop stores have been analyzed (e.g. Maier 1999; Bogaard 2004; Jacomet 2006) using, among others, the FIBS-approach (Charles et al. 1997). The ecological properties of the crop weed plants are interpreted as evidence for a crop husbandry regime, which is in contrast to SC—based on permanent fields that are cultivated for more than just a couple of years (Bogaard 2004, p. 41 ff.). The analysis of isotope relations of the cereal grains justify the assumption of the use of animal dung for manuring of the fields, so that a small-scale, permanent and highly intensive cultivation is reconstructed (Bogaard 2012; Bogaard et al. 2013). Based on data of the Rothamsted Research Station on long-term cultivation of wheat with manure application, I assume an average yield of 2000 kg/ha (100 % dry matter; Poulton 2006), also with annual variation due to weather events. IGC requires a large number of livestock for producing enough dung; however, archaeological reconstructions of the minimal number of animal individuals (MNI) in the lake-shore sites seldom meet these numbers (Ebersbach 2007; Ebersbach 2013). Furthermore, the hypothesis does not explain the peaks of charcoal and secondary forest found in the pollen stratigraphies.

(3) Non-Intensive Cultivation (NIC). This scenario is basically the same as IGC, but with the difference that no manure is applied and thus, yields are markedly lower and soil nutrient depletion may occur after some time. I assume an average yield of 800 kg/ha (100 % dry matter), also based on the Rothamsted dataset (Poulton 2006).

(4) Integrated Forest Horticulture (IFH). During the formulation of the model, it has become obvious that neither of the land-use models published so far (SC, NIC and IGC) is capable of integrating all data with confidence. Therefore, an

alternative scenario (IFH) has been formulated in the course of the modelling procedure, which combines elements of the other scenarios, but is in better agreement with the published archaeological and environmental evidence. In this scenario, a large amount of the calorie demand is covered by hazelnuts, the growth of which is promoted anthropogenically. Thus, the peaks of charcoal and secondary forest as documented by palynology (e.g. Rösch 2014) might result out of the targeted stimulation of hazel growth, not of cereal cultivation. Cereals, in contrast, could make up only a minor portion of the diet. Therefore, only small fields might be sufficient, and intensive cultivation and manuring as described for IGC can be performed with a lower livestock density. Both the observations that led to the formulation of the SC-Hypothesis and the evidence for manure application and small, permanent fields as in IGC are included in consistency.

Further models on economic subsystems include:

(5) Livestock husbandry regimes. The relative importance of livestock, especially cattle, is debated; while cattle bones with signs of butchery are found frequently, the reconstruction of an approximate number of cattle kept per person is difficult and varies spatially and chronologically (Ebersbach 2013). This is important not only with respect to the nutritional significance of livestock, but also in relation to the possible amount of manure available for IGC and IFH (see Bogaard 2012). As dense forests covered the land—at least at the beginning of the sequence—large areas were presumably needed for forest pasture and pollarding. As the fodder value (i.e. the amount of fodder per area) of secondary forest is much higher than that of old-growth primary forest, a further reason for the charcoal and hazel peaks may be found here.

(6) Forest management strategies. An ubiquitous and mostly well preserved element of the wetland sites are the remains of wooden construction piles. The analyses of their tree-ring patterns yields not only an absolute dating for the felling of the trees, but also information on the structural and compositional features of the forest stands they grew in (Billamboz and Köninger 2008; Bleicher 2009; Billamboz 2014). While coppiced forest or single tree selection dominated in some phases, in others only a few old trees seemed to be available. Likely for the ease of processing, quite young trees with a diameter of 5–20 cm were preferred in the beginning of the 4th Millennium. As these are not necessarily available in adequate numbers in a primeval forest, a suitable stand certainly constituted a valuable resource. Again, anthropogenically induced secondary forest growth might have been a valid strategy to improve resource availability.

(7) Foraging. Hunting, Gathering and Fishing are documented in most of the sites. The overall importance is difficult to assess for a number of reasons and may have varied largely (e.g. Schibler 2006; Jacomet 2006). Schlichtherle et al. (2010) stated a link between an increase in hunting and low crop harvests due to bad weather for the settlements at Lake Zürich. The importance of fish is not

well documented; however, Gross et al. (1990) stated that fish is low in calories and thus, a change in the quantity of fish cached would not necessarily make a large difference. Gathering of wild plants is documented regularly. Among the gathered plants are fruit, berries, herbs and especially nuts. Concerning the latter, it could be demonstrated that generally, they are extremely rich in calories and make an easy-to-store staple food (Holst 2010). While gathering activities are included in some detail within WELASSIMO, hunting and fishing are not treated as a single process but are instead merely represented in a schematic way.

9.4 The Model: Questions and Design

The proximate objective of WELASSIMO is an answer to the question, whether a need for a frequent settlement relocation (as documented by the archaeological record, e.g. Bleicher 2009; Dieckmann et al. 2006, p. 418; Ebersbach 2010) might have arisen out of the land use and the resource demand of the inhabitants of the wetland settlements at the beginning of the 4th Millennium BC. To this aim, I have programmed a simulation of the land use of a group of 1 to 20 households according to the relevant hypotheses integrating archaeological and (paleo-) environmental data. In contrast to the pattern observed by archaeology, households do not relocate after a number of years, but are permanently bound to one location. Thus, I want to observe whether resource scarcity arises after some time. Furthermore, an understanding of the systemic implications of different hypotheses on prehistoric land use as described above and of the resulting landscape is aimed at. I want to know, how large the economic area of the sites was, how the economic activities affected the environment—and vice versa, how the environmental conditions influenced the internal functioning of the sites. A more abstract objective is to analyze the human-environment-system and to define the fundamental parameters and factors. The research is facilitated by the large archaeobiological database published and the exact dating of settlement dynamics with annual resolution, as provided by dendrochronology. As a first step, I reconstructed the environment of a hypothetical settlement based on paleo-environmental and modern data. Therefore I chose an area of 5 × 5 km located in the Lake Constance area with similar geographic properties as in areas with well-known wetland settlements and a good availability of soil data and a high-resolution digital elevation model. This data (Table 9.1) was processed in Arc-GIS and transformed into grid cells with a

Table 9.1 Primary and derived data used to reconstruct the idealized environment of WELASSIMO. (DEM: © LGL Baden-Württemberg; Soil data: LGRB 2013)

Geodata	Derived grid cell data
Digital elevation model	Elevation; Slope; Aspect; Walking Chronozones
Modern soil map	Soil type; Vegetation cover

resolution of 25 × 25 m. These were used as the basis to generate a dynamic model environment with NETLOGO. Using the GIS-Extension of this agent-based programming software, a surface was created where every cell is characterized by a set of certain environmental parameters, some of which are static, such as elevation or soil type, others are dynamic and are updated in annual time steps, such as the state of the vegetation cover, the forest development phases or the quantity of relevant resources.

