Virtual Neanderthals : a study in agent-based modelling Late Pleistocene hominins in western Europe

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9. ACTIVATING PARTS OF THE MODEL VIA SETTINGS

9.1 Introduction

HomininSpace is built to be used as a tool to explore hypotheses and answer questions on hominin behaviour in a reconstructed landscape. To this end the implemented model is run in simulations while comparing simulation results against archaeological attested presence data. Questions in HomininSpace are addressed in scenarios. Each scenario contains a different combination of model elements describing aspects of hominin behaviour in the landscape (Groucutt *et al.* 2015). These elements have been designed to address the questions and implement associated hypotheses that extend the basic parameterized model described in the previous chapters. The system attempts to find the best scoring model parameter value sets per scenario since these describe the hominins most likely to have created the archaeological record under the given hypotheses. This chapter describes the hypotheses that were implemented to answer the questions put forward in the Introduction (Section 1.3).

The in- or exclusion of the model elements are controlled by the so-called *settings* in HomininSpace. A setting is a Boolean value that can be True or False, activating or deactivating certain functionality or elements within the model. An example are extra coastal resources that can be made available to the hominins (True) or not (False). Each setting has a unique and descriptive name. There are ten settings in total which must all be set to either True or False. The chosen combination of all ten settings describes the scenario to be explored. Three settings have been used in the development of the system (the zero model settings). They specifically control the implementation of certain key features (for instance the energy distribution in the landscape, or the direction of the mobility of the hominin groups). All settings are listed with a short description in Table 23 and are described in detail in the following sections.

Table 23: A list of the settings in the system. Each setting is a Boolean value, and must be activated or deactivated by assigning a value of True or False.

Setting name	*Description*
ENERGY_CONTINUOUS	The energy in the landscape is distributed via an energy continuum based on climate parameters (True) or via reconstructed habitats (False).
STATIC_DISPERSAL	The mobility in the landscape has a static character (True) or more dynamic where the groups keep

	moving with the changing environment (False).
USE_BEACHES	Do beaches have extra resources (True) or not (False).
USE_MAXIMUM_FORAGING_RANGE	Is there a maximum foraging range that groups adhere to and that is given in the parameter file (True) or is there no maximum range (False).
GROUPS_CAN_CROSS_WATER	Groups can cross larger water bodies (True) or not (False). If not, they cannot go to islands.
USE_FACTORIES	Activate core areas or factories (True) or not (False). If True, a maximum of one new group is generated per year near a factory if there are sufficient resources in the immediate surroundings.
DEATH_PENALTY_FOR_ABSENCE	Does the system implement the death penalty for simulations where absence intervals are violated (True) or are absence intervals ignored (False).
ZERO_MODEL_DISABLE_WATER	Are there water grid cells in the North sea or Mediterranean (False) or are these grid cells all landmass (True). This setting has been used during system development.
ZERO_MODEL_DISABLE_ENERGY	Do grid cells have a reconstructed energy level (False) or do all grid cells have the same amount of energy that replenishes every year (True). This setting has been used during system development.
ZERO_MODEL_RANDOM_WALK	Groups move randomly (True) or they move to that area which has the most resources (False).

9.2 Model elements of the reconstructed environment

In HomininSpace the underlying assumption is that energy available in the landscape will provide forage for the hominin groups that move through this landscape. For calculating energy levels reconstructed precipitation and temperature values are available. Available energy per grid cell is calculated using a continuous energy level reconstruction or with a habitat reconstruction with associated energy levels per habitat (Subsection 9.2.1). Furthermore, extra resources can be available for coastal areas with possibly great effect on the population distribution (Subsection 9.2.2).

9.2.1 Energy versus habitat reconstruction

Population responses to environmental change can be assessed by combining an energy budget and an agent based model build around individual responses to local circumstances (Johnston *et al.* 2014). Energy required by hominins for subsistence is taken from the landscape in the form of hunted or scavenged game, to some extent supplemented by plant foods (Henry *et al.* 2011). Diets for modern human hunter-gatherers are very diverse and difficult to model (Kelly 1995, 65-101). In the model underlying the HomininSpace simulation system the availability of medium to large ungulates is taken as the limiting resource defining the maximum population size. Individuals obtain energy from ingested food and expend it on movement, maintenance, growth and reproduction (Sibly *et al.* 2013). Exact energy needs by hominins are uncertain (but see Mateos *et al.* (2014)). HomininSpace implements two different approaches to calculate the available energy in the landscape: direct energy computation via extrapolation from the climate parameters, and a habitat reconstruction with for each habitat type an associated energy level.

The difference between a continuous energy landscape and a full habitat reconstruction was already built into HomininSpace 1.0. It is reflected in the way the available energy is calculated, the hominins in the system will not perceive the environment differently. The only thing hominin agents notice is the amount of available energy, whether that is calculated according to a continuous energy model based on data from McNaughton *et al.* (1989), or using reconstructed habitat data from Binford (2001) and Kelly (1983). The location in the source where the secondary biomass is calculated is in "HabitatCell.java", line 233. If the setting ENERGY_CONTINUOUS is True the following function is called: `calculateSecondaryBiomassAccordingToMcNaughton`, otherwise this function is used: `calculateSecondaryBiomassAccordingToKellyAndBinford`. The reader is referred to the source code included in the Supplementary Materials for the actual implementation of both functions, which contain 60-100 source lines each.

