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

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PART FOUR: AND ACTION!

"... for many years the objective of hunter-gatherer research has been to seek out the essential core of the hunter-gatherer lifeway and consequently to ignore or explain away variability as the product of extraordinary natural environments or particular historical circumstances."

(Kelly 1995)

10. SIMULATION RESULTS

10.1 Overview

The HomininSpace simulation system has been designed to answer questions about hominin behaviour in a reconstructed environment while comparing simulation results with archaeological presence (and absence) data. This chapter presents the results for all simulations that were run in this study. The simulations were executed in scenarios, each addressing one or more questions by including or excluding certain model elements. Settings indicate which elements are used. Each scenario first ran the same 1500 simulations, with the same parameter values (including the value for the random seed) in the Standard set. This allows effect assessment of the settings on the simulation score. Then the Genetic Algorithm for each scenario selects individuals and uses these to create new parameter value sets that are subsequently executed until the stop criterion is reached.

A scenario is given a readable name that is used in the analysis and the discussion. These names start with either Habitat or Energy, followed by a single character (for instance, Habitat-A or Energy-C). Scenarios are presented in alphabetical order. Each scenario also has an identifier that lists all the model settings in one string of boolean values (e.g. FTFTFFFFFF). Thus the setting combination FTFTFFFFFF implements a habitat reconstruction with static hominins with a maximized foraging range and with all other settings deactivated. To summarize the contents of each scenario, a descriptive name using the True values of the settings is also provided (for FTFTFFFFFF this is HabitatStaticMaxrange). Table 25 presents an overview of all the scenarios, with identifier, descriptive name, the number of simulations that were run, the maximum simulation score for the Standard set and for all simulations together.

Table 25: Summary of the simulated scenarios.

Identifier	*Readable and descriptive names*	*#sims*	*Max Standard*	*Max score*
FFFFFFFFF	Habitat-A (HabitatDynamic)	2,148	28434	30436
FFFFFFTFFF	Habitat-B (HabitatDynamicAbsence)	3,102	13432	13758
FFFTFFFFFF	Habitat-C (HabitatDynamicMaxrange)	2,008	28532	30206
FFFTFTTFFF	Habitat-D (HabitatDynamicMaxrangeCoreAbsence)	2,618	18521	19168
FFTTFTFFFF	Habitat-E (HabitatDynamicCoastalMaxrangeCore	2,420	26370	27948
FFTTFTTFFF	Habitat-F	2,240	17400	17486

	(HabitatDynamicCoastalMaxrangeCore Absence)			
FTFFFFFFF	Habitat-G (HabitatStatic)	2,043	30395	31016
FTFFTTFFF	Habitat-H (HabitatStaticCrosswaterCore)	2,192	30351	31119
FTFTFFFFF	Habitat-I (HabitatStaticMaxrange)	2,355	30123	31142
FTTTFFFFF	Habitat-J (HabitatStaticCoastalMaxrange)	2,210	29858	30954
TFFFFFFFF	Energy-A (EnergyDynamic)	2,089	28108	30522
TFTTFFFFF	Energy-B (EnergyDynamicCoastalMaxrange)	2,278	25249	29896
TFTTFFTFF	Energy-C (EnergyDynamicCoastalMaxrangeAbsence)	2,118	4766	6273
TFTTTFFFF	Energy-D (EnergyDynamicCoastalMaxrangeCrosswater)	2,012	25249	26112
TTTTFFFFF	Energy-E (EnergyStaticCoastalMaxrange)	2,176	30035	30651
TFTTFFFFT	Energy-BR (Scenario B + Randomwalk)	2,127	26286	28125
TFTTFFTFT	Energy-CR (Scenario C + Randomwalk)	2,079	3301	3301
TTTTFFFFT	Energy-ER (Scenario E + Randomwalk)	2,037	29262	30439
18 scenarios	**Total number of simulations:**	**40,252**		

For this study a total of 40,252 simulations were executed. Each run simulated 81,000 years resulting in data for a total of almost 3.3 billion modelled Neanderthal years. And this includes neither the many simulations that were run during development of the tool nor those that were executed in HomininSpace 1.0, for which this study is a successor.

For each scenario one batch of simulations was executed (with an additional duplication batch for scenario Energy-A). Each simulation in a batch has a unique number and a unique set of model parameter values. The results of each simulation are added to a combined data file per batch. A data file with all simulation results for each batch is included in the Supplementary Materials. The first 1500 parameter value combinations for every batch are referred to as the Standard set, and they are the same for all batches. When presented in figures or tables data for this set is always coloured cyan. Data from the Standard set is recombined to create additional parameter value combinations. These subsequent simulations are referred to as the Evolved parameter value set, and in figures and tables coloured in orange.

In the next sections results are presented per scenario, where for each scenario the following information is presented:

- The name of the scenario, the values for the settings and an informal description of the model elements that were included;
- A figure with the matchedIntervalCoverage score for all simulations in the batch, with results from the Standard set coloured cyan and the Evolved set orange;

- A table with the three best scoring parameter value sets from the Standard set in this scenario (again coloured in cyan), followed by the three best scoring parameter value sets from all simulations in the batch (in orange). In general, these latter are from the Evolved set, but occasionally a parameter combination from the Standard set performed so well that even after all improvements by the GA algorithm it still belongs to the top three scores overall.

10.1.1 Design of the Experiments (DOE)

There are ten different settings that control what model elements are included in the experiments using Boolean values to include or exclude those parts of the model. Even though three of these were mainly used in system development this leaves seven Boolean values or 128 different possible setting combinations. Since each setting combination requires at least 2000 simulations it is computationally impossible to do all combinations. A selection of settings in numbers and combinations has been made. Table 26 presents an overview of the usage per setting in the selected scenarios. The aim was to include each setting at least once.

Table 26: Overview of the setting values in all scenarios.

Setting name	*Setting is True in the following scenarios*
ENERGY_CONTINUOUS	Energy-A through Energy-E and in Energy-BR, Energy-CR, Energy-ER.
STATIC_DISPERSAL	Habitat-G through Habitat-J and in Energy-E and Energy-ER.
USE_BEACHES	Habitat-E, Habitat-F, Habitat-J, Energy-B through Energy-E, and Energy-BR, Energy-CR and Energy-ER.
USE_MAXIMUM_FORAGING_ RANGE	Habitat-C through Habitat-F, Habitat-I and Habitat-J. Energy-B through Energy-E and Energy-BR, Energy-CR and Energy-ER.
GROUPS_CAN_CROSS_WATER	Habitat-H, Energy-D.
USE_FACTORIES	Habitat-D, Habitat-E, Habitat-F, Habitat-H.
DEATH_PENALTY_FOR_ABSENCE	Habitat-B, Habitat-D, Habitat-F, Energy-C.
ZERO_MODEL_DISABLE_WATER	--
ZERO_MODEL_DISABLE_ENERGY	--
ZERO_MODEL_RANDOM_WALK	Energy-BR, Energy-CR and Energy-ER.

10.2 Scenario Habitat-A (HabitatDynamic)

This is the baseline simulation scenario against which others can be compared. The settings are all deactivated: FFFFFFFFFF. Therefore it features habitat reconstruction and dynamic hominins. The results for the MatchedIntervalCoverage variable are shown in Figure 49, where for each simulation a dot is shown in the graph, in cyan for the Standard set and orange for the Evolved. As expected the Evolved models score generally high matchedIntervalCoverage values. The top three scores for the Standard (cyan) and for the GA Evolved (orange) parameter sets are given in Table 27. In total there are 2148 simulations that are used from this batch[40]. The maximum score for the Standard set is 28434, for the Evolved set it is 30436, an improvement of 7%. Note that the use of a maximum foraging range is deactivated and all values for the maximum foraging range parameter are thus random and not involved in the GA improvement.

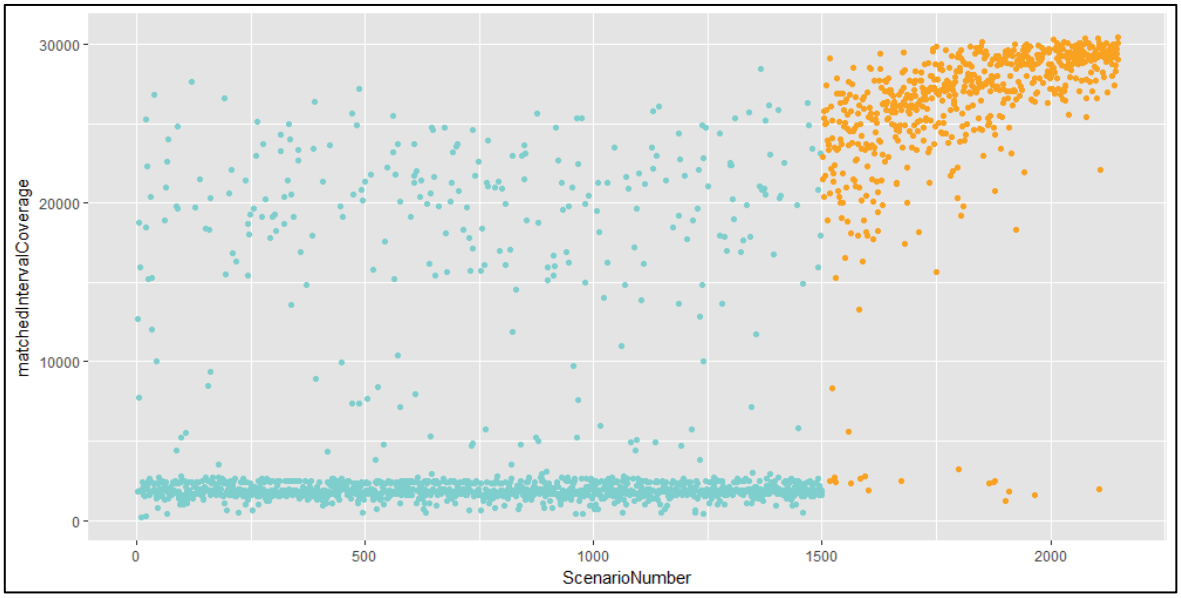

Figure 49: Simulation results for scenario Habitat-A.

Table 27: Best three simulation results and parameter values for scenario Habitat-A.

Settings: FFFFFFFFF	SimulationNumber	matchedIntervalCoverage	BirthRate	DeathRate_PreFertileCohort	DeathRate_FertileCohort	DeathRate_PostFertileCohort	Subsistence_PreFertileCohort	Subsistence_FertileCohort	Subsistence_PostFertileCohort	Years_Before_Group_Maturity	GroupSize_BeforeMerge	GroupSizeFertile_BeforeMerge	GroupSize_BeforeSplit	Temperature_Tolerance	CohortSize_PreFertile	CohortSize_Fertile	Calories_Per_Kg_Meat	Max_ForagingRange	ViabilityIndex
Standard 1	1365	28434	43	3	1	12	2000	5000	3250	2	4	2	16	-17	9	37	2700	12	28722
Standard 2	120	27636	43	1	1	12	3750	3250	5000	9	1	4	96	-29	8	32	2850	6	62186
Standard 3	486	27201	49	2	2	12	2750	4750	4250	5	2	1	56	-23	8	25	2550	10	41287
Evolved 1	2148	30436	49	1	1	12	2000	3000	5500	9	1	1	16	-23	13	41	3150	6	49118
Evolved 2	2076	30380	45	1	1	12	3000	2000	4750	2	4	2	16	-22	9	37	3500	14	76410
Evolved 3	2103	30380	48	4	1	12	2000	2000	4750	8	1	1	16	-21	13	41	3500	14	14905

[40] Seven simulation numbers were not assigned in this batch: 1984-1990.

