Computational methods and calculations

SUPPLEMENTARY MATERIAL | HEO v1.2 | 24 November 2026

Companion to Micronutrient Constraints on Seasonal Human Mobility: A Computational Investigation of Residential Strategy under Resource Scarcity. This document describes the actual archived implementation, provides worked numerical examples and locates the complete machine-readable calculations. It is not a second empirical study.

Scope and interpretation

The core experiment compares three residential strategies under a common set of food-resource limits with four nutritional targets versus sixteen. All habitat food caps are synthetic. The scores are fractions of selected reference targets, not health, survival, fitness or observed nutritional status. The archived research includes earlier exploratory models, negative findings and corrections; the v1.2 manuscript supersedes historical interpretations.

Material	Location in the accompanying ZIP
Main report	HEO_Final_Research_Report_v1.2.pdf
Initial trait and habitat catalogue	Human_Ecological_Origins_Phases_I-III.xlsx
Climate, energy and mobility	heo_iv_v/
Ethnographic subset and nutrient arithmetic	heo_vi/
Diet optimisation and iodine thresholds	heo_vii/
Annual reserve model and tracer decay	heo_viii/
Matched residential-strategy experiment	heo_ix/
Reproduction, corrections, source and assumptions audit	heo_x/
Extended sensitivity and measured tuber substitutions	heo_publication/

How to use the supplement

Pages 2–4 document the earlier models and the principal linear programme. Pages 5–6 document sensitivity tests and numerical checks. Page 7 explains reproduction and data provenance. All input cells and recorded outputs are in CSV files; every optimisation run can be reconstructed by the supplied scripts. The PDFs do not print millions of individual numbers. Per-solve decision vectors were not retained for every run; the scripts regenerate the reported scores.

AI disclosure: the research was initiated and directed by an independent researcher, with extensive ChatGPT assistance in literature searching, coding, calculations, analysis and drafting. No external scientific review or empirical field validation is claimed.

1 / Climate, energy and mobility

Phases IV–V use a 365-day calendar, representative adult energy demand and sinusoidal synthetic habitat inputs. For month m (1–12), with peak p, the seasonal factor is:

$$w(m,p) = \cos(2\pi(m - p)/12)$$

Temperature = mean + amplitude × w; obtainable food = mean × (1 + fractional amplitude × w) × technology multiplier. Water availability follows a similar additive wave. Values are specified in habitat_inputs.csv and technology_inputs.csv; they are not measurements.

Daily demand = 2500 + 25 × max(0, cold threshold − mean temperature) kcal Monthly net = (daily food − daily demand) × days − additional travel cost

The cold coefficient is a scenario approximation, not validated human heat balance. Water demand proxy = 3 + 0.15 × max(0, daytime temperature − 25) L/day. Stull (2011) wet-bulb approximation is implemented in wb(t,h); the 24°C screening threshold is arbitrary, not a medical safety threshold.

S* = 0.95 × opening stock; shortage = max(0, −net − S*) Closing stock = min(storage capacity, max(0, S* + net))

Six annual iterations are used to reach the final-year storage scenario. For the local mobility sensitivity, storage retention and costs vary by trial; seed 241126. Daylight is geometric: declination $\delta = 23.44° \times \sin(2\pi(284+n)/365)$, where n is mid-month day of year; duration = $(24/\pi) \times \arccos(\text{clamp}(-\tan(\text{latitude})\tan(\delta), -1, 1))$.

Worked travel comparison

Quantity	Calculation	Result
Round trip	2 × 1,500 km	3,000 km
Walking cost	3,000 × 42 kcal/km	126,000 kcal
Travel time	3,000 ÷ 20 km/day	150 days
Cold savings (illustrative)	49,151 − 10,155	38,996 kcal
Net travel penalty	126,000 − 38,996	87,004 kcal

At 42 kcal/km, the cold-only break-even one-way distance is 38,996/(2 × 42) = 464.24 km. Climate schedules assume instantaneous switching; the reported walking days do not replace months of residence. Modern climate transcriptions still require cell-level verification.

Files: heo_iv_v/model.py; monthly_habitat.csv (672 rows), migration_climate.csv (45), local_mobility.csv (432), local_sensitivity.csv (2,000).

2 / Ethnography and nutrient modelling

Phase VI — observed subset and arithmetic

The 80 matched D-PLACE Binford records relate B003 aquatic resource dependence to B014 annual residential distance. Spearman correlation is Pearson correlation on average ranks. The archived convenience sample is geographically clustered, contains zero distances and is not representative; unadjusted significance tests are diagnostic only.

Aquatic dependence	n	Median km	Mean km
0–20%	29	318.65	279.91
>20–<50%	24	442.57	379.74
50–100%	27	49.89	64.3

Winter nutrient contribution example: 3 portions of cod per week, 146 µg iodine per 85 g portion, plus assumed 35 µg/day background, gives 35 + (3 × 146)/7 = 97.57 µg/day, or 69.69% of the 140 µg reference. The independent salmon vitamin D calculation uses 14.2 µg per portion and 2 µg/day background. These are arithmetic contributions, not complete diets.