In HomininSpace consumption of resources does not change the habitat type. The type is always reconstructed using climate data, not (available or consumed) resources. Consuming resources does change the amount of available kcal. In the user interface it is possible to visualize both alternatives via the `VISIBLE_LAYER_WHILE_RUNNING` constant. This is illustrated in Figure 46, with both figures created just before the simulation is started and before any resources are consumed.

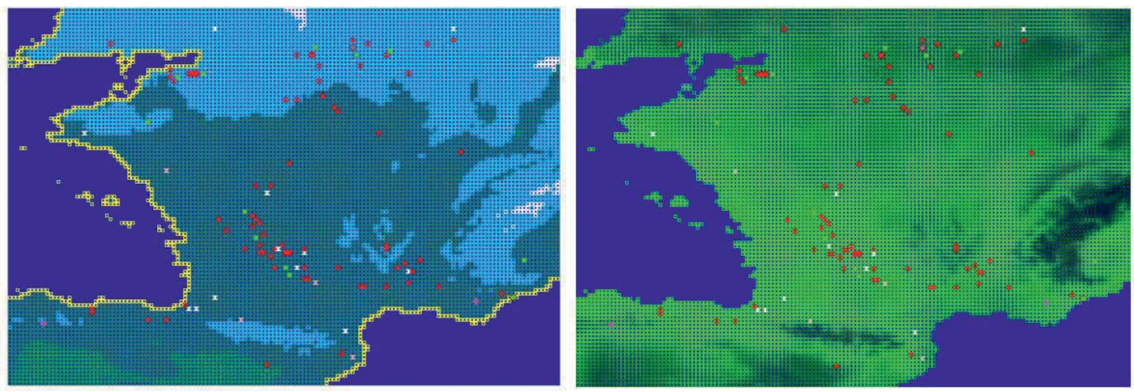

Figure 46: Habitat reconstruction (left) versus energy level reconstruction.

9.2.2 Coastal resources

Aquatic resources have been exploited throughout the long history of the genus *Homo*. The earliest fresh water fish is attested with *Homo erectus* (Braun *et al.* 2010). Joordens *et al.* (2015) suggest that freshwater molluscs could have been exploited more than 400 ka in Trinil, Indonesia. *Homo sapiens* consumed coastal shellfish from MIS 6 onward in South Africa (Kyriacou *et al.* 2014) and archaeologically retrieved specimens have been used to detect population growth (Klein and Steele 2013). Marine mollusks were exploited in the Mediterranean area by both Neanderthals and modern humans since MIS 5 (Fa *et al.* 2016). In the Levant, data suggest that structural coastal resource exploitation started during the Early Upper Palaeolithic, during which shellfish exploitation became increasingly more frequent and year-round (Bosch *et al.* 2017). The use of molluscs can be traced back to as early as MIS 6 at the Mediterranean coastline of the Southern Spain (Cortés-Sánchez *et al.* 2011). Coastal intertidal foraging return rates can be significant and overall energetic return rates can exceed other foraging activities (De Vynck *et al.* 2016). The question to be explored is if Neanderthals used coastal resources in the simulation area and during the whole simulation period.

Fresh water systems do not play a major role in HomininSpace. Most rivers and lakes are too narrow/small to be included in the topographical map due to gridcell size, and for habitat reconstruction water is assumed to be precipitation only. There is however an extensive coastline, both in the south where the simulation area is bordered by the Mediterranean Sea, as well as the western edge which is formed by the Atlantic and Channel coastal areas including the beaches from southern England. Therefore, the question about the use of aquatic resources focusses on the coastal regions. A value of True for the USE_BEACHES setting activates the coastal resources in a simulation.

In the topography land grid cells have a height greater than zero. If coastal resources are activated, those land grid cells that border at least one water grid cell (sea or lake) are labelled as `TOPOGRAPHY_TYPE_BEACH`. These are the yellow grid cells in Figure 46, the habitat reconstruction. Coastal resources are located on the beach cells (land), not in the water since foraging by hominins occurs only on land grid cells. The additional coastal resources are created by multiplying the regular resource production (based on habitat or energy level) by two. Additionally, coastal resources replenish completely every year, reflecting the seasonal character or the resource and assuming no over-exploitation of coastal resources is possible. Figure 47 illustrates that coastal resources apparently can be popular with the coastal areas being highly populated[37]. Coastal resources are implemented in the "HabitatCell.java" source file.