10.3 Scenario Habitat-B (HabitatDynamicAbsence)

The settings for this scenario: FFFFFFTFFF. It features habitat reconstruction and dynamic hominins with absence activated. The results for the MatchedIntervalCoverage variable are shown in Figure 50. The top three scores for the Standard (cyan) and for the GA Evolved (orange) are given in Table 28. In total there are 3264 simulations. The maximum score for Standard is 13432, for Evolved 13145 when following the rule to stop after 100 iterations without improvement. This is actually less than the standard set, a difference of minus 2%. If the rule above is augmented to include the condition that the results should actually be better than the Standard set the first individual to comply is 3102, with a score of 13758, an improvement of less than plus 2%. A very substantial improvement of 15.6% is actually found in simulation 3264, with a value of 15534 (included in the table). After all simulations #3 from the Standard set is still in the top three. Note that the usage of a maximum foraging range is not activated in this scenario.

Figure 50: Simulation results for scenario Habitat-B.

Table 28: Best three simulation results and parameter values for scenario Habitat-B.

FFFFFTFFF	ScenarioNumber	matchedIntervalCoverage	BirthRate	DeathRate_PreFertileCohort	DeathRate_FertileCohort	DeathRate_PostFertileCohort	Subsistence_PreFertileCohort	Subsistence_FertileCohort	Subsistence_PostFertileCohort	Years_Before_Group_Maturity	GroupSize_BeforeMerge	GroupSizeFertile_BeforeMerge	GroupSize_BeforeSplit	Temperature_Tolerance	CohortSize_PreFertile	CohortSize_Fertile	Calories_Per_Kg_Meat	Max_ForagingRange	ViabilityIndex
Standard 1	3	13432	36	5	6	8	4000	3750	3000	3	2	4	76	-29	20	37	2850	3	30
Standard 2	1186	12722	43	4	11	2	3250	2500	2250	6	1	3	96	-15	13	37	3200	13	38
Standard 3	160	11799	46	15	6	7	2500	3750	2000	2	3	3	126	-19	11	40	2550	2	29
Evolved 1	3264	15534	39	9	3	8	2250	4500	4000	8	2	2	16	-10	15	28	3200	8	83
Evolved 2	3102	13758	39	9	4	8	2475	4500	4000	8	2	2	16	-10	15	28	3200	7	43
Evolved 3	3	13432	36	5	6	8	4000	3750	3000	3	2	4	76	-29	20	37	2850	3	30

10.4 Scenario Habitat-C (HabitatDynamicMaxrange)

The settings for this scenario are: FFFTFFFFFF. It features habitat reconstruction and dynamic hominins, with the usage of a maximum foraging range activated. The results for the MatchedIntervalCoverage variable are shown in Figure 51. The top three scores for the Standard (cyan) and the top three for the GA Evolved (orange) parameter set are given in Table 29. In total there are 2008 simulations that are used from this batch. The maximum score for the Standard set is 28532, for the Evolved set it is 30206, an improvement of 5.9%.

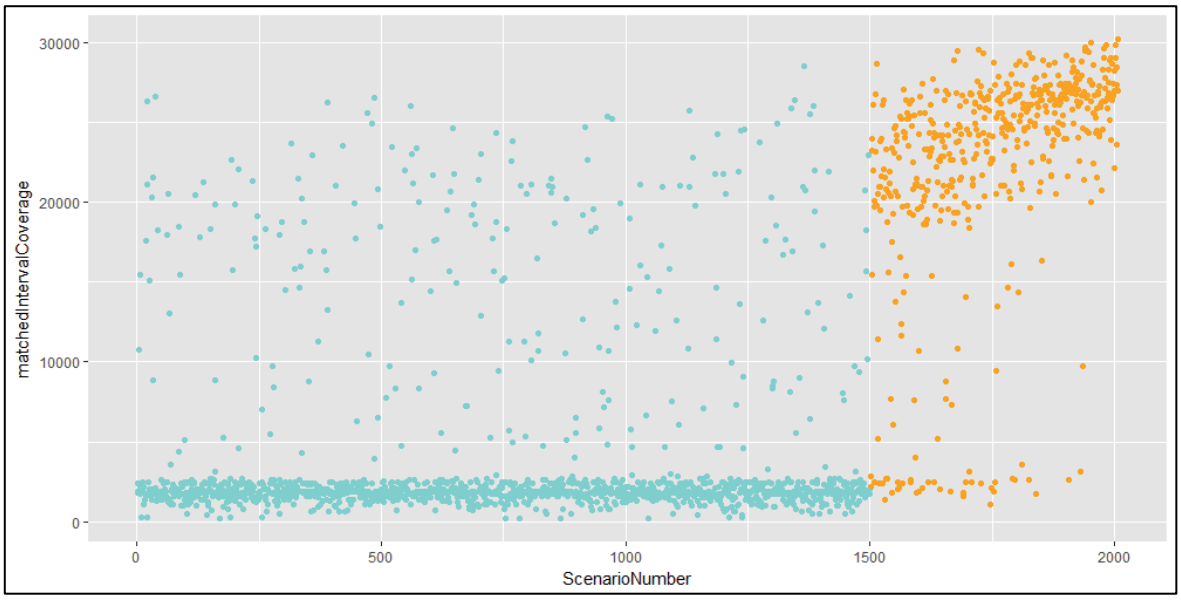

Figure 51: Simulation results for scenario Habitat-C.

Table 29: Best three simulation results and parameter values for scenario Habitat-C.

Settings: FFFTFFFFFF	SimulationNumber	matchedIntervalCoverage	BirthRate	DeathRate_PreFertileCohort	DeathRate_FertileCohort	DeathRate_PostFertileCohort	Subsistence_PreFertileCohort	Subsistence_FertileCohort	Subsistence_PostFertileCohort	Years_Before_Group_Maturity	GroupSize_BeforeMerge	GroupSizeFertile_BeforeMerge	GroupSize_BeforeSplit	Temperature_Tolerance	CohortSize_PreFertile	CohortSize_Fertile	Calories_Per_Kg_Meat	Max_ForagingRange	ViabilityIndex
Standard 1	1365	28532	43	3	1	12	2000	5000	3250	2	4	2	16	-17	9	37	2700	12	28722
Standard 2	39	26593	47	5	1	11	2750	3250	3750	5	5	2	56	-28	12	23	3000	10	4053
Standard 3	486	26542	49	2	2	12	2750	4750	4250	5	2	1	56	-23	8	25	2550	10	41287
Evolved 1	2008	30206	50	1	1	12	3500	3250	5000	8	1	1	16	-22	9	33	2750	14	138160
Evolved 2	1952	30001	43	3	1	2	2000	2475	3250	7	4	2	14	-25	9	37	3150	15	30712
Evolved 3	2002	29877	49	3	1	8	2500	4000	4675	4	4	2	14	-25	9	37	2750	10	73985

10.5 Scenario Habitat-D (HabitatDynamicMaxrangeCoreAbsence)

The settings for this scenario: FFFTFTTFFF. It features habitat reconstruction and dynamic hominins, with maximum foraging range, core areas and absence conditions activated. The results for the MatchedIntervalCoverage variable are shown in Figure 52. The top three scores for the Standard (cyan) and the top three for the GA Evolved (orange) parameter set are given in Table 30. In total there are 2618 simulations that are used from this batch. The maximum score for the Standard set is 18521, for the Evolved set it is 19168, an improvement of 3.5%.

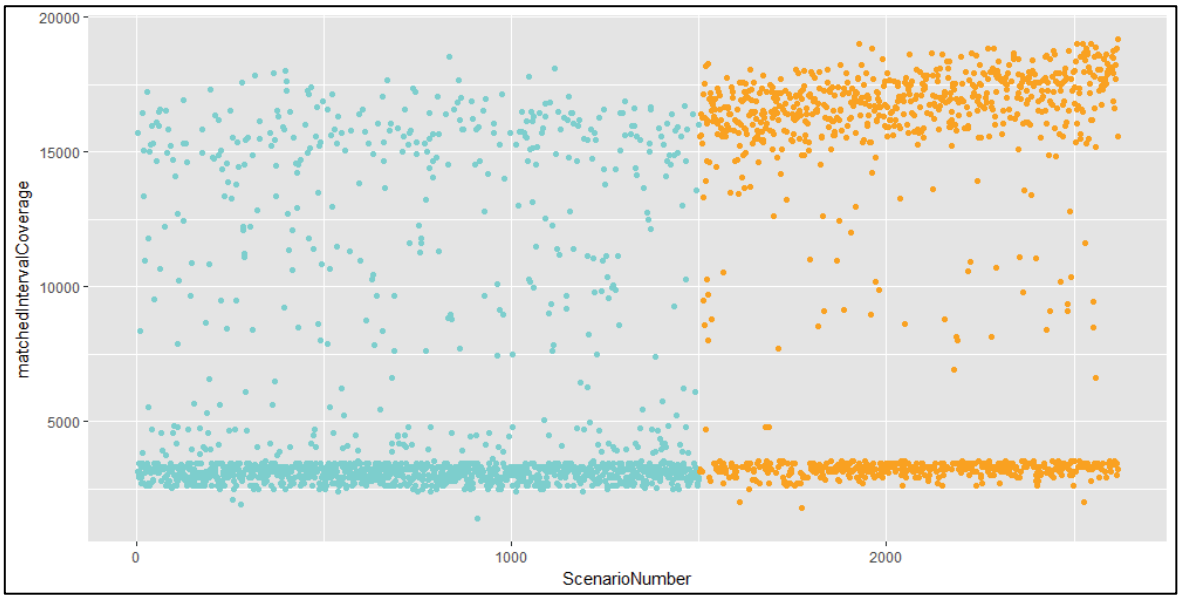

Figure 52: Simulation results for scenario Habitat-D.

Table 30: Best three simulation results and parameter values for scenario Habitat-D.