The modern soil map had to be adjusted to assumed Neolithic conditions, as certain modern soiltypes have only developed with intensified human impact since the Neolithic, and others have changed due to natural or anthropogenic processes (Gerlach 2006; Vogt 2014). Since the exact nature and amount of these changes is nearly impossible to assess, the reconstructions are necessarily tentative to a certain degree. Similarly, the allocation of a certain vegetation type to a grid cell is an idealized simplification. I defined standardized forest compositions, based on the naturally dominant tree species in the 4th Millennium as reconstructed by pollen analysis (Rösch 1990; Lechterbeck 2001) and on the modern natural vegetation in the region (Lang 1990), and assigned these communities to certain soil types. The age of the trees in primary lowland deciduous forests is not homogeneously distributed, but instead, these woods are characterized by a mosaic of stands of different development phases, as described by various authors (e.g. Härdtle et al. 2004, p. 85; Bernadzki et al. 1998; Bobiec 2012). Therefore also in WELASSIMO, the forest patches are grouped to "stands" randomly consisting of 1–20 cells sharing the same forest development phase. In the optimal and in the terminal phase, the characteristics and the resource availability are different from the regeneration and the juvenile phase. Especially, livestock fodder value, gathering value and timber availability vary. The stands mature with every model year and, by reaching a defined threshold, enter the next development phase. Thus, a simplified dynamic representation of vegetation succession and forest development phases is generated in a so-called cellular automaton.

The economic processes of interest are simulated as a second step inside of this environment. The basic unit (or "agent") of the model are the households = houses, which are idealized and represent a standardized group of assumed 6 persons comprising adults, children and elderly. The number of households is selectable in a range from 1 to 20, representing a population of 6–120 people. The main driver of the model is the annual demand in calories and non-finite resources of the households. The annual calorie demand of one household is defined as $365 * 6 * 2000 = 4{,}380{,}000$ kcal, which is the average demand of all potential inhabitants of the houses. In accordance with the objectives of this research, only non-finite resources that exhibit dynamic properties are considered: arable and fertile soil, livestock pasture, hunting/gathering/fishing areas, and suitable timber (see Table 9.2). Finite resources such as flint for tools or clay for pottery are not considered. The households have a set of subsistence strategies that they apply in order to meet their demand (see Fig. 9.2): crop husbandry, livestock husbandry, hunting/fishing and gathering, and timber extraction. While the basic properties, the timing and the functioning of these strategies is predefined and encoded inside of

Table 9.2 Quantitative data on resources per patch (1/16 ha = 25 × 25 m) as assumed in WELASSIMO. Numbers in brackets are the standard deviations of the specified mean. Values vary according to the forest development phase and environmental stochasticity (not for soil fertility). For livestock fodder, gather-value and soil fertility, the values are relative to 1 (the assumed maximum) and are further quantified in the model; values for suitable timber are absolute and give the range of numbers per patch

	Primary forest (beech) on luvisol	Primary forest (alder/ash) on gleysol	Primary forest (alder carr) on histosol	Young fallows	Secondary forest
Livestock fodder	0.2–0.3	0.3–0.4	0.2	1.0	0.5–0.6
Gather-value	0.005–0.01	0.005–0.01	0.005	0.05–0.6	0.6–1.0
Suitable timber	2–16	4–30	0	0	23–34 (7)
Soil fertility	1 (0.1)	0.7 (0.1)	0.2 (0.1)		

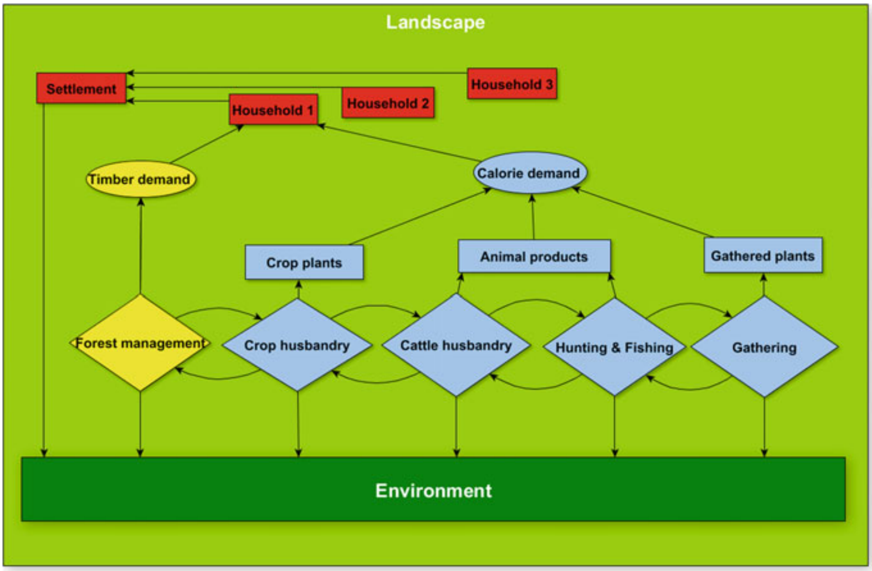

Fig. 9.2 Schema showing the interplay of the various elements of “Landscape” developing in the vicinity of a hypothetical wetland settlement in the 4th Millennium BC. Landscape is understood as the result of anthropogenic and natural processes shaping the human environment. Rectangles symbolize physical elements, diamonds denote processes, and ovals show system drivers. Arrows either denote influence on or affiliation to a certain element

the model, the exact configuration is defined by the observer, so that the outcome of various assumptions and hypotheses can be studied. The choice options for the observer are summarized in Table 9.3.