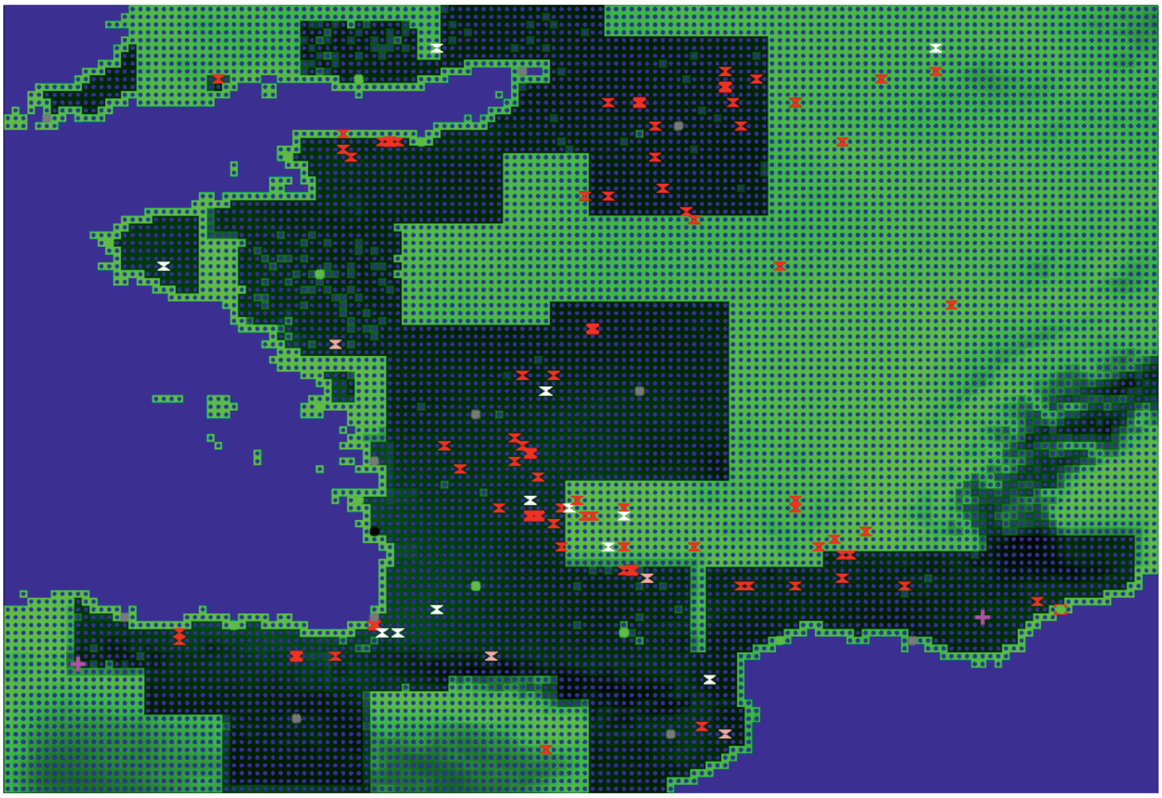

Figure 47: Illustrating the effect of coastal resources on population distribution.

9.3 Model elements of hominin behaviour

Hominins move through a reconstructed landscape in HomininSpace foraging for food. The user can explore hominin dispersal characteristics and demographical change. Hominin groups can implement a more static mobility versus more dynamic movement (Subsection 9.3.1). When groups forage it feels natural to impose a maximum foraging range (Subsection 9.3.2) but what maximum should that be? Some hunter-gatherers travel huge distances per year. And are hominins capable of crossing large surface waters (see Subsection 9.3.3)?

9.3.1 Mobility type: dynamic versus static hominins

Dramatic climatic fluctuations characterize the environment for the Late Pleistocene hominins. It is suggested that many organisms were pushed southwards as the northern areas became too inhospitable (Barnes 2010; Stewart and Lister 2001; Schmitt and Varga 2012). The Neanderthal range responded by contracting and expanding accordingly. Such

[37] Note that coastal resources replenish every year: even if inland areas shows intense foraging (dark colour), beaches remain light green (high energy levels).

processes could be explained by either large scale habitat tracking or regional extinction and subsequent recolonization (Hublin and Roebroeks 2009; Dennell *et al.* 2011). This research contrasts the "ebb and flow" model (habitat tracking) with the "regional extinction" theory. Henceforth the regional extinction model is also referred to as "sources and sinks" where needed to avoid confusion since also with habitat tracking there will invariably be local extinctions(e.g. Riede and Pedersen 2018). Habitat tracking hominins would move towards areas with better environments when the climate deteriorates.

With "sources and sinks" a sink area can have a declining population due to unfavourable environmental conditions but that population is replenished by immigration from different source locations with a net population growth and a surplus of individuals. Local populations are assumed to remain in the area and will become extinct when repopulation levels are below death rates. See for example Finlayson (2009) identifying Iberia as a source for western Europe, or Dennell *et al.* (2011) who identify Southwest Asia as a possible population source for Europe.