Settings: FFFTFTTFFF	SimulationNumber	matchedIntervalCoverage	BirthRate	DeathRate_PreFertileCohort	DeathRate_FertileCohort	DeathRate_PostFertileCohort	Subsistence_PreFertileCohort	Subsistence_FertileCohort	Subsistence_PostFertileCohort	Years_Before_Group_Maturity	GroupSize_BeforeMerge	GroupSizeFertile_BeforeMerge	GroupSize_BeforeSplit	Temperature_Tolerance	CohortSize_Prefertile	CohortSize_Fertile	Calories_Per_Kg_Meat	Max_ForagingRange	ViabilityIndex
Standard 1	832	18521	1	5	1	1	3000	2750	3000	7	1	1	6	-20	10	25	3200	6	8
Standard 2	1115	18110	38	12	5	11	4250	4000	2750	1	3	5	26	-16	18	20	2950	5	1
Standard 3	395	18012	38	4	3	4	2750	5000	4000	6	1	4	16	-26	14	17	3300	15	169
Evolved 1	2618	19168	1	4	1	1	3000	2750	3267	7	1	1	6	-20	10	25	3200	6	9
Evolved 2	2508	19024	1	5	1	1	3000	2750	3267	7	1	1	6	-20	10	25	3200	6	8
Evolved 3	2523	19024	1	5	1	1	3000	2750	3267	7	1	1	6	-20	10	25	3200	6	8

10.6 Scenario Habitat-E (HabitatDynamicCoastalMaxrangeCore)

The settings for this scenario are FFTTFTFFFF. It features habitat reconstruction and dynamic hominins, with coastal resources, a maximum foraging range and core areas activated. The results for the MatchedIntervalCoverage variable are shown in Figure 53. The top three scores for the Standard (cyan) and for the GA Evolved (orange) parameter value sets are given in Table 31. In total there are 2420 simulations that are used from this batch. The maximum score for the Standard set is 26370, for the Evolved set it is 29153, an improvement of 10.6%.

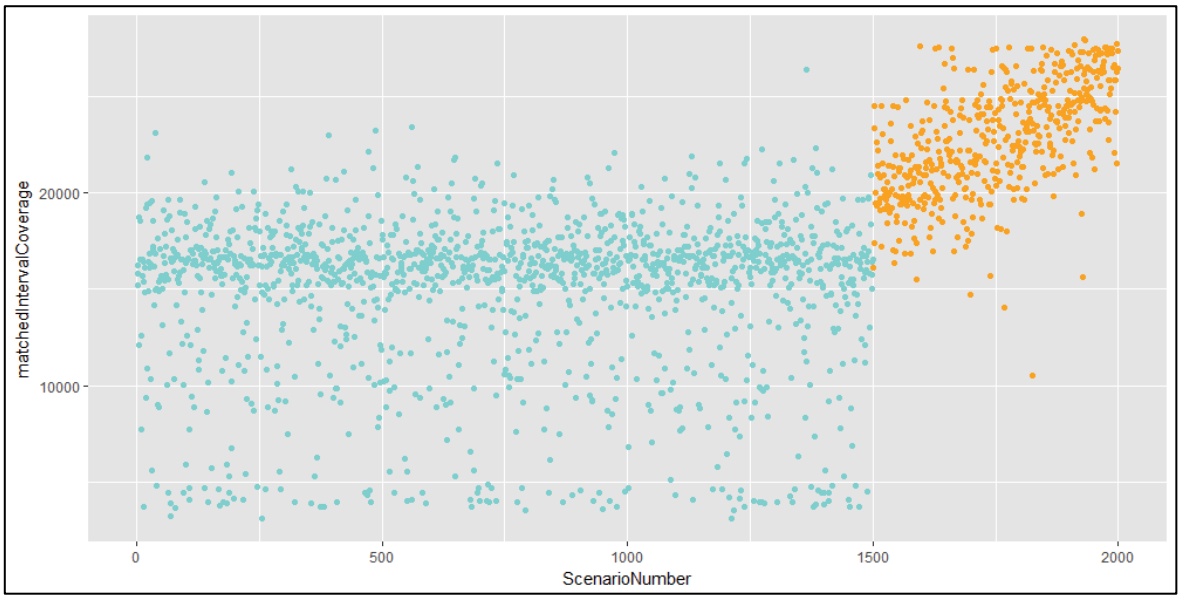

Figure 53: Simulation results for scenario Habitat-E.

Table 31: Best three simulation results and parameter values for scenario Habitat-E.

Settings: FFTTFTFFFF	SimulationNumber	matchedIntervalCoverage	BirthRate	DeathRate_PreFertileCohort	DeathRate_FertileCohort	DeathRate_PostFertileCohort	Subsistence_PreFertileCohort	Subsistence_FertileCohort	Subsistence_PostFertileCohort	Years_Before_Group_Maturity	GroupSize_BeforeMerge	GroupSizeFertile_BeforeMerge	GroupSize_BeforeSplit	Temperature_Tolerance	CohortSize_PreFertile	CohortSize_Fertile	Calories_Per_Kg_Meat	Max_ForagingRange	ViabilityIndex
Standard 1	1365	26370	43	3	1	12	2000	5000	3250	2	4	2	16	-17	9	37	2700	12	28722
Standard 2	560	23422	27	3	1	15	2500	4000	3500	8	4	2	16	-16	14	25	3100	9	301
Standard 3	486	23216	49	2	2	12	2750	4750	4250	5	2	1	56	-23	8	25	2550	10	41287
Evolved 1	2420	29153	50	1	1	11	2500	3250	3250	2	4	1	14	-29	8	33	3100	15	207291
Evolved 2	2388	29053	50	1	1	11	2500	3250	3250	1	4	1	16	-23	8	33	3410	15	207291
Evolved 3	2322	29050	50	1	1	11	2500	3250	3250	1	4	1	16	-26	8	33	3410	15	207291

10.7 Scenario Habitat-F (HabitatDynamicCoastalMaxrangeCoreAbsence)

The settings for this scenario: FFTTFTTFFF. It features habitat reconstruction and dynamic hominins, with coastal resources, a maximum foraging range, core areas and forces adherence to the absence condition. The results for the MatchedIntervalCoverage variable are shown in Figure 54. The top three scores for the Standard (cyan) and the top three for the GA Evolved (orange) parameter set are given in Table 32. In total there are 2240 simulations that are used from this batch. The maximum score for the Standard set is 17400, for the Evolved set it is 17486, with almost no improvement of 0.5%.

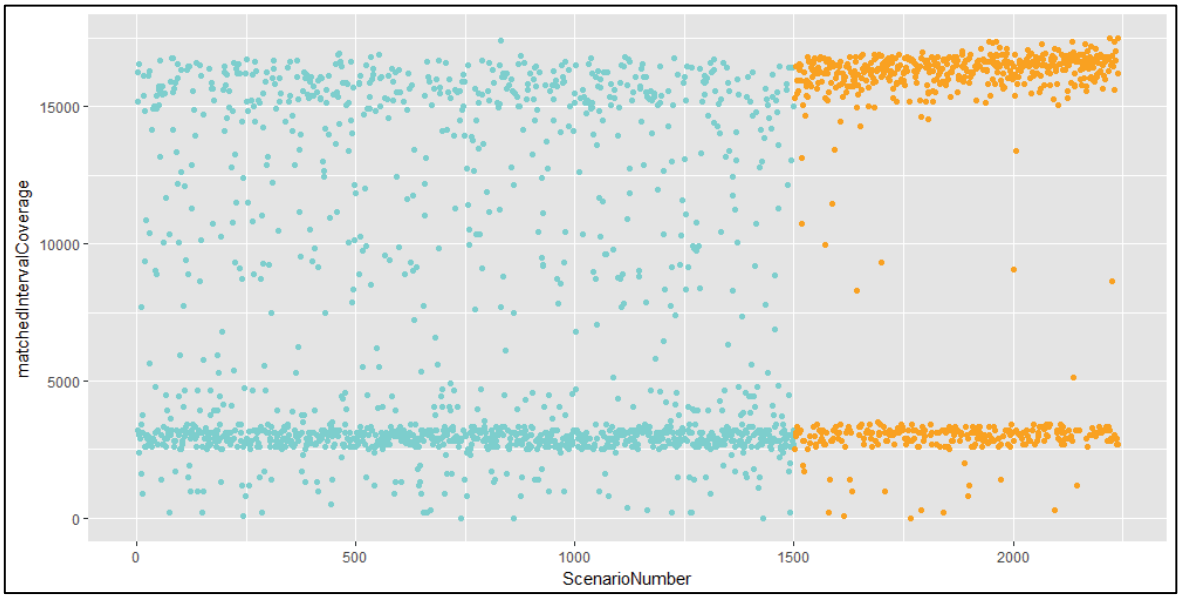

Figure 54: Simulation results for scenario Habitat-F.

Table 32: Best three simulation results and parameter values for scenario Habitat-F.

Settings: FFTTFTTFFF	SimulationNumber	matchedIntervalCoverage	BirthRate	DeathRate_PreFertileCohort	DeathRate_FertileCohort	DeathRate_PostFertileCohort	Subsistence_PreFertileCohort	Subsistence_FertileCohort	Subsistence_PostFertileCohort	Years_Before_Group_Maturity	GroupSize_BeforeMerge	GroupSizeFertile_BeforeMerge	GroupSize_BeforeSplit	Temperature_Tolerance	CohortSize_PreFertile	CohortSize_Fertile	Calories_Per_Kg_Meat	Max_ForagingRange	ViabilityIndex
Standard 1	832	17400	1	5	1	1	3000	2750	3000	7	1	1	6	-20	10	25	3200	6	8
Standard 2	461	16919	9	2	1	4	4250	4500	2000	8	5	5	16	-30	12	29	3350	9	18
Standard 3	554	16915	30	6	10	14	2500	3000	3000	9	2	1	96	-18	18	23	3500	9	0
Evolved 1	2240	17486	1	6	1	1	3000	2750	3000	7	1	1	6	-20	10	25	3200	6	8
Evolved 2	2220	17477	1	5	1	1	3000	2750	3000	8	0	1	6	-20	11	22	3200	6	8
Evolved 3	832	17400	1	5	1	1	3000	2750	3000	7	1	1	6	-20	10	25	3200	6	8

10.8 Scenario Habitat-G (HabitatStatic)

The settings for this scenario are FTFFFFFFFF. It features habitat reconstruction and static hominins. The results for the MatchedIntervalCoverage variable are shown in Figure 56. The top three scores for the Standard (cyan) and the top three for the GA Evolved (orange) parameter set are given in Table 34. In total there are 2043 simulations that are used from this batch. The maximum score for the Standard set is 30395, for the Evolved set it is 31016, an improvement of 2%. The use of a maximum foraging range is deactivated and all values for maximum foraging range are random.