Table 9.3 Choice options for the observer

Cropping system	Importance of meat and fish	Source of plant calories (cultivated/gathered)	Source of meat calories (livestock/hunted and fished)
SC	Low (5 %)	100 % cultivated	100 % livestock
IGC	Medium (15 %)	80/20	75/25
NIC	High (25 %)	50/50	50/50
IFH	Not consumed	20/80	25/75
			100 % hunting and fishing

During a simulation run, the households cover their demand according to the chosen scenario. They always choose the patches with the desired properties which have the minimal traveling cost—a parameter that differs from the mere Euclidean distance in that realistic walking time is calculated by additionally taking into account the decreasing walking speed with increasing slope. For the crop fields, the soil type of the patches must be "Luvisol" and the slope must be below 25°, an arbitrary value. The other soiltypes that supposedly covered relevant areas in the Lake Constance area in the Neolithic are "Gleysol" and "Histosol", which are less well suited by far and therefore are excluded a priori. The size of the crop fields is calculated at the beginning of the simulation and remains fix for the subsequent years. The underlying assumption is that Neolithic people had acquired or inherited a knowledge about the most appropriate size of their fields, with respect to the available work force and the minimal proportion of crop calories aimed at. They definitely had experienced that crop yields fluctuate in wide ranges, and that the success and the fulfilling of the aims is dependent on external factors. To account for this context, the annual crop yield is calculated using the assumed average yield for the respective crop husbandry method as described above, modified by a factor for the soil fertility of the patch (which is dependent on the duration of crop production on this spot) and a factor which represents weather stochasticity. The rate of soil degradation is taken from a simulation performed with the crop simulation model "MONICA" (Nendel et al. 2011), while the influence of weather stochasticity is extracted from the same dataset and additionally from the yield series of the Rothamsted Experimental Station (Poulton 2006). An example of both the Rothamsted and the simulated yield series is shown in Fig. 9.3. This procedure means that if the observer chooses a diet comprising of 50 % cultivated plants to be produced with "IGC", the aim of one household would be to produce (4,380,000/2) = 2,190,000 kcal. As 1 kg of cereals equals 3000 kcal, and the average yield in IGC is assumed to be 2400 kg/ha, in this simulation run, one household cultivates an area of 0.3 ha equaling 5 patches. Yet due to stochasticity, yield success is likely to differ from the average yield. For reasons of simplicity, the only crop plant considered are cereals, although pulses, flax and poppy are also documented to a minor extent.

Average yields for the use in WELASSIMO are taken from the Rothamsted Dataset for IGC, IFH and NIC and from Ehrmann et al. (2009) for SC, while loss in

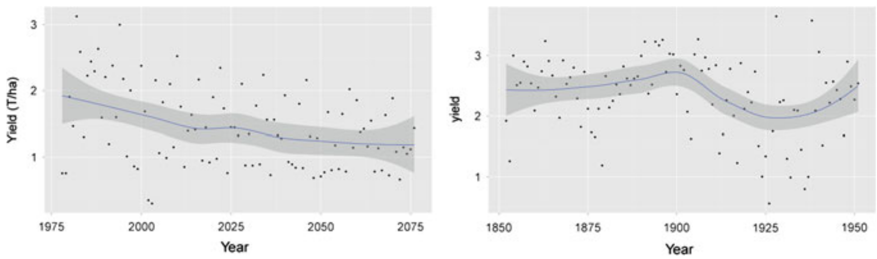

Fig. 9.3 *Left* Synthetic crop yield series (100 % dry matter) of 100 years simulated with the MONICA-model (Nendel et al. 2011). The scenario is IGC: annual application of manure (10 T/year/ha) and intensive weeding. The declining long-term trend is reflecting loss in soil fertility, while weather variability accounts for the annual variation. *Right* 100 years yield-series (100 % dry matter) as documented by Rothamsted Research. Yields increase slightly in the beginning due to a very high annual application of 35 T of manure per hectare. The decline in yields after 1900 AD is a consequence of reduced weeding, the rise of the curve is a consequence of renewed engagement and improved husbandry methods (Poulton 2006)

soil fertility is taken from the simulation. The annual demand in patches for livestock pasture and pollarding is dependent on the configuration set by the observer, and additionally on the vegetation cover of the patches. In the Neolithic wetland settlements, the minimum number of livestock individuals (MNI) per household lies between 0.1 and 4 (Ebersbach 2013). The livestock density in WELASSIMO uses these values as minimum and maximum values. Only cattle are considered, even if pigs, goat and sheep are also documented (e.g. Schibler 2006). If the importance of animal products and the proportion of domestics therein is set to high, or if IGC or IFH are selected and the need for animal dung is large, a higher MNI is used than if SC or NIC is chosen, and no livestock products are consumed at all. As shown by various authors, the area necessary to support one cow is highly dependent on the quality of the pasture or the area used for pollarding. While on grassland meadow (for which there is no proof in the Neolithic), 1.2 ha might be sufficient (Ebersbach 2002, p. 156), in a poor pine forest 20–30 ha are needed (Adams 1975, p. 148). In Welassimo, a minimum of 2 ha per cow on young fallowing areas and a maximum of 12 ha per cow in beech forest of the optimal and terminal phase are assumed. Livestock will choose patches with soil type not Histosol without crop fields with the least walking cost.

Also the area required for gathering is dependent on the model configuration as chosen by the observer and the vegetation cover of the respective patches. I assume that the maximal "gathering value" an area can have is reached when it is covered with secondary forest growth dominated by hazel, a vegetation type typical for the wetland sites as documented by palynology (e.g. Lechterbeck 2001; Rösch et al. 2014). Hazelnut kernels are extremely rich in calories (6000 kcal/kg). Using very conservative numbers given by Holst (2010), on one hectare of this vegetation type about 84 bushes may have grown in the Neolithic. 2000 nuts per bush may be harvested, adding up to an average of 900.000 kcal per year and hectare, divided by

16 for the patches (which have the size of 1/16 ha). These patches get the relative value of 1/16. The minimal gathering value a patch can have is arbitrarily set to 0.005/16. Thus, an area covered with mature hazelnut bushes yields 200 times more calories than the poorest areas (e.g. peat bog or optimal/terminal-phase beech forest). While the maximal value for nuts is backed by other studies, the lower number is speculative, and is open to discussion. The requirement in gathered calories of the households is the relative value of 1 * the proportion set by the observer, equaling a potential importance of minimum 0 and maximum 80 % of gathered calories. So, to meet this number, the households visit successively the patches beginning with the ones exhibiting the lowest travel costs, and add the respective gather value to their annual calories provision until the required amount is met.