Distribution maps of past species are generally however coarse-grained palimpsests of the traces of population expansion and contraction, probably hiding many populating events. There might have been many phases of range expansion and contraction or migration caused by the rhythm of climatic oscillations and these maps most probably understate the full impact and give only a rough approximation of the former distribution of the species (Dennell and Roebroeks 2005; Hublin and Roebroeks 2009). For the colder phases of the glacial-interglacial cycles, there are indications that large parts of the Neanderthal range in northern Europe were deserted in the early Middle Pleistocene, with Neanderthals maintaining core populations in the south (Hublin and Roebroeks 2009). The hominin presence in Pakefield, with a reconstructed near modern climate, is often seen as an example of pre-Neanderthal habitat tracking (MacDonald *et al.* 2012).

Neanderthals are usually seen as a western Eurasian species, but in fact little is known about the limits of their range, both in terms of their former distribution as well as regarding the factors which limit their survival (Roebroeks 2010). A different mobility pattern in response to a changing climate is one of the suggested causes that could have led to the demise of the Neanderthals (Holliday and Falsetti 1995). For the colder phases of the glacial-interglacial cycles, there are indications that large parts of the Neanderthal range in northern Europe were deserted with Neanderthals maintaining core populations in the south (Hublin and Roebroeks 2009). The limits of the Neanderthal geographic range are usually constructed by drawing lines around the maximum distribution of their fossil remains, but differences in site preservation, reconstructed periods as well as in research intensity and history make such estimates very rough and preliminary (Roebroeks *et al.* 2011; Roebroeks and Soressi 2016). In HomininSpace large mountain ranges and arid areas are passable although distribution is hindered by limited resources in and around such grid cells which makes them less attractive destinations.

The tracking of favourable habitats has been described as the "ebb and flow" of populations (e.g. Hublin and Roebroeks 2009). This is the setting STATIC_DISPERSAL with value True. The "ebb and flow" of moving populations has often been opposed to a "sources and sinks" model where some local populations must adapt behaviourally and/or genetically to cope with the changing climate or become extinct when conditions become less favourable (Pulliam 1988; Pulliam 1996): value of the setting is False. In the source code of "HomininGroup.java", where this is implemented (lines 145-198), this setting allows a group to 'settle', via the boolean `isGroupSettled`. A group can only settle if the setting STATIC_DISPERSAL is True. If a group is settled it can no longer move and must obtain the required resources from the area limited by its foraging range[38]. A group can only settle if the following conditions are met:

- The group is not hungry, that means that there are sufficient resources in the area given the current size and composition of the group;
- The group is mature (that is older than the age indicated by the Years_Before_Group_Maturity parameter value);
- There are no other groups within the foraging range that are settled (this does not prevent two foraging ranges to overlap);
- The current location is not within three grid cells from any border of the simulation area.

9.3.2 Imposing a maximum foraging range

Hominin groups in HomininSpace obtain the required energy from the landscape around them. They forage to retrieve resources translated into kilocalories. This is implemented in a two-step process:

1. First each group assesses how many kcal are available within a searching radius of one grid cell from the current position (this encompasses nine grid cells including the current location). If that is insufficient for their needs the radius is increased by one[39] and the total number of available resources calculated for the new radius. The radius is increased until sufficient resources are found or the maximum foraging

[38] Note that a group that is settled and becomes too small can still merge with another group in the foraging range.
[39] A searching radius of 1 encompasses 9 grid cells, 2 covers 25 grid cells, 3 covers 49 grid cells and 4 is 81 grid cells.

range is reached. In the calculations the groups include the presence of other groups that have claimed resources. The final radius is referred to as the current foraging range in which all grid cells are claimed;

2. Then in the second step, after all groups have calculated their current foraging range, resources are consumed by emptying grid cells in a random order from the current foraging range, sharing resources with other groups if their foraging range overlap.

Implementing foraging strategies in this two-step manner will allow groups to co-exist in the same area, and prevents the random order of group activation to unnecessarily cause groups to become hungry (and in extreme cases to die) when one group by chance forages before the other group which is then left with insufficient resources. Note that the foraging event actually represents one full year of resource extraction from the environment within the (annual) foraging range. Not all grid cells within the calculated foraging range will be exploited every year. If sufficient resources are present some cells are not needed (Figure 48).

If maximum foraging ranges are deactivated (setting USE_MAXIMUM_FORAGING_RANGE is False) resources can be obtained for a potentially unlimited foraging range (only limited by the extent of the map and the resource needs of other groups). Large ranges are not impossible since the foraging behaviour encapsulates the period of one year, and there is no data to limit the migration distance of Neanderthals (Benito *et al.* 2016). Cold and arid circumstances seems to increase mobility and range sizes since resources are more sparse and wider distributed (Binford 1991; Kelly 1983). Also the exploitation of meat resources by hunter-gatherers, especially when the prey is migrating, requires large (annual) foraging ranges (Kelly 1983, 296; Kelly 2003). Nunamiut and for example Cheyenne hunter-gatherers hunt large mammals in colder environments and are extensively mobile (Wragg Sykes 2017).