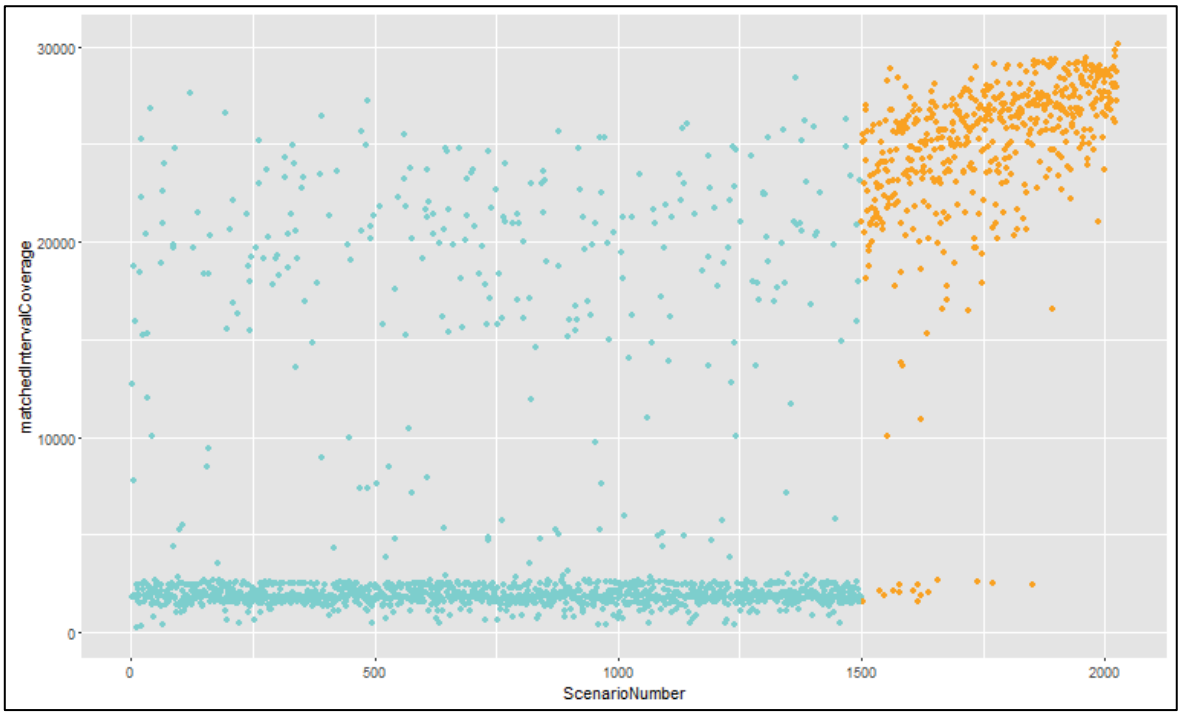

Figure 55: Simulation results for scenario Habitat-G.

Table 33: Best three simulation results and parameter values for scenario Habitat-G.

Settings: FTFFFFFFF	SimulationNumber	matchedIntervalCoverage	BirthRate	DeathRate_PreFertileCohort	DeathRate_FertileCohort	DeathRate_PostFertileCohort	Subsistence_PreFertileCohort	Subsistence_FertileCohort	Subsistence_PostFertileCohort	Years_Before_Group_Maturity	GroupSize_BeforeMerge	GroupSizeFertile_BeforeMerge	GroupSize_BeforeSplit	Temperature_Tolerance	CohortSize_PreFertile	CohortSize_Fertile	Calories_Per_Kg_Meat	Max_ForagingRange	ViabilityIndex
Standard 1	333	30395	38	6	1	13	4500	4250	4250	1	1	1	66	-25	13	27	2500	3	917
Standard 2	486	30365	49	2	2	12	2750	4750	4250	5	2	1	56	-23	8	25	2550	10	41287
Standard 3	120	30340	43	1	1	12	3750	3250	5000	9	1	4	96	-29	8	32	2850	6	62186
Evolved 1	2043	31016	49	1	1	12	3750	2000	4250	5	2	0	46	-23	13	32	3245	7	34246
Evolved 2	2021	30961	43	1	1	12	2200	4000	4675	5	2	1	16	-28	8	36	3300	4	75658
Evolved 3	2031	30961	43	1	1	12	2200	4000	4675	5	2	1	16	-31	8	36	3300	4	75658

10.9 Scenario Habitat-H (HabitatStaticCrosswaterCore)

The settings for this scenario are FTFFTTFFFF. It features habitat reconstruction and static hominins who are able to cross larger water bodies and with core areas activated. The results for the MatchedIntervalCoverage variable are shown in Figure 56. The top three scores for the Standard (cyan) and the top three for the GA Evolved (orange) parameter set are given in Table 34. In total there are 2192 simulations that are used from this batch. The maximum score for the Standard set is 30351, for the Evolved set it is 31119, an improvement of 2%. The use of a maximum foraging range is deactivated and all values for maximum foraging range are random, clearly illustrated by the model parameter values for Evolved 1 and Evolved 2 where the only difference is the value for the foraging range.

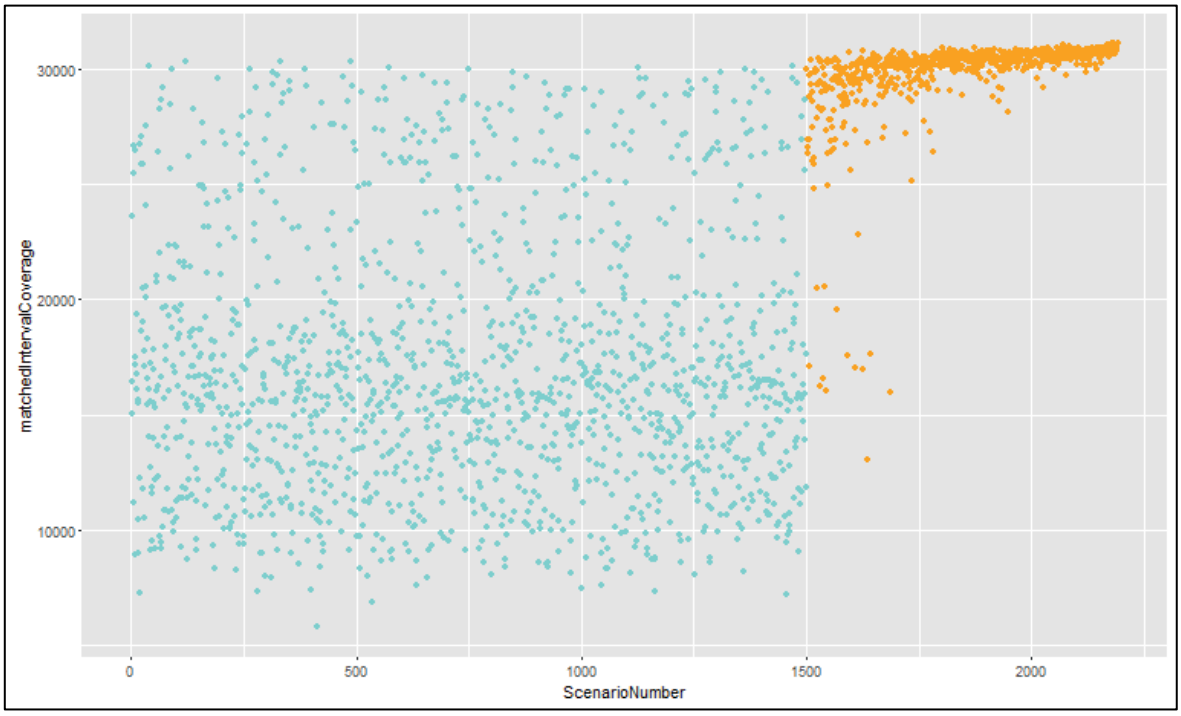

Figure 56: Simulation results for scenario Habitat-H.

Table 34: Best three simulation results and parameter values for scenario Habitat-H.

Settings: FTFFTTFFFF	SimulationNumber	matchedIntervalCoverage	BirthRate	DeathRate_PreFertileCohort	DeathRate_FertileCohort	DeathRate_PostFertileCohort	Subsistence_PreFertileCohort	Subsistence_FertileCohort	Subsistence_PostFertileCohort	Years_Before_Group_Maturity	GroupSize_BeforeMerge	GroupSizeFertile_BeforeMerge	GroupSize_BeforeSplit	Temperature_Tolerance	CohortSize_PreFertile	CohortSize_Fertile	Calories_Per_Kg_Meat	Max_ForagingRange	ViabilityIndex
Standard 1	486	30351	49	2	2	12	2750	4750	4250	5	2	1	56	-23	8	25	2550	10	41287
Standard 2	120	30346	43	1	1	12	3750	3250	5000	9	1	4	96	-29	8	32	2850	6	62186
Standard 3	333	30331	38	6	1	13	4500	4250	4250	1	1	1	66	-25	13	27	2500	3	917
Evolved 1	2180	31119	48	1	1	7	4500	2250	2250	1	1	1	56	-26	10	40	3500	15	98065
Evolved 2	2192	31119	48	1	1	7	4500	2250	2250	1	1	1	56	-26	10	40	3500	13	98065
Evolved 3	2181	31113	42	1	1	7	2475	2025	3442	1	1	1	66	-28	8	28	3500	13	41872

10.10 Scenario Habitat-I (HabitatStaticMaxrange)

The settings for this scenario: FTFTFFFFFF. It features habitat reconstruction and static hominins with a maximum foraging range activated. The results for the MatchedIntervalCoverage variable are shown in Figure 57. The top three scores for the Standard (cyan) and for the GA Evolved (orange) parameter set are given in Table 35. In total there are 2355 simulations that are used from this batch. The maximum score for the Standard set is 30123, for the Evolved set it is 31142, an improvement of 3.4%.

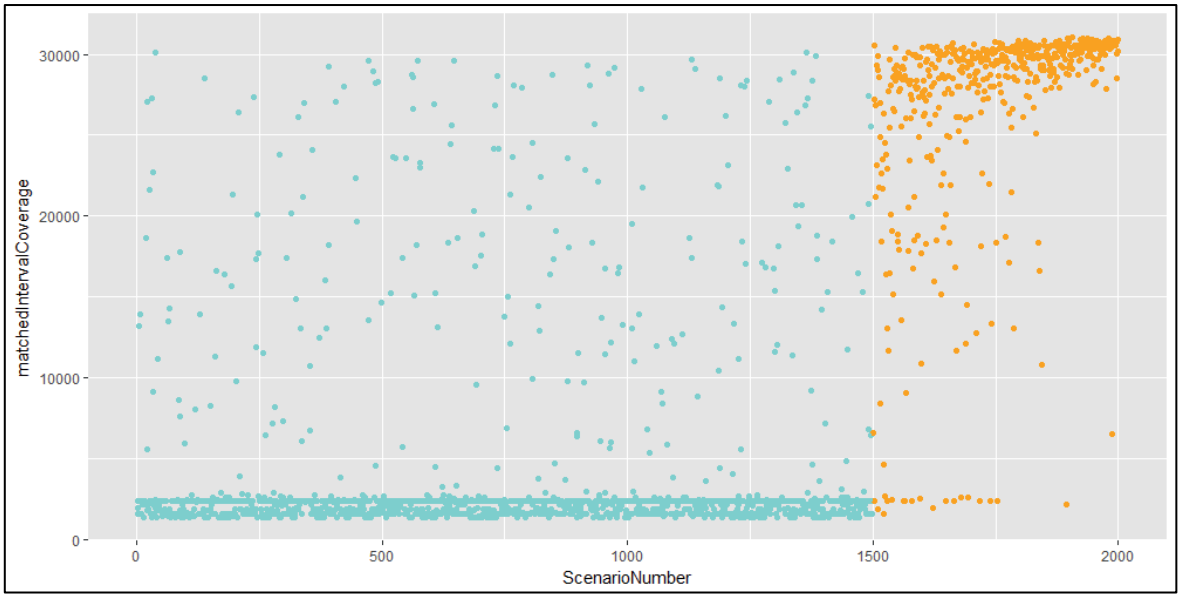

Figure 57: Simulation results for scenario Habitat-I.

