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Estimating Accessibility to Natural Resources Using a New Energy-based Travel-cost Model

An Archaeological Case Study of Jomon Net-fishing in Eastern Japan

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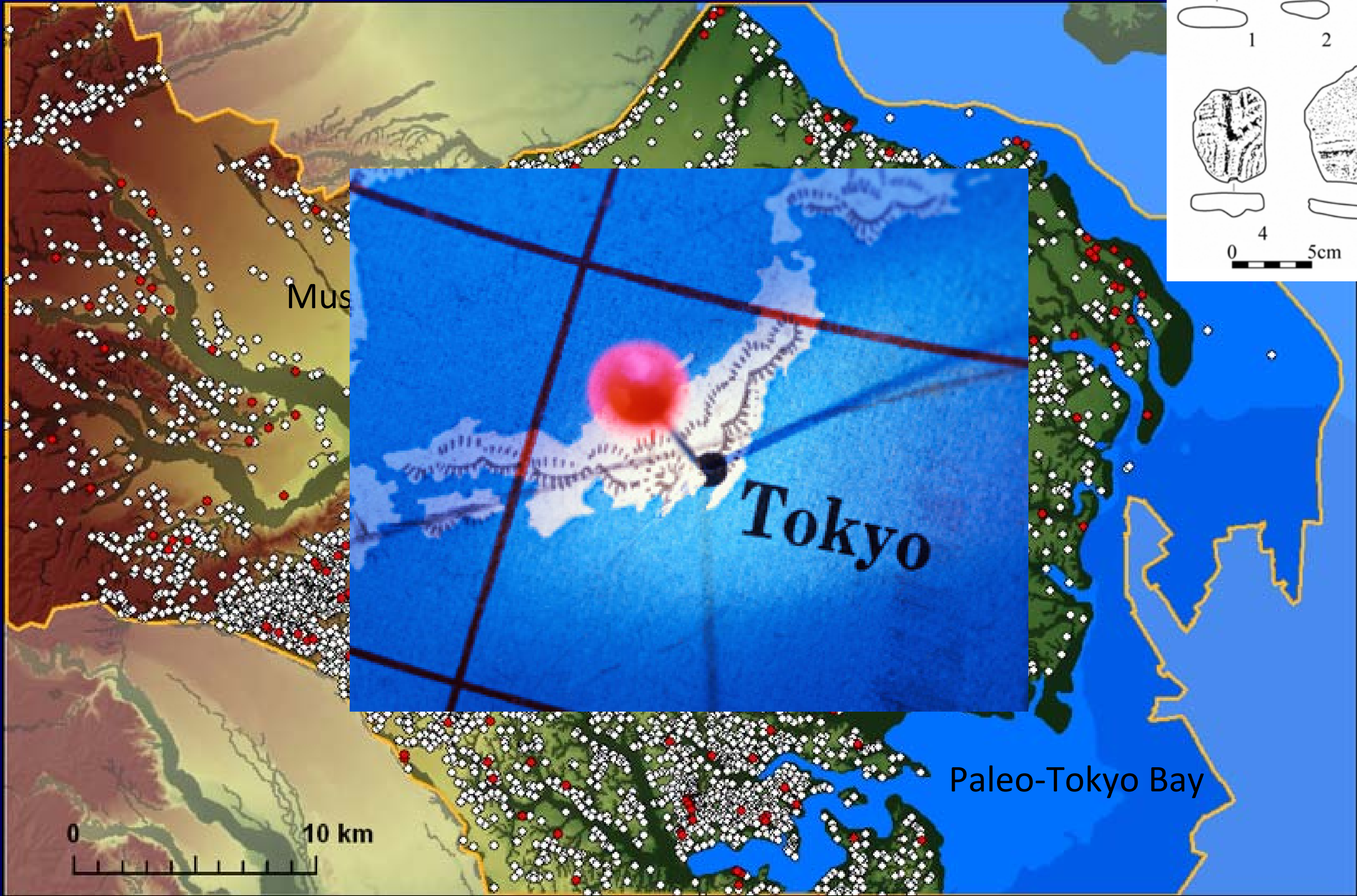
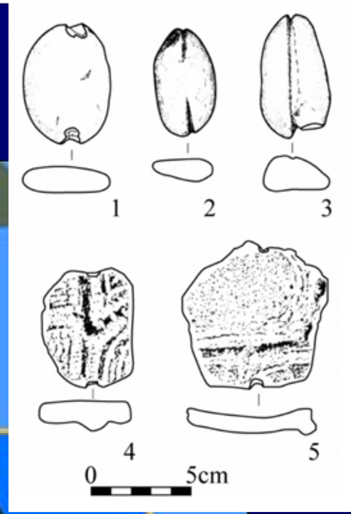
独立行政法人日本学術振興会 Japan Society for the Promotion of Science