Phase VII — monthly nutrient optimisation

Twenty food proxies and 16 targets are used in a linear programme. Eight conditions, five profiles, 14 habitats and 12 months yield 6,720 monthly cases. An additional 168 iodine threshold investigations use iterative optimisation to identify the extra notional iodine contribution required where otherwise feasible. The original 216 migration schedules had a fixed energy ceiling; the corrected output in Phase X adjusts it and uses day-weighted annual averages. Both versions are preserved.

Phase VIII — annual stock and tracer calculations

A cyclic annual optimisation uses 12 sets of food quantities, 12 coverage scores and 12 abstract iodine stock variables. The stock capacity is 0, 30 or 90 times the daily reference intake, and opening stock retains 95% per month. The iodine constraint incorporates previous and ending stock, with December connected to January:

$$\text{Iodine intake} + \text{water credit} + (0.95 \times S[m-1] - S[m])/\text{days}[m] \geq q[m] \times \text{iodine target}$$

This is a bookkeeping proxy, not a model of thyroid physiology. Example: 30 µg iodine/L × 2 L/day = 60 µg/day. Tracer persistence is 2^(−elapsed days/half-life); at 30 days and half-life 15.1 days the fraction is approximately 0.252. This does not predict total circulating vitamin D.

Files: heo_vi/model.py; heo_vii/model.py, observed_cells.csv, iodine_thresholds.csv; heo_viii/model.py, annual_results.csv (1,260 rows), monthly_results.csv (15,120).

3 / Principal optimisation problem

Phase IX uses the same underlying food matrices and resource caps in both modes. Let x_i be daily quantities in units of 100 g of food proxy i; M_{ji} is the amount of nutrient j per 100 g; t_j is the reference target, c_j a credit (water iodine or assumed UV-related vitamin D), and q the common fractional target coverage.

Maximise q, with $0 \le q \le 1$ and $x_i \ge 0$. For each enabled target j: $\Sigma_i M_{ji} x_i + c_j \ge q\, t_j$. For each food group g: $\Sigma_{i \in g} x_i \le \text{cap}[g,m]$.

The Phase IX implementation minimises $-q + 10^{-9}\Sigma x_i$ (a tiny mass tie-breaker). Phase X uses a deficit variable $d = 1 - q$ and minimises d without the mass tie-breaker. It solves the unnormalised inequality $-\Sigma M_{ji} x_i - t_j d \le c_j - t_j$. Both formulations reproduce the coverage scores to numerical precision in the audit.

Constraint	Implemented value
Energy ceiling	Σ energy ≤ 1.05 × adjusted daily energy target
Animal vitamin A proxy	≤ 3,000 µg/day (not a full retinol analysis)
Zinc ceiling	≤ 40 mg/day, provisional
Protein energy share	4 × protein grams ≤ 0.35 × kcal
Iodine ceiling	Food iodine ≤ 600 µg/day − water iodine credit
Coverage	0 ≤ q ≤ 1; lower targets are scaled by q

Actual adult target vectors

Target (unit in field)	Adult male	Early lactation	Target (unit in field)	Adult male	Early lactation
kcal	2500.0	2600.0	folate_ug	200.0	260.0
protein_g	55.5	56.0	calcium_mg	700.0	1250.0
fat_g	55.6	57.8	iron_mg	8.7	14.8
fiber_g	30.0	30.0	zinc_mg	9.5	13.0
A_ug	700.0	950.0	iodine_ug	140.0	140.0
C_mg	40.0	70.0	magnesium_mg	300.0	320.0
D_ug	10.0	10.0	potassium_mg	3500.0	3500.0
B12_ug	1.5	2.0	selenium_ug	75.0	75.0

Control: first four targets (energy, protein, fat and fibre). Expanded: all sixteen. Protein energy-share and nutrient upper bounds remain in both modes. Full coverage does not establish a complete or safe diet; the model does not represent all essential nutrients or absorption.

4 / Residential strategies and results

A: select the better of the two single-habitat bases. B: select the better base with a 25% blend of complementary caps (not an addition of unlimited food); charge 2 km/day additional walking. C: test all twelve starting months for a six-month split; charge for two moves a year. Each distance is evaluated separately, 25, 100 or 300 km one way.

B cap = [(1 − s) cap_base + s cap_alt] × access; s = 0.25 C extra energy in movement month = 42 × distance / days C access multiplier in movement month = 1 − 0.5 × distance/(20 × days)

At 100 km in a 30-day travel month, extra energy = 140 kcal/day; access loss = 8.333%; a 2,500 kcal target becomes 2,640, and the upper allowance becomes 2,772. If scarcity multiplier is 0.7, final group cap multiplier is 0.7 × 0.916667 = 0.641667. These are scenario parameters, not observed procurement rates.