Table 35: Best three simulation results and parameter values for scenario Habitat-I.

Settings: FTFTFFFFFF	SimulationNumber	matchedIntervalCoverage	BirthRate	DeathRate_PreFertileCohort	DeathRate_FertileCohort	DeathRate_PostFertileCohort	Subsistence_PreFertileCohort	Subsistence_FertileCohort	Subsistence_PostFertileCohort	Years_Before_Group_Maturity	GroupSize_BeforeMerge	GroupSizeFertile_BeforeMerge	GroupSize_BeforeSplit	Temperature_Tolerance	CohortSize_Prefertile	CohortSize_Fertile	Calories_Per_Kg_Meat	Max_ForagingRange	ViabilityIndex
Standard 1	39	30123	47	5	1	11	2750	3250	3750	5	5	2	56	-28	12	23	3000	10	4053
Standard 2	1365	30123	43	3	1	12	2000	5000	3250	2	4	2	16	-17	9	37	2700	12	28722
Standard 3	1384	29927	41	11	1	14	4250	2750	4250	10	5	1	46	-29	9	28	2900	11	1289
Evolved 1	2355	31142	47	1	1	9	3750	2750	4750	2	1	1	56	-26	9	35	3795	15	97015
Evolved 2	2293	31074	47	4	1	12	2500	2700	2500	6	1	1	50	-27	7	35	3200	13	87097
Evolved 3	2327	31069	47	1	1	11	2500	2750	4750	4	2	1	56	-26	9	35	3795	15	96320

10.11 Scenario Habitat-J (HabitatStaticCoastalMaxrange)

The settings for this batch: FTTTFFFFFF. It features habitat reconstruction and static hominins, with coastal resources and a maximum foraging range. The results for the MatchedIntervalCoverage variable are shown in Figure 58. The top three scores for the Standard (cyan) and the top three for the GA Evolved (orange) parameter set are given in Table 36. In total there are 2210 simulations that are used from this batch. The maximum score for the Standard set is 29858, for the Evolved set it is 30954, an improvement of 3.7%.

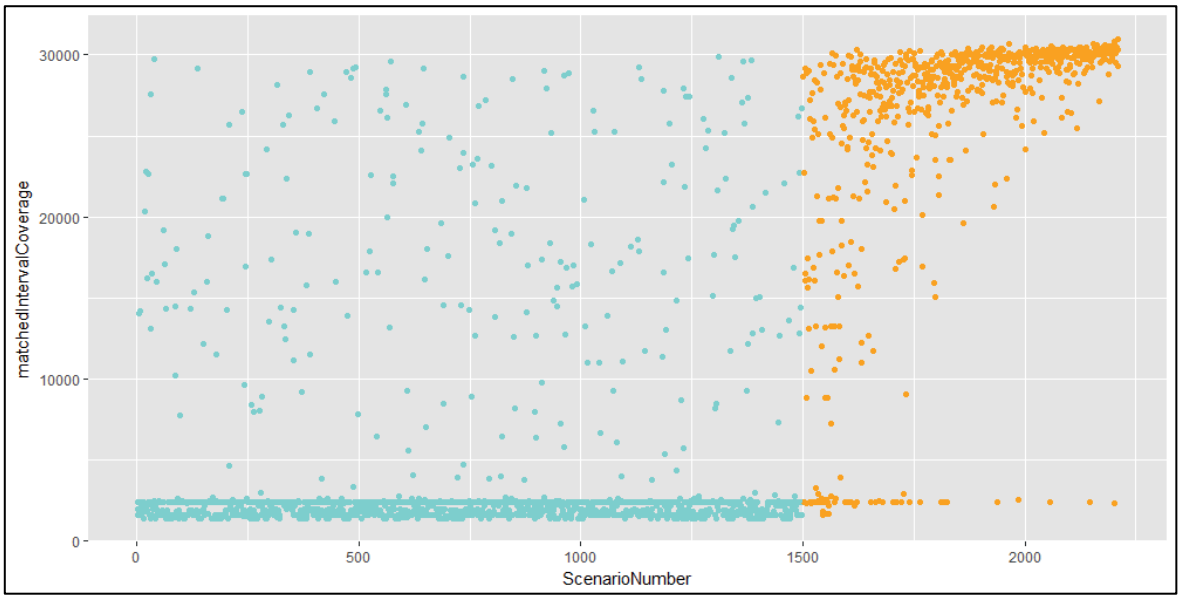

Figure 58: Simulation results for scenario Habitat-J.

Table 36: Best three simulation results and parameter values for scenario Habitat-J.

Settings: FTTTFFFFFF	SimulationNumber	matchedIntervalCoverage	BirthRate	DeathRate_PreFertileCohort	DeathRate_FertileCohort	DeathRate_PostFertileCohort	Subsistence_PreFertileCohort	Subsistence_FertileCohort	Subsistence_PostFertileCohort	Years_Before_Group_Maturity	GroupSize_BeforeMerge	GroupSizeFertile_BeforeMerge	GroupSize_BeforeSplit	Temperature_Tolerance	CohortSize_PreFertile	CohortSize_Fertile	Calories_Per_Kg_Meat	Max_ForagingRange	ViabilityIndex
Standard 1	1309	29858	30	1	3	6	3000	4250	5000	6	3	1	56	-28	15	38	2700	10	692
Standard 2	39	29737	47	5	1	11	2750	3250	3750	5	5	2	56	-28	12	23	3000	10	4053
Standard 3	1384	29636	41	11	1	14	4250	2750	4250	10	5	1	46	-29	9	28	2900	11	1289
Evolved 1	2210	30954	35	5	1	9	2750	2250	3000	7	1	1	16	-20	8	40	3100	14	6643
Evolved 2	2201	30819	35	5	1	9	2750	2250	3000	1	1	1	62	-23	8	40	3100	14	6643
Evolved 3	2153	30712	31	5	1	9	3750	3750	2000	4	1	1	23	-21	7	40	3300	14	4434

10.12 Scenario Energy-A (EnergyDynamic)

The settings for this scenario are coded as: TFFFFFFFFF. This scenario models the landscape using an energy reconstruction and has hominins with dynamic mobility. The results for the MatchedIntervalCoverage variable are shown in Figure 60. The top three scores for the Standard (cyan) and the top three for the GA Evolved (orange) parameter set are given in Table 38. In total there are 2089 simulations that are used from this batch. The maximum score for the Standard set is 28108, for the Evolved set it is 30522, an improvement of 8.6%.

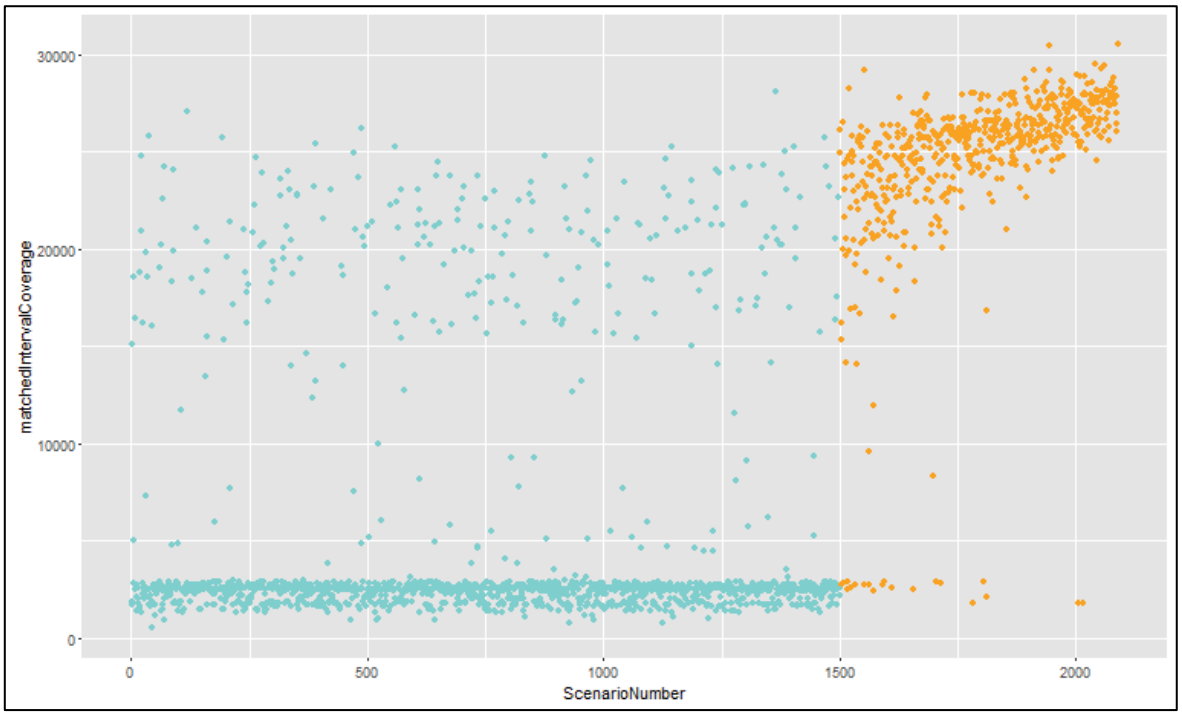

Figure 59: Simulation results for scenario Energy-A.

Table 37: Best three simulation results and parameter values for scenario Energy-A.

Settings: TFFFFFFFF	SimulationNumber	matchedIntervalCoverage	BirthRate	DeathRate_PreFertileCohort	DeathRate_FertileCohort	DeathRate_PostFertileCohort	Subsistence_PreFertileCohort	Subsistence_FertileCohort	Subsistence_PostFertileCohort	Years_Before_Group_Maturity	GroupSize_BeforeMerge	GroupSizeFertile_BeforeMerge	GroupSize_BeforeSplit	Temperature_Tolerance	CohortSize_PreFertile	CohortSize_Fertile	Calories_Per_Kg_Meat	Max_ForagingRange	ViabilityIndex
Standard 1	1365	28108	43	3	1	12	2000	5000	3250	2	4	2	16	-17	9	37	2700	12	28722
Standard 2	120	27034	43	1	1	12	3750	3250	5000	9	1	4	96	-29	8	32	2850	6	62186
Standard 3	486	26202	49	2	2	12	2750	4750	4250	5	2	1	56	-23	8	25	2550	10	41287
Evolved 1	2089	30522	43	1	1	9	2000	2750	3250	2	5	2	16	-29	9	41	2700	12	64869
Evolved 2	1945	30456	43	1	1	12	2000	3250	4500	2	4	4	16	-29	9	32	3300	14	43815
Evolved 3	2040	29481	44	1	1	12	2000	2700	3250	2	3	2	16	-29	11	28	3190	6	22280

10.13 Scenario Energy-B (EnergyDynamicCoastalMaxrange)

The settings for this scenario are coded: TFTTFFFFFF. Simulations in this scenario feature energy level reconstruction and dynamic hominins, with coastal resources and a maximum foraging range. The results for the MatchedIntervalCoverage variable are shown in Figure 60. The top three scores for the Standard (cyan) and the top three for the GA Evolved (orange) parameter set are given in Table 38. In total there are 2278 simulations that are used from this batch. The maximum score for the Standard set is 25249, for the Evolved set it is 29896, an improvement of 18.4%.