The required area for hunting and fishing is not (yet) quantified, due to difficulties with finding reliable data. It is hypothetically assumed to have been sustainable; the simplifying assumption behind is that neither the populations of wild animals nor fish are severely limited in quantity as long as relatively small human populations exploit them. Furthermore, the degree of uncertainty with the decline in game or fish density due to human exploitation is dependent on too many factors to be simulated with confidence in this project. The only representation of these activities inside the model is the annual filling up of stocks according to the chosen parameters, with slight variations allowed for. The fluctuation of the success of calorie provision by livestock products, hunting, gathering and fishing in WELASSIMO is lower than the fluctuation of crop yields. If the observer chooses an importance of 5 % for one of these foodstuffs, than the actual value will be around 3–7 %. The reason for this is that field size is fix, and bad yields cannot be compensated by simply harvesting more patches. To the contrary, in hunting, fishing and gathering, endless resources are assumed, if the radius of action is extended. This is only possible because worktime limitations are not accounted for in WELASSIMO. The main reason is that they are used for validation; this is discussed below. As can be seen on the center panels of Figs. 9.4, 9.5, 9.6 and 9.7, in many cases the sum of all foodstuffs does not equal 100 % of the aim, but instead, over-and underachieving happens quite frequently. While in a real situation, people would try to mitigate this by increased investment in other calorie sources, this is not accounted for in WELASSIMO in order to highlight this effect.

The demand in timber is determined by the house age. A few logs are needed every year for reparations, while the probability of a complete reconstruction increases every year. In the year of the breakdown of the house, 120 logs of 5–20 cm are needed (combined after Luley 1992; Petrequin 1991). The area necessary to meet these numbers is dependent on the numbers of suitable timber per patch—again, patches with lowest travel cost are considered first, suitable timber extracted as needed and provided, and if needed, the next patch will be used as well. In the model, a beech forest in the optimal phase may have no suitable logs at all, while in the regeneration and in the juvenile phase of a mixed alder-ash forest, 400–600 such

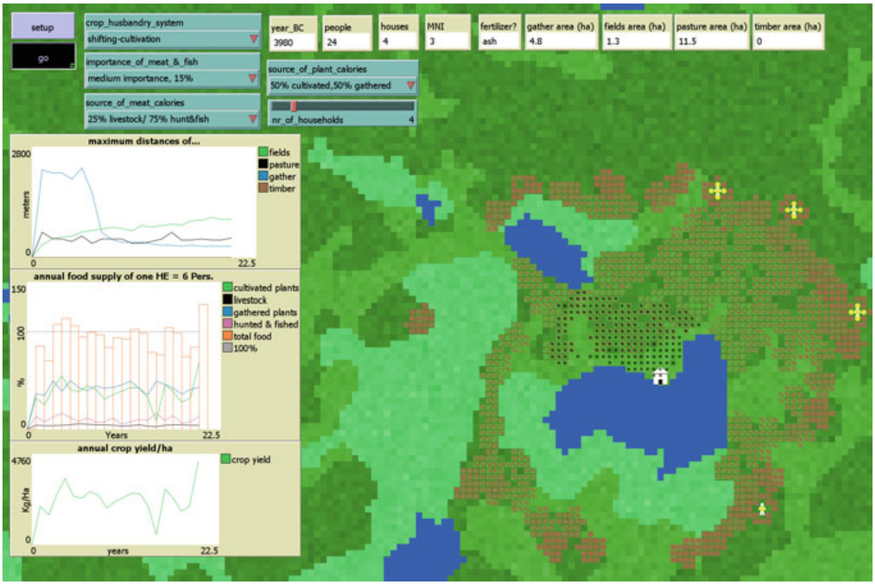

Fig. 9.4 Scenario 1 simulating land use, resource use and economic parameters of a hypothetical Neolithic wetland settlement relying on SC. *Grey* and *blue boxes* in the *upper left corner* are observer choice options, *white boxes* are monitors displaying current model conditions and results. (MNI = minimum number of individuals = livestock). *Blue areas* are lakes, different shades of *green* are forests of different species composition on specific soil, and brownish colors are fallowing patches. Only *dark green* colors (representing Luvisols) are soils suitable for agriculture. A *white house symbol* represents the settlement. *Black circles* mark patches affected by livestock browsing. One raster cell equals 25 * 25 m = 1/16 ha, the largest lake measures 750 m from east to west. Note that the maximum on the y-axis of the lowest panel is higher than in the other three scenarios

trees may be found (calculated after Korpel 1995, S. 127–137). On young secondary forest with ages of 20+ years, an assumed maximum of 700–800 suitable trees per hectare is simulated.

9.5 Four Scenarios

In order to exemplify the simulations, four scenarios with a configuration as described in Table 9.4 are presented in the Figs. 9.4, 9.5, 9.6 and 9.7, which show the simulations 20 years after the start (i.e. in the year 3980 BC). In order to highlight the implications of the cropping systems, the other parameters are unaltered or vary only to a minor extent. The model allows for any of the parameters in Table 9.4 to be changed, so the scenarios shown here represent only a few out of 320 possible configurations. The main window shows the landscape development due to the processes performed by the inhabitants of the households. In the upper

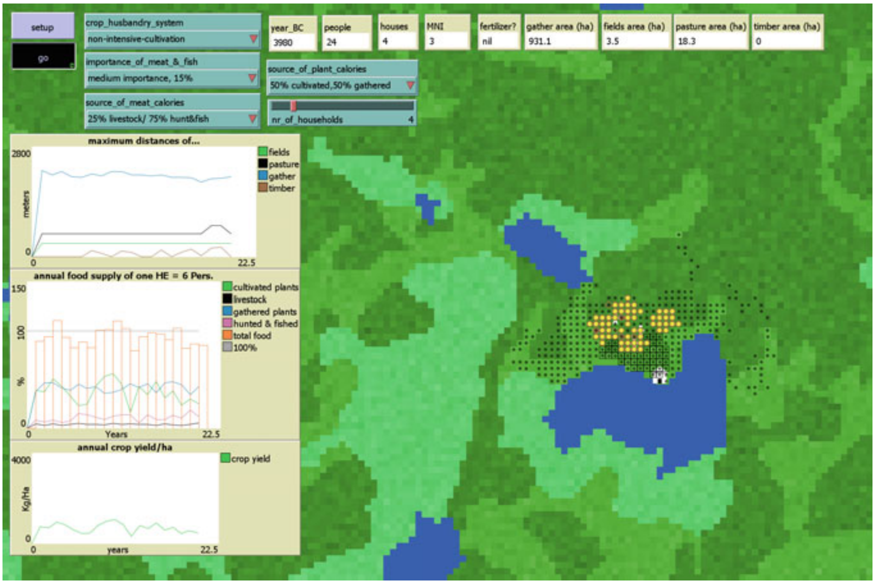

Fig. 9.5 Scenario 2 simulating land use, resource use and economic parameters of a hypothetical Neolithic wetland settlement relying on non-intensive cultivation. *Black boxes* are patches affected by timber extraction. The other symbols have been described in Fig. 9.4