Annual mean Q = Σ(days[m] × q[m])/365; worst-month Q = min(q[m])

For each mode, choose the maximum annual score within A, B and C; ties are within 0.005 coverage (0.5 percentage points) of the best. A strict reversal requires different unique winners. The worst-month alternative reselects the best schedule using the stored worst-month objective.

Reproduced worked comparison: E02/E05, 100 km, adult male, combined stress

Mode	A (%)	B (%)	C (%)	Winner
all16	55.697	53.151	53.473	A
macro	96.274	96.886	98.597	C

C − A = +2.323 percentage points with four targets; C − A = −2.224 points with sixteen. Six habitat pairs × two profiles × four conditions × three distances = 144 matched settings. The conditions are baseline, 60 µg/day water iodine, 70% access, and combined stress (70% access, 22 kcal root energy, 0.4 g root protein, 0.1 g root fat, no UV credit, 6.4 µg/day water iodine).

6,912 distinct cached monthly LP evaluations; 3,840 annual schedule rows. 111 changed winner sets; five strict reversals, of which four are C→A and one B→A. They occur in one synthetic habitat pair under combined stress. Counts are not probabilities or independent empirical observations.

5 / Extended sensitivity and measured inputs

Source: Schoeninger et al. (2001), DOI 10.1006/jfca.2000.0961, Tables 3–4. Concentrations are converted using moisture fraction, without a second edible-fraction correction:

Fresh concentration = dry concentration × (1 − moisture percent/100) Sample 4: energy = 97 × (1 − 0.765) = 22.795 kcal/100 g Protein = 4.2 × (1 − 0.765) = 0.987 g/100 g

Sample	Moisture %	Dry kcal	Fresh kcal	Fresh protein g
sample2	83.4	146	24.236	0.730
sample3	75.1	164	40.836	0.822
sample4	76.5	97	22.795	0.987
sample5	75.8	61	14.762	1.500
Vigna_mean	77.7	146	32.558	1.003
Eminia	79.9	199	39.999	1.387
Ipomoea	85.9	298	42.018	0.324

Fresh peeled mass is not swallowed mass. Sample 5 is a duplicate-preparation average; Vigna_mean is a derived mean, not an independent specimen. Measured-pair scenarios set unmeasured fat to zero and retain proxy values for other nutrients. The resource caps are not calibrated to the mass denominator.

Additional tests

Design	Settings	Mean reversals	Worst-month reversals
grid	36	16	18
joint	32	13	10
measured	21	13	14
reference	6	5	6
root	5	5	5

A 32-point Latin hypercube (seed 926) varies access 0.5–1, measured tuber pair, water iodine 0–60 µg/day, UV multiplier 0–1, walk cost 30–70 kcal/km, distance 25–300 km, patch share 0.1–0.5, boundary walking 0–5 km/day, travel access-loss factor 0–1, life-stage profile, energy scale 0.8–1.2, root micronutrient/fibre scale 0.5–1.5. These ranges are design choices, not estimated distributions.

Total: 100 settings × 2 modes × 16 schedules × 12 months = 38,400 schedule-month evaluations before caching; 14,400 reported distinct LP calls. The extra 21 energy-only comparisons used 3,024 LP calls. Full outputs: heo_publication/final_results.csv and energy_only_results.csv.

6 / Verification, provenance and reuse

Archived numerical verification

Phase X reran the earlier five models and compared 42 CSV tables (including unchanged inputs). The independent LP formulation reproduced 3,840 annual evaluations. The reported audit maximum differences are approximately 2.2×10^{-15} for annual means and 2.8×10^{-14} for worst-month scores. This package checks archived tables and file integrity; it does not claim a new full solver replay or an independent researcher replication.

Check	Archived result recalculated from saved CSV
Phase X comparison rows	3840
Max |mean difference|	2.22e-15
Max |worst difference|	2.75e-14
Replay records	42
Assumption register rows	1195

Reproduction sequence

Extract the publication ZIP to a working folder. Preserve an untouched copy. Install the recorded Python dependencies (requirements.txt); version information is in heo_x/environment.txt. From the extracted root run:

```
bash heo_x/reproduce.sh python heo_publication/sweep.py python heo_publication/energy_only.py
```

The shell script copies historical models into heo_x/replay before running them, then updates audit files. The publication scripts overwrite their output CSVs. Run in a disposable copy; small solver-version differences may occur. The original report generator is optional and not needed to reproduce the calculations. For Windows, run equivalent Python commands in the directories described in README.md.

Limitations and publication responsibilities

Of 320 original food–nutrient cells, only eleven initially had individual source anchors. The full food matrix and resource caps are not empirically verified. Climate transcriptions, all source claims, novelty and actual predictive accuracy remain incompletely validated. Do not present a nutrient target score as a probability of survival or claim discovery of an ancestral habitat.

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