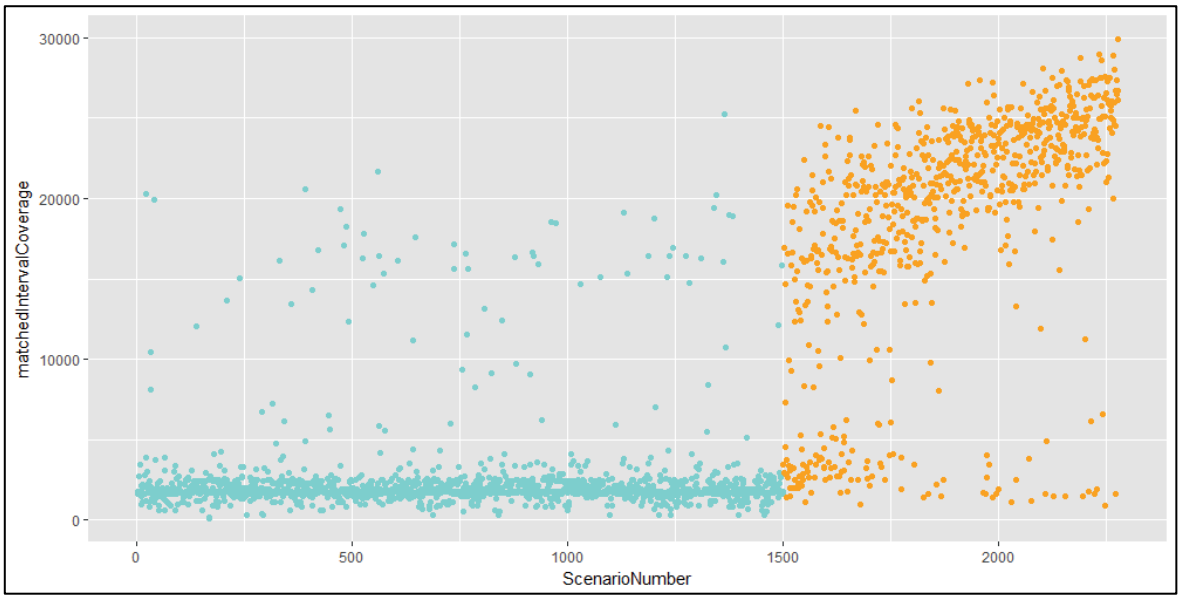

Figure 60: Simulation results for scenario Energy-B.

Table 38: Best three simulation results and parameter values for scenario Energy-B.

Settings: TFTTFFFFFF	SimulationNumber	matchedIntervalCoverage	BirthRate	DeathRate_PreFertileCohort	DeathRate_FertileCohort	DeathRate_PostFertileCohort	Subsistence_PreFertileCohort	Subsistence_FertileCohort	Subsistence_PostFertileCohort	Years_Before_Group_Maturity	GroupSize_BeforeMerge	GroupSizeFertile_BeforeMerge	GroupSize_BeforeSplit	Temperature_Tolerance	CohortSize_Prefertile	CohortSize_Fertile	Calories_Per_Kg_Meat	Max_ForagingRange	ViabilityIndex
Standard 1	1365	25249	43	3	1	12	2000	5000	3250	2	4	2	16	-17	9	37	2700	12	28722
Standard 2	560	21679	27	3	1	15	2500	4000	3500	8	4	2	16	-16	14	25	3100	9	301
Standard 3	390	20583	47	6	2	2	3250	4750	2000	1	5	5	56	-29	9	38	3150	13	12842
Evolved 1	2278	29896	49	1	1	10	2000	2000	2000	8	1	0	6	-26	9	32	3300	6	113555
Evolved 2	2235	28946	49	7	1	9	2000	2000	2000	8	1	0	6	-23	8	32	3300	10	26703
Evolved 3	2265	28915	49	3	1	9	2000	2000	2000	8	1	0	6	-23	14	35	3300	6	14941

10.14 Scenario Energy-C (EnergyDynamicCoastalMaxrangeAbsence)

The settings for this scenario are coded: TFTTFFTFFF. It features energy level reconstruction and dynamic hominins. Coastal resources and a maximum foraging range are also activated, and the absence condition is imposed. The results for the MatchedIntervalCoverage variable are shown in Figure 61. The top three scores for the Standard (cyan) and the top three for the GA Evolved (orange) parameter set are given in Table 39. In total there are 2118 simulations that are used from this batch. The maximum score for the Standard set is 4766, for the Evolved set it is 6273, an improvement of 31.6%.

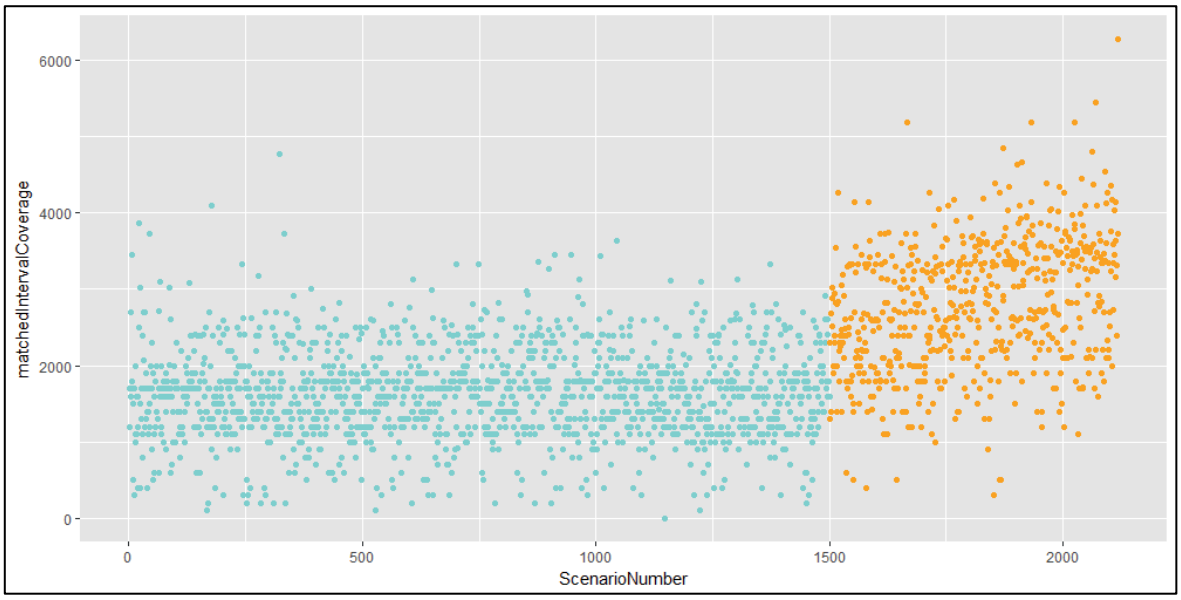

Figure 61: Simulation results for scenario Energy-C.

Table 39: Best three simulation results and parameter values for scenario Energy-C.

Settings: TFTTFFTFFF	SimulationNumber	matchedIntervalCoverage	BirthRate	DeathRate_PreFertileCohort	DeathRate_FertileCohort	DeathRate_PostFertileCohort	Subsistence_PreFertileCohort	Subsistence_FertileCohort	Subsistence_PostFertileCohort	Years_Before_Group_Maturity	GroupSize_BeforeMerge	GroupSizeFertile_BeforeMerge	GroupSize_BeforeSplit	Temperature_Tolerance	CohortSize_PreFertile	CohortSize_Fertile	Calories_Per_Kg_Meat	Max_ForagingRange	ViabilityIndex
Standard 1	323	4766	30	12	1	14	2500	3000	3000	8	2	1	136	-27	9	21	3250	4	71
Standard 2	178	4091	43	14	3	2	3250	3250	3000	7	5	2	16	-8	20	40	2550	8	39
Standard 3	22	3861	35	11	4	10	3750	2250	2000	1	3	4	46	-26	9	39	3300	5	115
Evolved 1	2118	6273	22	1	1	12	2750	3250	4250	7	1	1	26	-11	11	27	3050	3	427
Evolved 2	2070	5445	22	1	5	14	2500	3250	3000	8	2	1	26	-10	9	22	3250	4	31
Evolved 3	1667	5186	30	12	1	14	2500	2700	3000	8	2	1	136	-27	9	21	3250	4	71

10.15 Scenario Energy-D (EnergyDynamicCoastalMaxrangeCrosswater)

The settings for this scenario are coded: TFTTTFFFFF. These simulations feature energy level reconstruction and dynamic hominins, with coastal resources, a maximum foraging range and the hominins have the ability to cross larger water bodies. The results for the MatchedIntervalCoverage variable are shown in Figure 62. The top three scores for the Standard (cyan) and the top three for the GA Evolved (orange) parameter set are given in Table 40. In total there are 2012 simulations that are used from this batch. The maximum score for the Standard set is 25249, for the Evolved set it is 26112, an improvement of 3.4%. Since only a few more simulations were included in the GA analyse than the more or less arbitrarily minimum of 500, more improvement can be expected with more simulations. And indeed with simulation 2265 a score of 27479 was observed (a substantial improvement of 8.8%, but far beyond the stop criterion of the genetic algorithm and thus not included in this research).

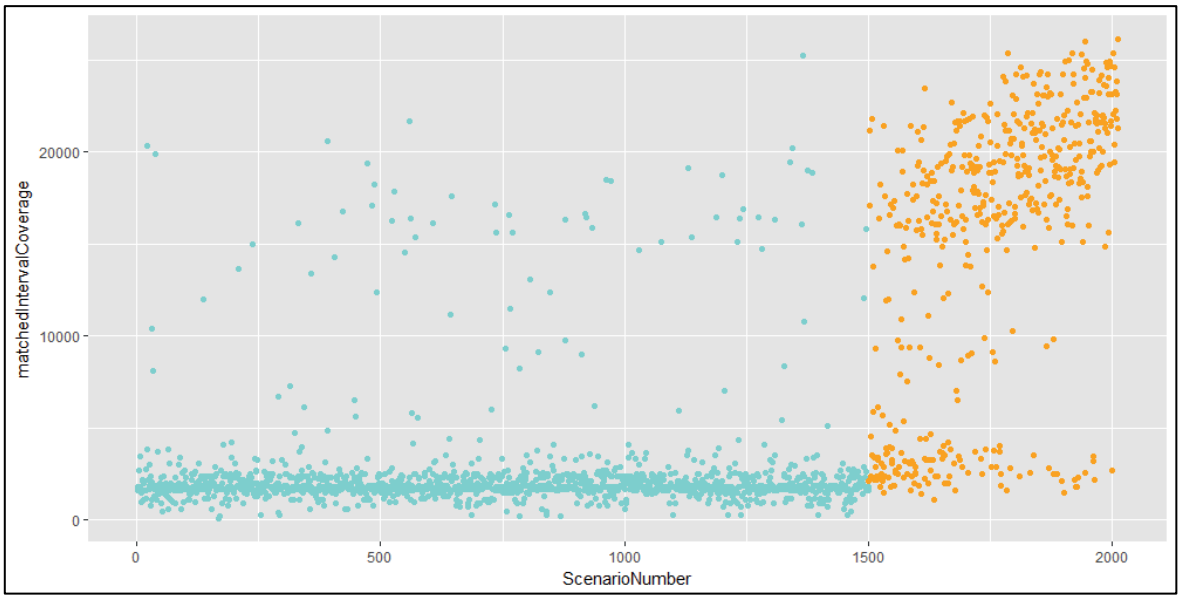

Figure 62: Simulation results for scenario Energy-D.