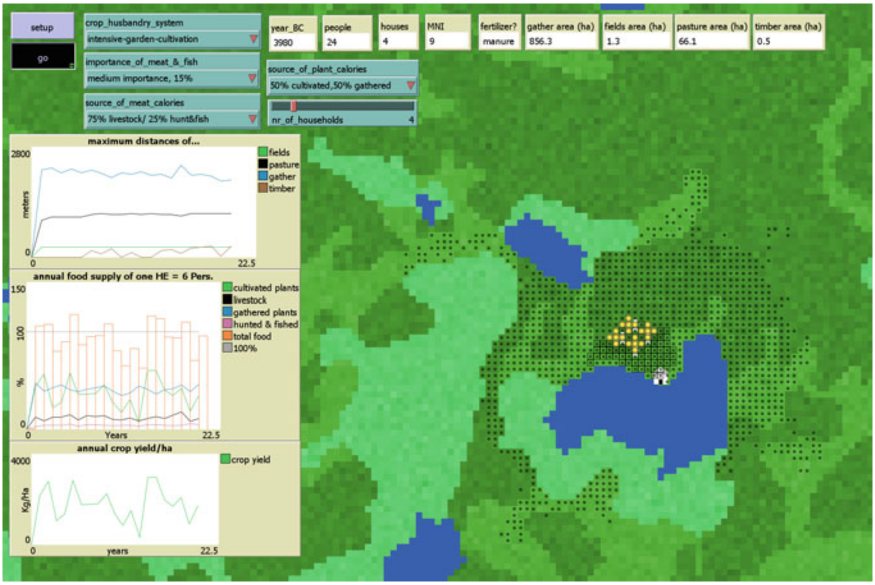

Fig. 9.6 Scenario 3 simulating land use, resource use and economic parameters of a hypothetical Neolithic wetland settlement relying on IGC. All symbols have been described in Figs. 9.4 and 9.5

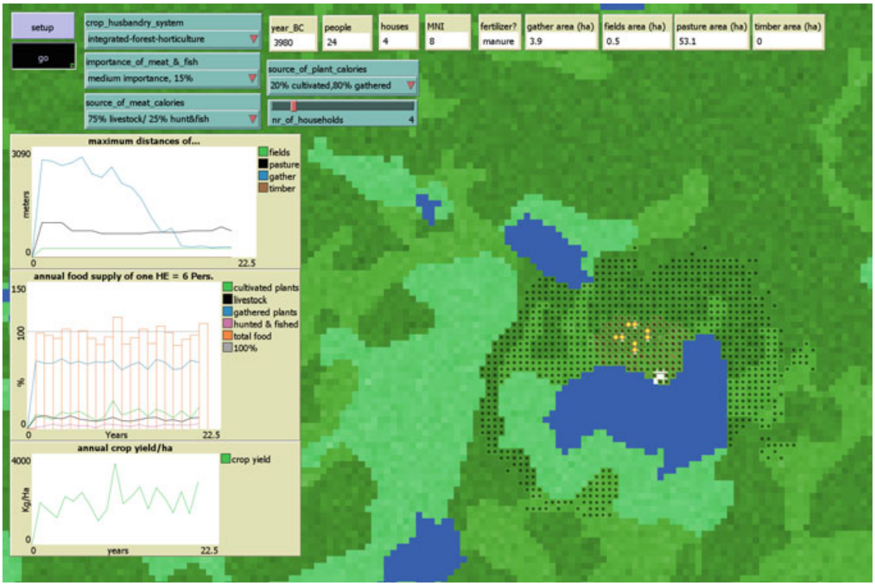

Fig. 9.7 Scenario 4 simulating land use, resource use and economic parameters of a hypothetical Neolithic wetland settlement performing IFH. All symbols have been described in Figs. 9.4 and 9.5

Table 9.4 Specifications of the Scenarios 1–4 as shown in Figs. 9.4, 9.5, 9.6 and 9.7 and discussed in the text. Abbreviations as above

	Cropping system	Importance of animal products	Source of plant calories	Source of meat calories
Scenario 1	SC	"Medium (15 %)"	"50 % cultivated, 50 % gathered"	"25 % livestock/75 % hunting and fishing"
Scenario 2	NIC	"Medium (15 %)"	"50 % cultivated, 50 % gathered"	"25 % livestock/25 % hunting and fishing"
Scenario 3	IGC	"Medium (15 %)"	"50 % cultivated, 50 % gathered"	"75 % livestock/25 % hunting and fishing"
Scenario 4	IFH	"Medium (15 %)"	"20 % cultivated, 80 % gathered"	":75 % livestock/25 % hunting and fishing"

left corner, model parameters can be specified. The small white boxes on the upper rim show details of the actual model status. On the lower left side of each of the panels, three monitors are located. The upper one shows the annual maximum distances for the economic activities of the settlers as conditioned by the model parameters. The panel in the center shows a graph where the annual food supply is plotted. Lines of different colors give the annual supply of the different categories adding to the calorie supply, while red bars show the total provisions in relation to the aim (=100 %), which may or may not be met due to stochastic factors of food production.

The lower panel displays the annual crop yield given in kg/ha, which is dependent on weather variability, soil fertility and the chosen cropping system. In each scenario, 24 persons in 4 households perform land and resource use in order to meet their requirements. The proportion of animal products is 15 % in all scenarios, while the cropping systems and the composition of the vegetal and the animal shares vary. Scenario one (Fig. 9.4) shows the application of SC. This practice allows for high yields per ha with a maximum of 4330 kg/ha in year 20 and thus, individual field size per year need not be large. Each household unit is burning and cultivating only 5 patches (yellow field symbol) equaling less than one third of a hectare. Altogether, the four households require an area of 1.3 ha to produce enough crop plants to cover $(100 - 15)/2 = 42.5$ % of their calorie demand (see Table 9.3). However, due to the additional forest area required to gain wood suitable for this specific burning procedure, large areas are affected in the course of twenty years. This is depicted by the brown patches symbolizing fallowing areas due to prior field use or forest cutting. As large forest areas are cleared annually, I assume that no additional areas for timber extraction are required. The fallowing areas provide possibly a very good livestock pasture, and only a small area is needed annually for this use category. Similarly, the growth of wild food plants such as berries, apples and especially hazelnuts is strongly stimulated on fallows of a certain age. Even when no direct anthropogenic promotion of these plants is assumed, the area necessary to cover a relevant proportion of the calorie demand by gathering is relatively low when the hazel bushes reach a certain age and start bearing nuts. Hazelnut—bushes need a few years to establish, and only from their 5th year on will they produce an annually increasing harvest of nuts in WELASSIMO. In year 15, they reach their maximum harvest potential and hold this for 35 years. In the upper panel of Fig. 9.4, the decreasing distances for gathering activities are observable. Pasture distances decrease less pronounced, as the difference in fodder—value between primary forest and fallowing land is not as large as in gathered human foodstuff. Additionally, the effect is masked by the low MNI and the large fallowing area from year two on. The farthest distance of economic activities is about 1000 m after twenty years, and the reason for this distance is the high land demand for SC. As can be seen in the center panel, food requirements are met in 9 years out of twenty. This is however not related to the cropping system, but is due to the built-in stochasticity of yields due to weather variability simulated by the model. A bad series of low crop yields occurs in years 1 and 2 and in the years 14 and 15 of the simulation. In WELASSIMO, this has no consequences for the settlers, as an assessment of the consequences of food shortages and demographic implications are not the aim of this research.