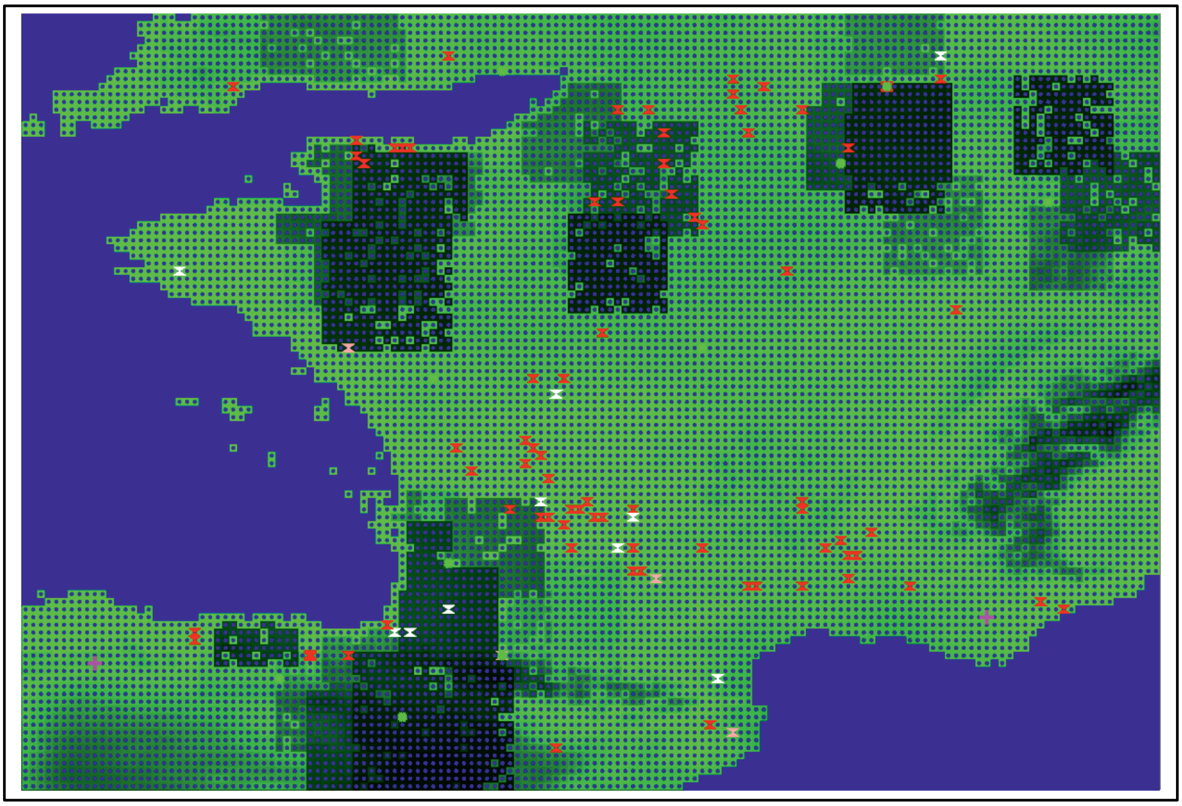

Figure 48: Screenshot of simulation 1384 illustrating the patch wise foraging behavior with a varying foraging range (different sizes for the foraging squares).

9.3.3 Allowing the crossing of open water systems

Sea barriers can hinder colonisation efforts, particularly difficult crossings like for example the Strait of Gibraltar (Derricourt 2005). Analysis of flora and fauna, including comparisons of genetic material, shows no direct contact between the Maghreb and Iberia (Spain) (Close 2009, 45; Tafelmaier *et al.* 2017). Some similarities have however been observed between Mousterian and other assemblages on both sides (Hublin 2000, 170; Straus 2001) but no Neanderthal remains have been retrieved from African soil yet. This could suggest that Neanderthals were not capable of crossing a relatively small strait of 14 kilometres wide with opposite shores clearly visible. Turbulence makes this a hazardous crossing indeed which could mean that they were not capable of crossing larger water bodies at all. However, very early presence of modern humans has been attested in Northern Africa (Hublin *et al.* 2017), and yet no fossil remains have been found for the simulation period in Spain for that matter. Nevertheless, the ability to travel over large water bodies might have been a specific trait associated with certain modern humans only (Davidson and Noble 1992).

Larger river systems do not seem to be able to stop Neanderthal dispersal, although the Ebro river basin is suggested to separate Neanderthal populations in the south of the Iberian peninsula from more modern northern populations (Zilhão 2000; Vaquero *et al.* 2006; Daura *et al.* 2013) allowing a late survival of Neanderthals in the south. This model (see discussion in Cucart-Mora *et al.* (2018)) and the late survival is however contested (Higham *et al.* 2014).