Table 40: Best three simulation results and parameter values for scenario Energy-D.

Settings: TFTTTFFFFF	SimulationNumber	matchedIntervalCoverage	BirthRate	DeathRate_PreFertileCohort	DeathRate_FertileCohort	DeathRate_PostFertileCohort	Subsistence_PreFertileCohort	Subsistence_FertileCohort	Subsistence_PostFertileCohort	Years_Before_Group_Maturity	GroupSize_BeforeMerge	GroupSizeFertile_BeforeMerge	GroupSize_BeforeSplit	Temperature_Tolerance	CohortSize_Prefertile	CohortSize_Fertile	Calories_Per_Kg_Meat	Max_ForagingRange	ViabilityIndex
Standard 1	1365	25249	43	3	1	12	2000	5000	3250	2	4	2	16	-17	9	37	2700	12	28722
Standard 2	560	21679	27	3	1	15	2500	4000	3500	8	4	2	16	-16	14	25	3100	9	301
Standard 3	390	20583	47	6	2	2	3250	4750	2000	1	5	5	56	-29	9	38	3150	13	12842
Evolved 1	2012	26112	48	1	1	6	2925	4500	2000	2	4	0	16	-25	11	21	3410	13	22418
Evolved 2	1945	25998	48	1	1	6	2925	4500	2000	2	4	2	16	-17	14	38	3410	13	31629
Evolved 3	2002	25382	43	3	1	10	2000	4500	3250	2	4	1	16	-17	9	37	2700	12	28937

10.16 Scenario Energy-E (EnergyStaticCoastalMaxrange)

The settings for this scenario are coded: TTTTFFFFFF. It features energy level reconstruction and static hominins with coastal resources and a maximum foraging range. The results for the MatchedIntervalCoverage variable are shown in Figure 63. The top three scores for the Standard (cyan) and the top three for the GA Evolved (orange) parameter set are given in Table 41. In total there are 2176 simulations that are used from this batch. The maximum score for the Standard set is 30035, for the Evolved set it is 30651, an improvement of 2%.

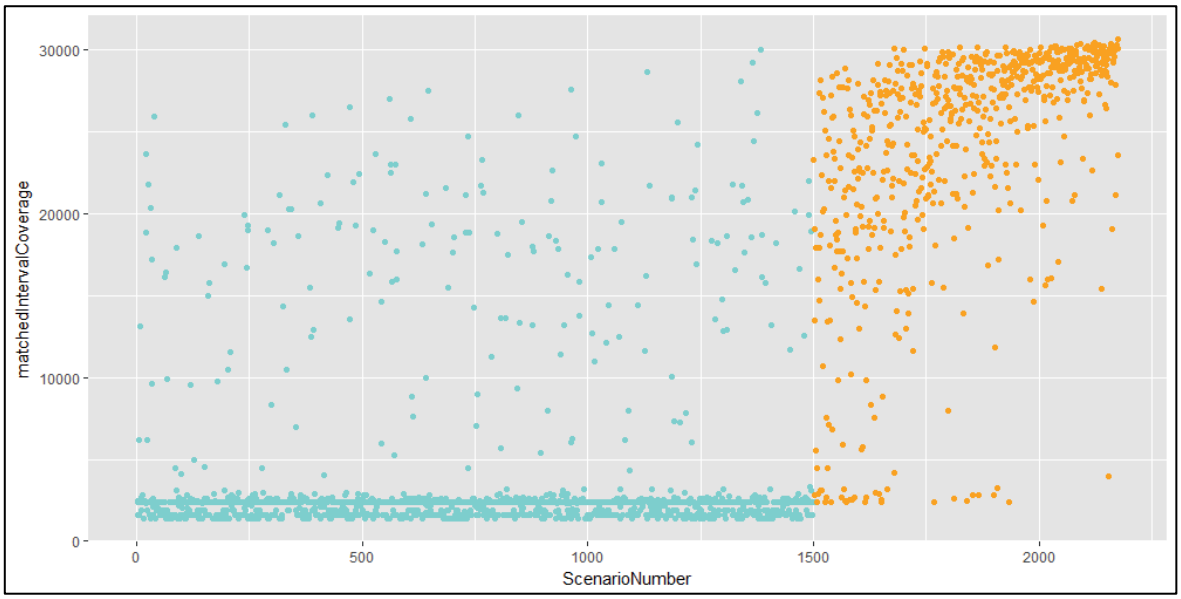

Figure 63: Simulation results for scenario Energy-E.

Table 41: Best three simulation results and parameter values for scenario Energy-E

Settings: TTTTFFFFF	SimulationNumber	matchedIntervalCoverage	BirthRate	DeathRate_PreFertileCohort	DeathRate_FertileCohort	DeathRate_PostFertileCohort	Subsistence_PreFertileCohort	Subsistence_FertileCohort	Subsistence_PostFertileCohort	Years_Before_Group_Maturity	GroupSize_BeforeMerge	GroupSizeFertile_BeforeMerge	GroupSize_BeforeSplit	Temperature_Tolerance	CohortSize_Prefertile	CohortSize_Fertile	Calories_Per_Kg_Meat	Max_ForagingRange	ViabilityIndex
Standard 1	1384	30035	41	11	1	14	4250	2750	4250	10	5	1	46	-29	9	28	2900	11	1289
Standard 2	1365	29226	43	3	1	12	2000	5000	3250	2	4	2	16	-17	9	37	2700	12	28722
Standard 3	1131	28670	35	8	2	12	3000	3750	4750	4	1	3	46	-26	8	40	3100	15	1502
Evolved 1	2176	30651	47	1	1	6	2500	3500	4750	2	1	1	16	-28	8	37	3100	15	156980
Evolved 2	2123	30454	30	2	1	13	4500	2475	3500	10	3	0	76	-29	17	21	3450	15	335
Evolved 3	2159	30360	43	2	1	13	2000	2000	3250	9	1	1	46	-17	9	31	3150	12	29327

10.17 Additional simulations

This section addresses some of the extra simulation scenarios that were executed.

10.17.1 Three simulation scenarios with Random walk activated

This subsection presents three simulation scenarios with Random walk activated. They are used explicitly to explore question seven that investigates movement through the landscape for hominin groups with the effects of random population distribution opposing a directed search for the best resource patches.

Scenario Energy-B + Randomwalk: TFTTFFFFFT

This scenario has energy level reconstruction and dynamic hominins, with coastal resources and a maximum foraging range. The results for the MatchedIntervalCoverage variable are shown in Figure 60. The top three scores for the Standard (cyan) and the top three for the GA Evolved (orange) parameter set are given in Table 42. In total there are 2127 simulations that are used from this batch. The maximum score for the Standard set is 26286, for the Evolved set it is 28125, an improvement of 7%.

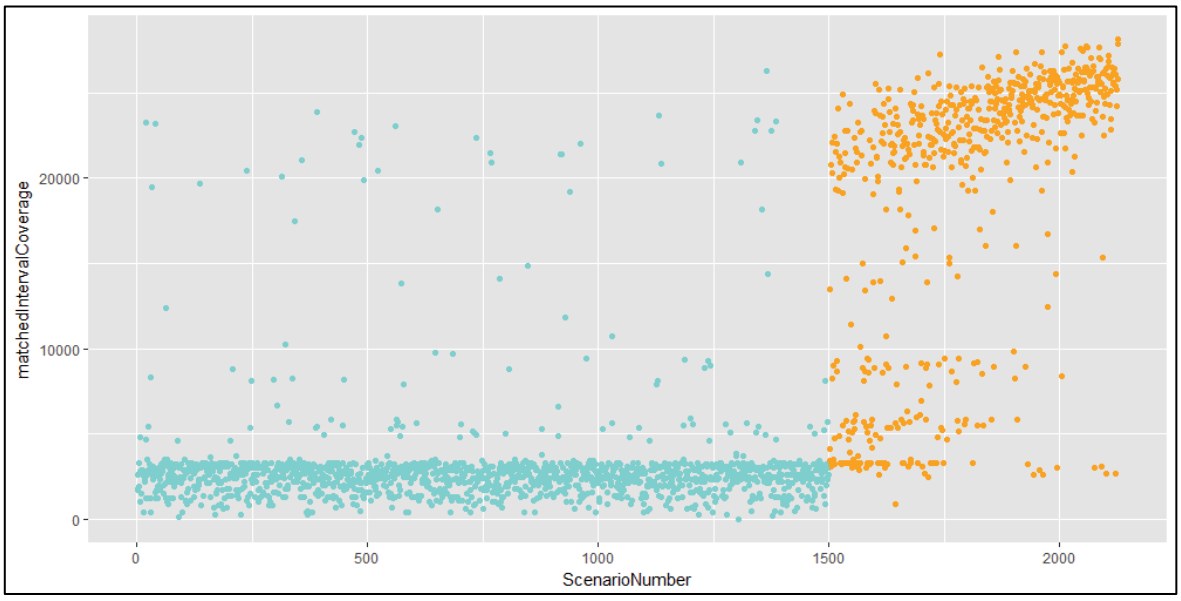

Figure 64: Simulation results for scenario Energy-BR, with random walk.

Table 42: Best three simulation results and parameter values for scenario Energy-BR, (with randomwalk) for Standard and Evolved parameter value sets.