Scenario two shows the situation for NIC (Fig. 9.5). All model parameters except the cropping system are the same as in Scenario 1. As no fertilizing occurs, annual yields are quite low with a maximum of 1050 kg/ha in year 10, and nutrient depletion further affects the crops as cultivation duration increases. 14 patches are needed per household, equaling 3.5 ha for the four households. Successively, the households will relocate the fields when a certain threshold of soil fertility is reached and yields begin to decrease largely. Only a few fallowing patches are seen bordering the fields. As most other areas are primary forest, which is relatively low in animal fodder, a larger area than in scenario 1 is needed for the feeding of the livestock. The same holds true for wild edible plants, so in order to cover the same proportion of calorie demand from wild plants as in the SC scenario, a much larger area is needed (931 ha in comparison to 4.8 ha). Black boxes around patches in Figs. 9.5 and 9.6 symbolize areas affected by timber extraction. In the course of time, the distances for this activity increase, as nearest suitable trees to the settlement are felled first and more distant ones later. After 20 years, the distance to meet the demand in suitable construction timber has reached 200 m for the 4 households. The distance to the other economic activities does not change to a large extent in the course of time. The calorie requirements are met in 9 out of 20 years. In year 12, a bad crop yield occurs, and only 78 % of the food provisions are acquired.

Scenario three (Fig. 9.6) depicts the situation for IGC. All model parameters remain the same as before, except the source of meat calories as described below. Due to intensive weeding and manuring, permanent fields cultivated for several years may be assumed without relevant soil nutrient depletion. Field sizes are quite small due to relatively high yields per ha (avg. 2400 kg), and 5 patches equaling a third of a hectare are sufficient for one household. The fact that the number of patches for crop husbandry are the same as in scenario 1 is due to rounding of decimal places in the model; exact numbers differ, but this is not shown. The high manure application necessitates a quite large MNI (Minimal Number of Individuals, i.e. livestock). This is automatically accounted for inside the model script when IGC or IFH are selected; to highlight these relationships, I have raised the share of livestock for the supply with animal products (which remains medium = 15 %) deliberately to 75 %. The high MNI require a large area annually for forest-grazing and pollarding. As already discussed above, primary forest is lower in livestock fodder; thus in scenario three, very large areas are needed to feed the livestock. Yet similar as in scenario 2, the largest area is needed for gathering wild edible plants. While the distances of fields and pastures remain more or less stable, the need for suitable timber constantly leads to more distant timber areas as already shown in scenario two. The calorie requirements are met in 7 out of 20 years only, with a remarkable depression in calorie supply in the years 10–13—but again, this is not reflecting any other factor than the built-in stochasticity of yields due to weather variability.

Scenario four simulates the application of IFH. The source of calories of animal origin is 75 % livestock and 25 % hunted, as in scenario 3, but in contrast to the other scenarios, only 20 % of the vegetable calories are covered by crop plants, while 80 % are collected, the bulk of which is assumed to be hazelnuts. This represents the hypothesis that the well-documented hazel and charcoal peaks in the pollen profiles might rather reflect the use of fire for the opening and shaping of the vegetation cover, than being coincidental side-effects of SC. As the benefit of these measures would not only be the promotion of hazel growth, but as well good livestock browsing and presumably higher numbers of suitable timber than found in primary forest, the necessary zone of land-use activities may be smaller than in the

Table 9.5 An overview of the maximum distances for economic activities for a simulated settlement size of 4 households (=24 persons) as a result of WELASSIMO

Scenario	5 years, 4 households	20 years, 4 households
1	2.2 km, gathering	1.0 km, fields
2	2.0 km, gathering	2.0 km, gathering
3	2.1 km, gathering	2.1 km, gathering
4	2.8 km, gathering	0.7 km, pasture

previous scenarios. This effect will show after a few years of cultivation, as can be seen in the upper graph of Fig. 9.7. In the beginning of the simulation, when no nut-bearing hazel bushes exist, the high proportion of gathered calories causes a large radius for gathering activities (note the maximum value on the y-axis, which is different from the other three scenarios). After a couple of years, however, this distance is reduced drastically, and then the most distant activities are livestock browsing in 740 m distance—thus, IFH allows for the smallest economic area of all scenarios. The annual opening of new fields for the creation of new “forest gardens” is assumed to cover the need in timber, thus no extra area is needed similar as in scenario 1, and in contrast to scenarios 2 and 3. As intensive cultivation of the fields is assumed here similar to IGC, and due to the low proportion of cultivated plants, only two field patches per household are sufficient, which is equivalent to an eighth of a hectare per household or 0.5 ha for 4 households An MNI of 8 heads of livestock for the settlement results out of this configuration. The calorie requirements are met in 18 out of 20 years, with a set of bad harvest in collected plants paralleled by low crop yields in the years 5 and 6 of the simulation. Annual variation in the harvest of gathered plants is assumed to be less fluctuating than for crop yields, which is discussed below; the effect of this hypothesis is less variation and less pronounced extremes of food supply. This is especially evident in year 10 of the simulation, where a remarkable peak in crop yields of 3570 kg/ha results only in a minor over-achieving of the total provisions. Table 9.5 gives an overview of the maximum distances for economic activities resulting out of different configurations after 10 and 25 years of simulation for the scenarios described above.