ARCHAE-GIS WORKSHOP

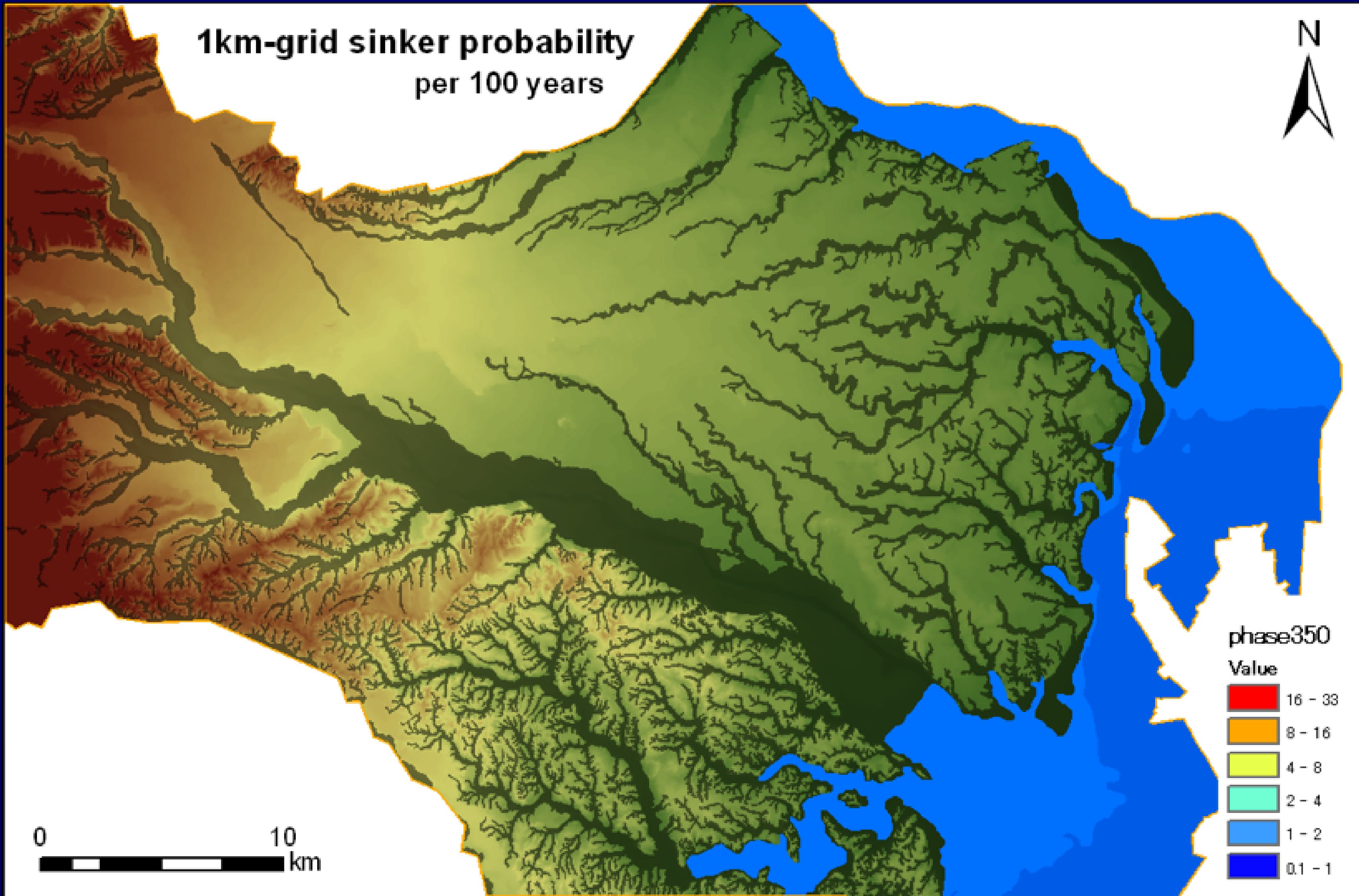
The Tokyo-Yokohama study area