In the wider Mediterranean area there are suggestions for long-term persistent archaic populations on islands proximate to the Eurasian mainland (Broadfield *et al.* 2001). There is evidence for maritime dispersal in monkeys (Ferràndez-Cañadell *et al.* 2014) and for other large-bodied mammals and this latter could induce short-distance maritime dispersal of local Neanderthal populations (Broodbank 2006; Broodbank 2014). Passive dispersal across larger water bodies has been argued as a possible agent for archaic hominins (Dennell *et al.* 2014; Leppard 2015). This does not necessarily mean that hominins were seafaring but the possibility of crossing is based on the occurrence of rare but suggestive long range dispersal events in the distribution of the genus *Homo* (Strasser *et al.* 2010; Leppard 2015). Thus under certain circumstances water crossing could have been part of the colonisation repertoire of Neanderthals.

The most important area however for which the crossing of larger water bodies influences Neanderthal dispersal in the simulation area is the Channel, where colonisation of England can be prohibited when sea levels are high and England becomes an island (Ashton and Lewis 2002; White 2006; Gilmour *et al.* 2007; Lewis *et al.* 2011; Sier *et al.* 2015; Ashton and Scott 2016). Only a lowered sea level and ameliorated climate allowed over land access to Britain in MIS 3 with hominins possibly crossing the Dogger Plains to avoid the large Channel River system (Wragg Sykes 2010). There is scarce evidence of earlier presence which could only have been made possible by Neanderthals having the ability to cross larger water bodies (Wenban-Smith 2010; Wenban-Smith *et al.* 2010). But this absence could be taphonomical rather than cultural or biological (but see Wragg Sykes 2017).

HomininSpace attempts to explore this issue by in- or excluding the ability to cross larger bodies of water, since it is an important element in hominin dispersal (Leppard and Runnels 2017). In the HomininSpace simulation system, hominins cannot live on and will never move to water grid cells. The fluctuating sea level allows and forbids land access to a small but significant part of the simulation area (the south of Britain). HomininSpace implements the ability to cross larger water bodies with the `GROUPS_CAN_CROSS_WATER` setting. If this setting is activated (True) any grid cell within dispersal range (two times the active foraging range) can be targeted as a new destination for a group, even if this involves the crossing of (very) large water bodies. If the setting is set to False, islands cannot be reached by the hominin groups.

Since the actual route that an agent follows is never calculated step by step (only the maximum distance is used as a limiting factor) the implementation of this feature requires the identification of all the islands on the map. Only then it can be tested if a new destination is on the same or on a different island. This is not straightforward since the map is quite large (with at least 6000 land grid cells). An intuitive recursive implementation to identify islands requires too many resources often leading to stack overflow. An iterative implementation was made, one that searches for unassigned land cells and when finding such a grid cell, expanding this in all directions. As there are only few islands in the area (generally around nine in total) this is an efficient routine and since it is executed every time step the computational gain in speed opposed to the more elegant recursive implementation is important as well.

The actual code is implemented in “HomininSpaceContextBuilder.java”, routines `assginIslandNumbers`, `assginIslandNumberIter` and `setIslandNumber` (lines 1217-1305).

9.4 Model elements of population distribution

There is only one question that is related directly with archaeological data, and that is about absence of evidence of hominin presence (Subsection 9.4.1). The associated hypothesis states that for certain areas it is plausible that hominins were *not* in the area. Such information is very important when attempting to restrict the urge of the system to create an omni-present hominin. Furthermore, new hominins can be created from existing groups or by immigration from more productive areas. HomininSpace can model such areas and offers the possibility to create a core population area anywhere on the map, as described in Subsection 9.4.2.

9.4.1 Using hominin absence data

If simulation results have hominins in an area and time frame for which absence has been proven this is clearly an error of the model (Pearson *et al.* 2006). It has been shown that for species distribution models the presence-absence models perform better than models with presence only data (Elith *et al.* 2006). If simulated hominins are present where the absence is implicit (that is, there is no presence record) this is considered a non-conformity (but not an error!), maybe due to an incomplete model, maybe due to sampling biases (Anderson 2003). A generalised scoring scheme when comparing modelling results and real world presence and absence data is presented in Table 24. In this table modelled absence versus proven presence is less severe than modelled presence with proven absence since a modelled (local) absence could still mean that modelled hominins were nearby (compare archaeological presence). Often, pseudo-absence data is generated to create a counter weight to the presence only information (Benito *et al.* 2016).

If only presence data is used, an always omni-present species would provide maximum match with the data. Excavation results show that, at least in many locations, Neanderthals were not *always* present at *all* sites all the time (for instance illustrated by the overview in Discamps *et al.* (2011), or for a specific location in Bertran *et al.* (2013)), however local such absence must be taken. Modelling efforts and interpretation of simulation results where only presence data is matched must take into account the tendency of the system to 'fill the map', and must try to distinguish between the natural tendency of a species to grow and the intrinsic modelling drive to match all presence points.

Table 24: Relative scoring schema when matching real world absence and presence versus modelling results. A '+' indicating a positive contribution of the match to an overall modelling score.