9.6 Discussion

What can we learn from these scenarios? Are they plausible, and can the degree of credibility be estimated? Is it possible to validate such as model at all? WELASSIMO is a simulation of a complex system of human—environment interactions and processes, which took place 6000 years ago; it is impossible to validate such a model with the same degree of reliability as a model of recent processes, because of the lack of real, “living” analogies of the model. However, it is possible to check the general plausibility and perform some tests to build confidence. The basic properties are taken for granted and need not be validated, as they are evidenced unequivocally by archaeology and archaeobiology: people lived in wooden houses that were constructed in close vicinity of lakes and mires and lived on a diet comprising of cultivated and gathered plants and animal products of domestic and wild animals. Also, a general transferability of knowledge on recent ecosystem features to the reconstructed ecosystem of the 4th Millennium can be taken for granted. When it comes to the details in the data used, the difficulties arise; e.g. for the amount of calories that may be gathered on one hectare of primary deciduous forest (see Table 9.2), or for the rate of annual variation in the gathering success of the settlements. Such numbers are very difficult to verify, as modern analogies of hunter-gatherers especially in the biome of the mid-latitude deciduous forests are virtually non-existent and thus, ethnographic evidence is scarce. Thus, I regard these data as good estimations that are open to discussion. Here lies the first one of a number of advantages of the approach: the input data is transparent, and can be modified or supplemented quite easily, if necessary. If the validity of the database is generally agreed on, keeping the articulated uncertainties in mind, the next question concerns the plausibility of the different scenarios. With the presented approach, a broad variety of different assumptions and hypotheses can be displayed. This helps to reduce the danger of too narrow or fixed presumptions in the modeling process. But at the same time, the question arises how to evaluate the scenarios; is it possible to isolate the one “solution scenario”, giving an answer to “how were things REALLY working back then”? The answer must be “no”, because no validation method exists with the required degree of reliability. But can certain scenarios be ruled out for some reasons? Work load calculations are an important factor in this discussion. These are not included in WELASSIMO, because only independent data that is not used for the simulations can be used as a test for the scenarios. Furthermore, the temporal resolution of one year turned out to be unsuited to integrate work load in detail, which is relevant rather on a daily or even lower scale. To check whether the scenarios are in accordance with the available work force, I use data published by Kerig (2008). He could demonstrate that one person may prepare one ha of crop fields on already established plots in 29 days. Probably imposing a somewhat stronger limitation for field size was the labor associated with weeding and crop harvest; here, Kerig states that one worker with a silex-knife can process 0.9 ha during the harvesting season (Beginning of July—mid of September). If the available workforce of the households in WELASSIMO is assumed to be 2.5 full-working persons (two adults and one child), 2.5 ha can be seen as the potential maximum a household could handle. The largest fields in a permanent cultivation technique (for which Kerigs figures apply) are simulated to be 2 ha, if 100 % of the calories are provided by crop plants and NIC is assumed. IGC and IFH have higher yields per ha, which possibly decreases the associated work load—however, this might be neutralized due to the additional workload in these systems for manuring and intensive care. The work load associated with SC is described by Ehrmann et al. (2009) according to results obtained in a large-scale experiment in Forchtenberg, Germany. According to their research, 800 full working days are necessary for one hectare of fields in SC. With an assumed average yield of 3000 kg of cereal using SC, as found by Ehrmann et al. on soils of "average" quality, and 2.5 workers as above, 96 full working days per year are required in order to meet the calorie requirements discussed for scenario 1 (see above). Ehrmann et al. calculate with the value they found for "good" soils of 5000 kg/ha; thus, a total of 50 days would be needed with the other configurations unchanged. Even if a hypothetic proportion of 100 % crop plants is assumed, and parts of the work could be done outside of the time needed for field preparation and harvesting, the respective work load could be handled. To sum up, the work load associated with crop production would most probably not pose a severe limitation for any of the scenarios realized within WELASSIMO. To investigate on the combined work load of all subsistence practices together would require a simulation with daily resolution; this is aimed at in future projects. The work load associated with Hazelnuts is in detail discussed in Holst (2010). She states that the harvesting season for Hazelnuts lasts around 14 days in the end of September, so no conflict arises with crop harvest. In one hour, she could harvest 1.26 kg of Nutmeat (equivalent of 1400 Nuts with 0.9 g each). 2.5 workers could harvest at the very least 300 kg per season. With 6000 kcal per kg of nutmeat, this equals 1.800.000 kcal per group of 6 or 300,000 kcal per person. For the configuration as in Scenario 4 with 85 % vegetable foodstuff of which 80 % are gathered, the requirements are 496,000 kcal gathered. So these numbers do not seem realistic; but if the importance of gathered food is reduced to 50 %, the assumed 300 kg Hazelnuts per group of 6 are sufficient.

As stated above, it has become evident in the modelling process that neither of the previous land-use models (SC, NIC and IGC) is capable of integrating all data with confidence. This is better achieved with the alternative scenario of "Integrated Forest Horticulture (IFH)", which is formulated above. The fact that seemingly contradictory positive evidence on crop husbandry in the wetland settlements in the early 4th Millennium, which led to the formulation of the hypotheses SC, IGC or NIC, is included without being contradictory, is a hint that IFH might be the closest one to the Neolithic "reality" of all 4 land-use methods discussed. Until now, the charcoal and secondary forest peaks detected by pollen analyses were mainly seen as a by-product of SC (e.g. Rösch et al. 2014); if this was true, the evidence of manuring of the crop plants as documented for the site Ho1A (Bogaard et al. 2013) as well as the evidence for permanent fields with a distinct weed flora (e.g. Maier et al. 2001; Maier 1999; Jacomet et al. 2004, p. 136) would require explanation—which is very hard to give, then. Yet if it is assumed that the origin of the weed remains and the evidence for manuring is indeed a permanent and intensive form of crop husbandry, as interpreted by the researchers (e.g. Bogaard 2002; Bogaard et al. 2013), an explanation for the peaks documented by palynology is needed. As shown in scenario 4, a targeted promotion and facilitation of secondary forest growth by the use of fire and the parallel application of intensive cultivation methods for crop husbandry would be in good accordance with the existing data and at the same time provide systemic benefits, which could be demonstrated above. Here, the second advantage of an agent-based simulation approach becomes evident: the loose ends of the observed system, which are provided by the involved disciplines, may be woven into a stringent net of explanation, which considers the most of the available data. In the discussion of the increased value of patches with fallows or young secondary forest vegetation in contrast to their "wild" environment, the term "landscape" is so illustrative that I want to highlight its significance and sharpen its scope. One might as well use the term "cultural landscape", but this is actually a pleonasm; both denote a strip of land that has been anthropogenically shaped. In the case observed, the landscape offers a higher economic value than the "wild" environment (I set "wild" in quotation marks because most likely, even those areas were influenced by humans to a certain degree). This applies most drastically for the amount of calories from gathered plants, especially from hazelnuts. To a minor extent, also the quantity and quality of livestock fodder increases in these areas, and also the availability of suitable timber in the right dimensions for house construction is triggered by the initiation of secondary forest growth. It is likely, that even the density of certain wild animal species used for hunting is positively correlated with a certain degree of openness of the landscape. In spite of these advantages, I do not claim that IFH is depicting "true" Neolithic conditions without any doubt, and that the other hypotheses are wrong; to the contrary, it is highly probable that elements of SC, IGC and NIC have been realized as well, but not in an exclusive, but in an integrative manner. And even the IFH Scenario is simply a model that explains some data—many aspects are not included, others are generalized, rough assumptions are used: it has to be stressed that no model can ever display the full complexity of such a system.