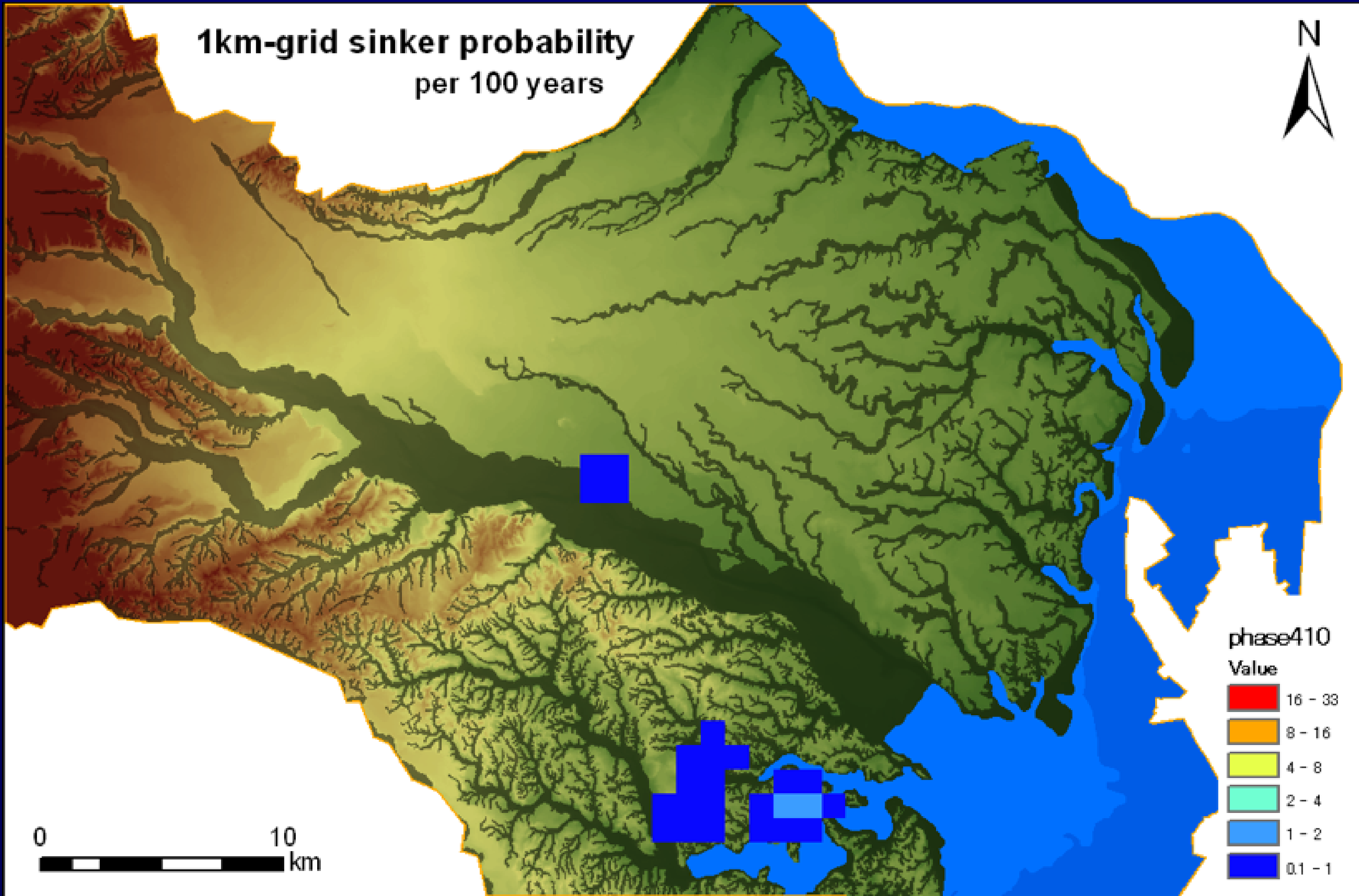
3,800 sinkers have been recovered from 235 Jomon sites (red).