	Modelled absence	Modelled presence
Proven absence	++	---
Implicit absence	+	-
Proven presence	--	++

The above illustrates the importance of matching absence information as well as the (relatively) limited value of local absence data. If absence is however attested for many sites in a wider, delimited area, with reasons that explain why, and with taphonomy and other potential causes for absence sufficiently countered it can be argued that hominins were indeed *not* present in that area for a given time frame (proven absence). There is one larger area for which absence has been postulated for an extended period of time: the whole of Great Britain during MIS 5 and MIS 4 (Ashton 2002; Ashton and Scott 2016;

White and Pettitt 2011; Wragg Sykes 2017). The initial breach of the chalk barriers formed the Strait of Dover sometime during MIS 12, and since then allowed a rising sea level to isolate Britain from the main land of Europe (for a discussion see Ashton *et al.* (2018)).

For Britain the cold and associated glaciations have been identified as the main cause of absence, with any (larger) waterbody between Britain and the main land of Europe as an additional barrier for hominins (Antoine *et al.* 2003; Scott and Ashton 2011; Sier *et al.* 2015). Two flakes from a questionable late MIS-5 occupation were retrieved (Wenban-Smith *et al.* 2010; White and Pettitt 2011) which are here taken to be insufficient as proof of presence (following Wragg Sykes (2017)). In this study the absence information on Great Britain is used to illustrate the effects of adherence to true absence on modelling efforts, and to explore the hypothesis that there was indeed an absence of Neanderthals in Britain during a significant part of the Late Pleistocene and what that means for a model.

The identification of areas with true absence of hominins is notoriously difficult. Therefore the inclusion of the southern parts of England in the simulation area is key, since here is a larger area for which true absence has been attested (at least with a large degree of certainty, see Section 6.2). From late MIS-7 until the end of MIS-4 or the start of MIS-3 (c.190 – 60 ka), Britain appears to have been “effectively abandoned” (Wragg Sykes 2017). Table 24 indicates that modelled presence in proven absence is the least desirable modelling result.

For evolutionary algorithms penalty functions are the most common method to handle constraints (Yeniay 2005). For genetic algorithms, a popular and simple method is the *Death Penalty* which just rejects unfeasible solutions from the population (Back *et al.* 1991). This states that when a constraint is *not* met, the solution is incorrect and can be removed from the collection. The risk with this method is that most time is spent calculating infeasible solutions that are subsequently rejected.

In the implementation in HomininSpace absence information is taken as an absolute constraint that is punished with the Death Penalty and made explicit by defining absence intervals with checkpoints. These intervals are constructed in a similar fashion as the presence intervals, with the only difference in the input file the type of interval which is ‘absence’ instead of ‘presence’. One of the best dated sites in the UK is Lynford quarry (Ashton 2002), and data for this site suggest an absence sometime before 72 ka (Boismier *et al.* 2012). It also suggests that around 142 ka and earlier Neanderthals might have been present. For the purpose of this study two checkpoints in England have an (identical) absence interval defined:

1. Boxgrove: 107 ka +/- 35 kyr
2. Kent's Cavern: 107 ka +/- 35 kyr

Whenever a hominin group is near a checkpoint, they are registered in the interval administration. For these routines the type of interval is unimportant. Only when the data is written to the output file the type is included. When the absence hypothesis is tested the genetic algorithm will filter away all solutions with presence registered in the absence intervals before selecting promising parameter value combinations. Only when the setting DEATH_PENALTY_FOR_ABSENCE is True, those simulations are ignored. Note that they are still present in the output file for all other purposes.

9.4.2 Using population core areas (hominin factories)

In the HomininSpace model new groups can be created in *core areas*. These are locations on the map from which, conditions permitting, new groups move into the simulation. Two such points have been designated based on suggestions in the literature: the peninsulas of Iberia and Italy. Production from core areas can be activated (True) or deactivated (False) by the user with the setting USE_FACTORIES.

Although hominin occupation in Iberia may have been discontinuous and it is unclear where the western European hominin populations originate from (MacDonald *et al.* 2012), the Iberian peninsula is one of the areas within the HomininSpace modelled area from where new populations can move into western Europe. The second source of possible population influx is the Italian peninsula, with hominins moving along the Mediterranean coastline passing the Alpine mountain ridges. The selected locations of these population core areas are based on their southerly location, topographic heterogeneity and ecological diversity, presence of extensive coastlines with associated resource availability, favourable weather patterns and the archaeological record (Carrión *et al.* 2008; Finlayson and Giles Pacheco 2000; Finlayson *et al.* 2006; Jennings *et al.* 2011).

The core area population sources are implemented with *Hominin Factories*. Factories, when conditions are right, will produce as many new groups as the surrounding area will sustain. Factories will check local conditions before production and will make sure that:

- There are no hungry groups in the area around the factory location (this area is based on the Factory *scanning range* and configurable, by default 30 cells);

- There are sufficient resources in the area surrounding the factory for a new group (estimated by adding together all the resources within the scanning range);
- There are empty cells where the new group can be located.

When these conditions are met new groups are created at random empty grid cells in the area. Local populations are thus replenished from more productive areas when the situation improves (MacDonald *et al.* 2012). All new hominin groups are considered to be in optimum condition and consist of the default population structure: 8 pre-fertile size hominins, 11 fertile hominins and 6 post-fertile hominins. These numbers are configurable. New groups immediately start moving and consuming, possibly in direct competition with other groups nearby.