9.6.1 Resource Use as a Need for Relocation?

The main question named initially is, whether a necessity for a settlement relocation arises due to the land and resource use of the people. Which subsistence strategy might contribute to this need, if any? For crop husbandry, the only scenario simulated in WELASSIMO, where a settlement shift after one or two house generations arguably makes sense, is SC. After this time, the distance to new fields might have grown large enough to motivate a settlement shift. If the parameters are set to force the maximum number of 120 people in WELASSIMO as far away as possible in a system that is still in accordance with the data—exhibiting the general properties as described above—then, a maximum distance of 2.5 km is necessary, which is reached after 30 years (SC, 5 % animal products, 80 % of plant calories are cultivated). In his investigation on current practices of SC in India, Pratap (2000, p.72) describes an example that daily walking distances to SC plots are normally 1–2 km. On the other hand, the same author states on p. 84 that "the axiom of settlement mobility, as a logical necessity in SC Systems, is itself an a priori assumption often overriding the complexity of real-world situations." Furthermore, Saradindu (1967) observes that fields are shifted annually in much larger radii of 6–7 miles. This means that daily travelling distances of 2.5 km are not necessarily forcing households to shift their location. Considering the alternative explanations of findings—

that were originally used to back the hypothesis of SC—as described in the IFH-scenario, I think, that the theoretical benefits of the SC-Hypothesis need not further be discussed, because there is positive bioarchaeological counterevidence against it as the dominant mode of husbandry. In the other scenarios 4, 3 and 2, no economic reason appears to be motivating a settlement shift (for 2 and 3, the same restrictions are valid as for scenario 1: they are rather theoretically relevant, because they do not explain all data). To the contrary: as described above, the economic value of a landscape would rather increase with ongoing duration of use through an increase in the amount of livestock fodder and especially the gathering value connected with hazelnuts. Furthermore, paths have formed and familiarity with the surroundings may be suspected. The only resource which causes slightly increasing distances for its extraction is timber; but distances are far less than for the other activities with a maximum of 200 m for 4 households after 20 years. From all this it seems plausible to assume a certain degree of spatial stability and commitment to the site—but nonetheless, in many cases, the contrary is evidenced: a highly dynamic settlement system with a frequent relocation of the sites (e.g. Ebersbach 2010). From the preceding considerations, it is highly implausible that the land use activity of a small community caused the observed relocation pattern. Even if the number of households is set to 20, this does not change the situation drastically. It is a different thing, however, when not a hypothetical determining necessity for a relocation, but the relative benefit of a settlement shift is considered. Even if the landscape around the settlement is something appraised that is to be maintained, low-distance relocations might nonetheless be assumed, as the appreciation of the economic area does not necessarily include the site itself. A similar situation is documented for the site of Ho1A: after the documented destruction of many of the houses in 3910, a number of new houses with the building year 3909 were constructed only a few hundred meters away in the site of Ho3 (Dieckmann et al. 2006, p.418; Billamboz 2006, p. 314). As the construction elements of the houses had a limited lifetime seldom exceeding the span of 10–20 years, a restoration or rebuilding was required quite frequently. Suitable timber in considerable numbers was thus needed in a temporal pattern of relatively high predictability. Additionally, the availability of fuel wood likely decreased in the proximity of the settlement in the course of several years. Furthermore, the specific site preferences might have caused a small-scale shift of the buildings, as lake levels of Lake Constance as well as of smaller lakes in the vicinity did fluctuate markedly and frequently. So if a house needed to be rebuilt for whatever reason, and a stand of suitable timber was growing adjacent to a suitable settlement location—maybe people rather carried their few belongings to a newly constructed house, than carrying (the timber of) their new house to their belongings, if all the economic benefits of the cultural landscape could be maintained. Drivers and benefits of the abandonment of a specific site and its relocation inside the cultural landscape may have been acts of convenience, of hygiene or of environmental forcing other than resource availability—or a combination of those. The above discussions are valid especially for smaller settlements with a relatively low population density of the landscape; a different situation might arise, if more and larger settlements in a defined landscape need more resources and affect their environment more intensely; a simulation to deal with this situation is currently prepared for the sites located near the effluence of Lake Zürich into the river Limmat.

9.7 Conclusions

In this chapter, I have presented an agent–based simulation of landscape development due to anthropogenic processes in the context of the Neolithic wetland settlements in the north-western pre-alpine forelands. WELASSIMO integrates (paleo-) environmental and archaeological data and is capable of dynamically displaying the implications of various hypotheses on land use. The requirements of the non-finite resources soil fertility, suitable timber, livestock fodder and gathered plants is dynamically quantified, while finite resources such as flint are not considered. The major motivation for this research is the question, why the inhabitants of the settlements shifted their houses and thus abandoned the settlements with the high frequency observed. The hypothesis was put forth, that this might be related to the land–use activities of the people and decreasing or degrading resources or ecosystem services. To test this hypothesis, 4 scenarios were simulated, which display 4 different models on crop husbandry: Shifting Cultivation (SC), Intensive Garden Cultivation (IGC), Non-intensive Cultivation (NIC) and Integrated Forest Horticulture (IFH), the latter of which has been described here for the first time. Most other specifications of the observed system such as livestock herding, foraging and timber extraction and the settlement size have been unchanged, while nutritional habits were changed to a minor extent to underline assumptions made in the formulation of the scenarios. The results of the simulations are indicating that for a relatively small settlement, the non-finite resources probably have not been limiting and thus did most likely not determine the observed settlement pattern, which is characterized by a high mobility. To the contrary, the landscapes around the settlements did most likely provide a higher economic value than their environments, and were thus probably regarded as a valuable resource in themselves. IFH is regarded as the most proximate scenario to the conditions in the early 4th Millennium BC, as it comprises all positive evidence that support the other hypothesis IGC, SC and NIC, without the necessity to ignore data. This implies the possibility that hazelnuts play a more important role than assumed before. Long-established proof for large areas covered with hazel scrubland in the environment of the settlements, the very high nutritional value of hazelnuts and the ease of processing and the high suitability for storage justify these assumptions.

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