Settings: TFTTFFFFT	SimulationNumber	matchedIntervalCoverage	BirthRate	DeathRate_PreFertileCohort	DeathRate_FertileCohort	DeathRate_PostFertileCohort	Subsistence_PreFertileCohort	Subsistence_FertileCohort	Subsistence_PostFertileCohort	Years_Before_Group_Maturity	GroupSize_BeforeMerge	GroupSizeFertile_BeforeMerge	GroupSize_BeforeSplit	Temperature_Tolerance	CohortSize_PreFertile	CohortSize_Fertile	Calories_Per_Kg_Meat	Max_ForagingRange	ViabilityIndex
Standard 1	1365	26286	43	3	1	12	2000	5000	3250	2	4	2	16	-17	9	37	2700	12	28722
Standard 2	390	23882	47	6	2	2	3250	4750	2000	1	5	5	56	-29	9	38	3150	13	12842
Standard 3	1131	23640	35	8	2	12	3000	3750	4750	4	1	3	46	-26	8	40	3100	15	1502
Evolved 1	2127	28125	30	1	1	12	3025	5000	2250	2	3	1	6	-29	9	39	3150	12	5991
Evolved 2	2126	27847	43	1	1	12	2000	3500	3250	2	4	1	16	-23	9	37	2700	12	55429
Evolved 3	2057	27761	50	1	2	12	3500	3000	2000	4	1	1	6	-24	11	33	2700	10	40880

Scenario Energy-C + Randomwalk: TFTTFFTFFT

It features energy level reconstruction and dynamic hominins. Coastal resources and a maximum foraging range are activated, and the absence condition imposed. The results for the MatchedIntervalCoverage variable are shown in Figure 61. The top three scores for the Standard (cyan) and the top three for the GA Evolved (orange) parameter set are given in Table 43. In total there are 2079 simulations that are used from this scenario. The maximum score for the Standard set is 3301, for the Evolved set it is 3301, so no improvement is achieved.

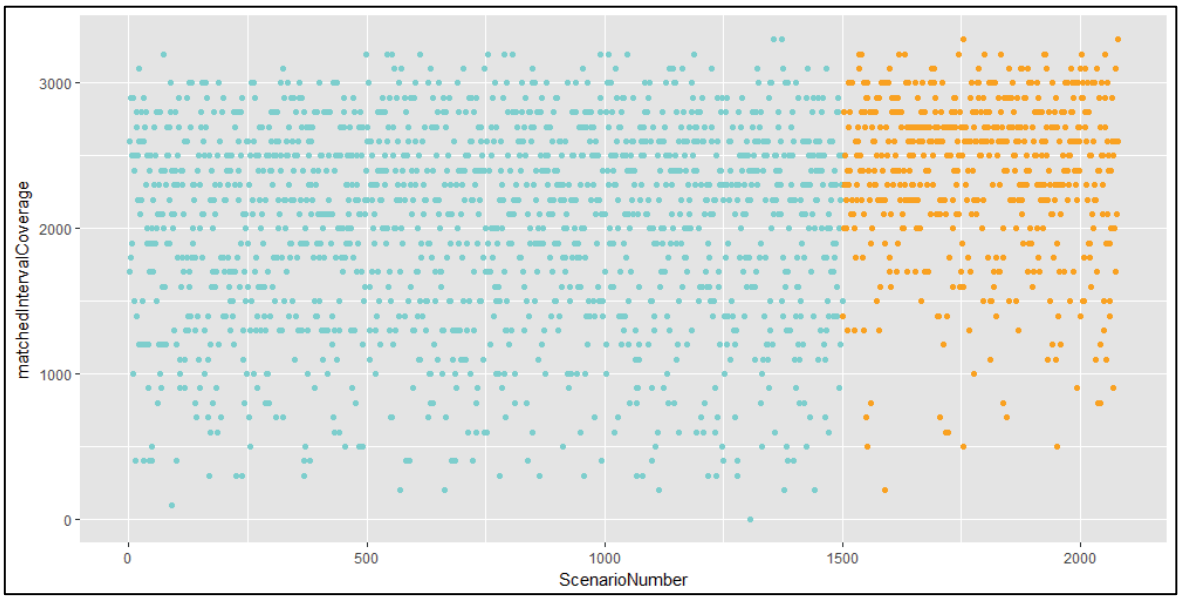

Figure 65: Simulation results for scenario Energy-CR, with random walk.

Table 43: Best three simulation results and parameter values for scenario Energy-CR, with randomwalk.

Settings: TFTTFFTFT	SimulationNumber	matchedIntervalCoverage	BirthRate	DeathRate_PreFertileCohort	DeathRate_FertileCohort	DeathRate_PostFertileCohort	Subsistence_PreFertileCohort	Subsistence_FertileCohort	Subsistence_PostFertileCohort	Years_Before_Group_Maturity	GroupSize_BeforeMerge	GroupSizeFertile_BeforeMerge	GroupSize_BeforeSplit	Temperature_Tolerance	CohortSize_PreFertile	CohortSize_Fertile	Calories_Per_Kg_Meat	Max_ForagingRange	ViabilityIndex
Standard 1	1355	3301	50	2	13	8	3750	2750	2000	7	2	1	136	-30	20	22	3200	12	28
Standard 2	1373	3301	49	10	4	10	3250	2000	4250	10	3	1	116	-15	13	27	3250	2	172
Standard 3	499	3201	48	14	4	2	4250	3500	4000	2	4	5	66	-17	8	31	3250	6	520
Evolved 1	1355	3301	50	2	13	8	3750	2750	2000	7	2	1	136	-30	20	22	3200	12	28
Evolved 2	1373	3301	49	10	4	10	3250	2000	4250	10	3	1	116	-15	13	27	3250	2	172
Evolved 3	1754	3301	48	5	5	2	4250	2000	2250	2	5	3	117	-27	8	27	3250	6	2843

Scenario Energy-E +Randomwalk: TTTTFFFFFT

This scenario has energy level reconstruction and static hominins with coastal resources and a maximum foraging range. The results for the MatchedIntervalCoverage variable are shown in Figure 63. The top three scores for the Standard (cyan) and the top three for the GA Evolved (orange) parameter value sets are given in Table 44. In total there are 2037 simulations used from this scenario. The maximum score for the Standard set is 29262, for the Evolved set it is 30439, an improvement of 4%.

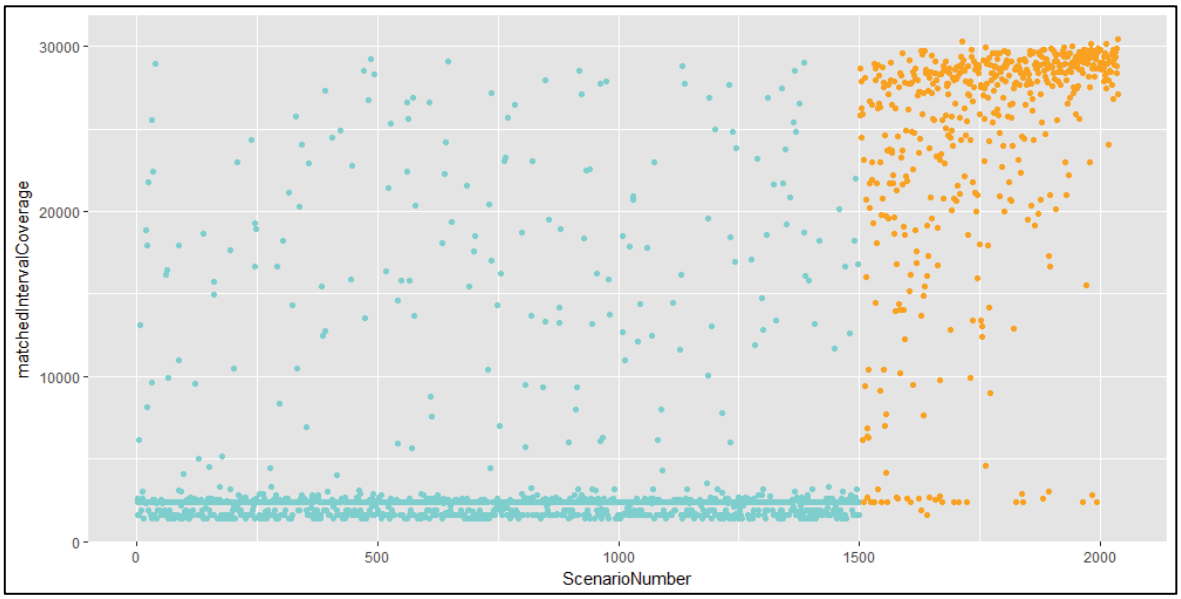

Figure 66: Simulation score for scenario Energy-ER (with random walk).

Table 44: Best three simulation results and parameter values for scenario Energy-ER, with randomwalk.

Settings: TTTTFFFFT	SimulationNumber	matchedIntervalCoverage	BirthRate	DeathRate_PreFertileCohort	DeathRate_FertileCohort	DeathRate_PostFertileCohort	Subsistence_PreFertileCohort	Subsistence_FertileCohort	Subsistence_PostFertileCohort	Years_Before_Group_Maturity	GroupSize_BeforeMerge	GroupSizeFertile_BeforeMerge	GroupSize_BeforeSplit	Temperature_Tolerance	CohortSize_PreFertile	CohortSize_Fertile	Calories_Per_Kg_Meat	Max_ForagingRange	ViabilityIndex
Standard 1	486	29262	49	2	2	12	2750	4750	4250	5	2	1	56	-23	8	25	2550	10	41287
Standard 2	646	29131	30	11	1	1	3000	3750	2500	6	4	2	66	-19	9	40	2550	15	577
Standard 3	1384	29042	41	11	1	14	4250	2750	4250	10	5	1	46	-29	9	28	2900	11	1289
Evolved 1	2037	30439	36	4	1	8	4500	2000	2000	7	1	1	56	-22	18	40	2950	12	1174
Evolved 2	1712	30328	36	4	1	8	4500	2000	2000	7	1	1	56	-22	18	40	2950	14	1174
Evolved 3	2012	30180	41	4	1	5	3250	3500	2250	7	2	1	76	-24	10	28	2950	15	6924

10.17.2 Duplication of scenario Energy-A for verification purposes

For verification purposes the scenario was rerun, producing the second batch. The first 1500 were still the same Standard simulations, but after that the genetic algorithm will select different individuals in the tournaments and apply different mutations or combinations. The result is summarized in Figure 67 and Table 45.

Figure 67: Simulation results for scenario Energy-A, batch 2.

Table 45: Best three simulation results for scenario Energy-A, batch 2.

FFFFFFFFF(2)	ScenarioNumber	matchedIntervalCoverage	BirthRate	DeathRate_PreFertileCohort	DeathRate_FertileCohort	DeathRate_PostFertileCohort	Subsistence_PreFertileCohort	Subsistence_FertileCohort	Subsistence_PostFertileCohort	Years_Before_Group_Maturity	GroupSize_BeforeMerge	GroupSizeFertile_BeforeMerge	GroupSize_BeforeSplit	Temperature_Tolerance	CohortSize_PreFertile	CohortSize_Fertile	Calories_Per_Kg_Meat	Max_ForagingRange	ViabilityIndex
Standard 1	1365	28108	43	3	1	12	2000	5000	3250	2	4	2	16	-17	9	37	2700	12	28722
Standard 2	120	27034	43	1	1	12	3750	3250	5000	9	1	4	96	-29	8	32	2850	6	62186
Standard 3	486	26202	49	2	2	12	2750	4750	4250	5	2	1	56	-23	8	25	2550	10	41287
Evolved 1	1884	29136	43	2	1	12	2000	5000	3250	2	5	2	16	-17	9	37	2700	12	39669
Evolved 2	1998	29067	44	3	1	9	3250	4750	2000	3	5	2	16	-18	8	38	2700	14	52123
Evolved 3	1809	29030	49	2	1	14	2500	4500	3750	9	3	1	16	-19	10	40	2950	6	78628