Areas outside the simulation area can accept groups when the option 'Open borders' is selected. With this option active, groups can pass the borders of the simulation area and are removed from the simulation and considered to have been absorbed into refugia. However, during the development of HomininSpace it appeared that the open borders of Iberia always absorbed most of the groups present. Especially the dynamic groups, continuously moving towards the highest energy levels, all moved towards the south and disappeared from the simulation. This also occurred when conditions were relatively mild. Therefore, in the simulations the 'Open border' option is not selected. This mimics refugia that continuously contain maximum population densities and only serve as sources. Most competition for resources occurs therefore at the threshold of the border areas.

9.5 Neutral models - levelling the playing field

The following model elements implement when applied in succession an increasing more neutral or zero model. In a zero model all elements of the model have equal impact on the results, excluding agent strategies and preferences (Brantingham 2003, 491). Such a model is used to test if there is a bias or error in the implementation of certain model elements like the environment. For instance if all groups move south when there is no energy level differences this could indicate an error in the implementation of the model. A zero model can also be used as the neutral data pattern to be tested against to quantify or to qualify the effect of individual parameters.

When developing a simulation the global patterns that become visible while executing the model (in the case of HomininSpace the distribution of hominins through time and space) should match general expectations derived from reality. For instance, it can be expected with resource availability in mind that hominins move towards the south when conditions deteriorate, and return when conditions improve. Such expected patterns are used when developing a simulation where deviations from expected behaviour are closely investigated. The following global patterns were observed in developing HomininSpace:

- General movement of the population according to resource availability;
- Patterns of death and visit density to identify hotspots and match these against the available resources (for instance, this identified the death traps, singular localities like islands with high resource availability but hardly any surrounding carrying capacity that attracted many hominin groups that subsequently perished);
- Resource availability and distribution through the landscape through time;
- Birth statistics versus resource availability; in general, if more resources become available it is expected that more hominins are being born.

The environment is for a large part defined by the topography of the area. What would happen if there is no topography at all (Subsection 9.5.1)? That means no water cells and no mountains. It is also possible to create an equal distribution of the energy by simply assigning each grid cell an exact same amount of kcal (Subsection 9.5.2). And suppose the hominins do not search for the best resource patches, but instead move randomly through the environment, foraging where chance brings them? Subsection 9.5.3 implements random movement for groups of hominins.

9.5.1 Implementing topographical differences in the landscape

It is possible to turn all water grid cells into land masses with the setting ZERO_MODEL_DISABLE_WATER. A value of True will effectively remove all water from the grid, turning them into accessible landmasses. This levels the playfield by disabling the restrictive element of water cells. Note that height is not a factor of importance for the modelled hominins. This means that hominins will not be restricted in their movement by water bodies like the Mediterranean Sea or the Channel. Temperature and precipitation values will be distributed across the former water grid cells and used in reconstructing energy levels (note that water grid cells if present have zero energy). Without water there are also no beach areas. This setting has only been used to verify that actual water grid cells do limit hominin movement. With this setting activated it can be observed that groups actually move onto former water grid cells. This also verifies the functionality of the lowering sea levels that expose new accessible land.

9.5.2 Distributing energy equally throughout the grid

With the setting ZERO_MODEL_DISABLE_ENERGY set to True all energy level reconstructing is turned off. Effectively an equal amount of energy is assigned to all (land) grid cells, and this amount replenishes every year. Energy differences can thus no longer steer hominin groups in the landscape, and movement will resemble random movement. This setting has been used to test if other factors besides resource availability influence the directional decisions of the groups. For instance to check if the shape of the topography (land masses) steer hominins in certain directions.

9.5.3 Randomly walking hominins

Food in the landscape can be obtained following an optimal foraging based strategy (Belovsky 1988). Groups head for those areas that can give them the most resources. Opposing this would be a random walk algorithm for hominin groups. Comparison against results from these simulations allows assessment if more complexity in decision making add value to the model. When the setting ZERO_MODEL_RANDOM_WALK is activated (True), hominin group agents select their next destination grid cell randomly from the list with available grid cells they can move to. The choice where to go next is implemented in the HomininGroup.move() routine. Within this routine first a list of grid cells that can be reached is collected, and then they are randomly ordered using the default uniform distribution ("HomininGroup.java", line 209):

```
SimUtilities.shuffle(theNeighborhoodThatCanBeReached,
RandomHelper.getUniform());
```

This is opposed to (setting value False) selecting the grid cell with the most available energy as the best destination, implementing this algorithm ("HomininGroup.java", line 256-266):

```
// potential target area to move to
// to avoid death traps we compare cells and their immediate
environments with each other, not just cells
double cap = h.getAvailableCalories() + h.getEnvironmentCalories();
cap = cap / (1 + h.getForagingGroupCount());
if (cap > bestCapacity)
{
      bestHabitatCell = h;
      bestCapacity = cap;
}
```