Diachronic change of the distribution density of sinkers



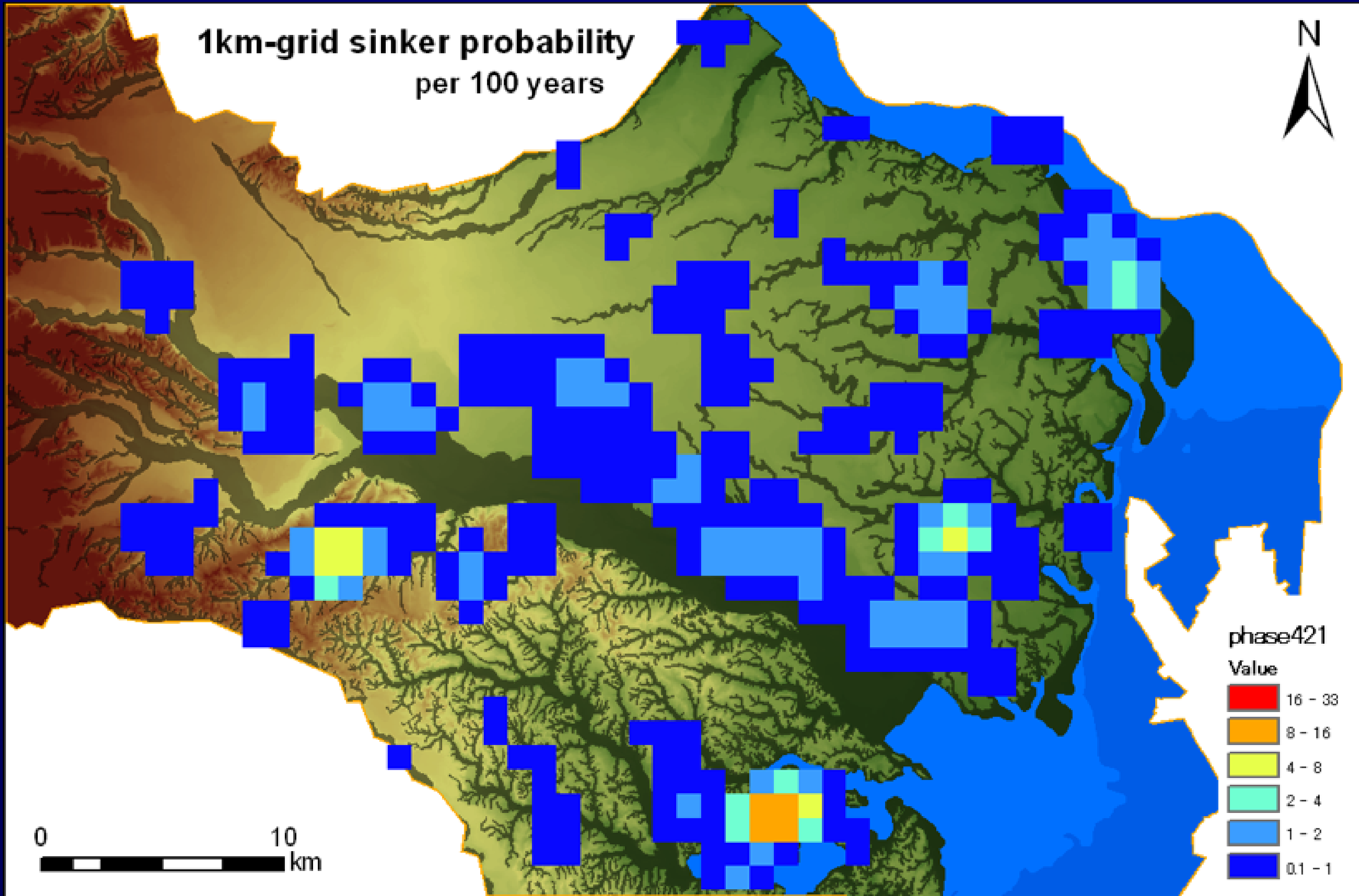
3580 cal. BC

Diachronic change of the distribution density of sinkers



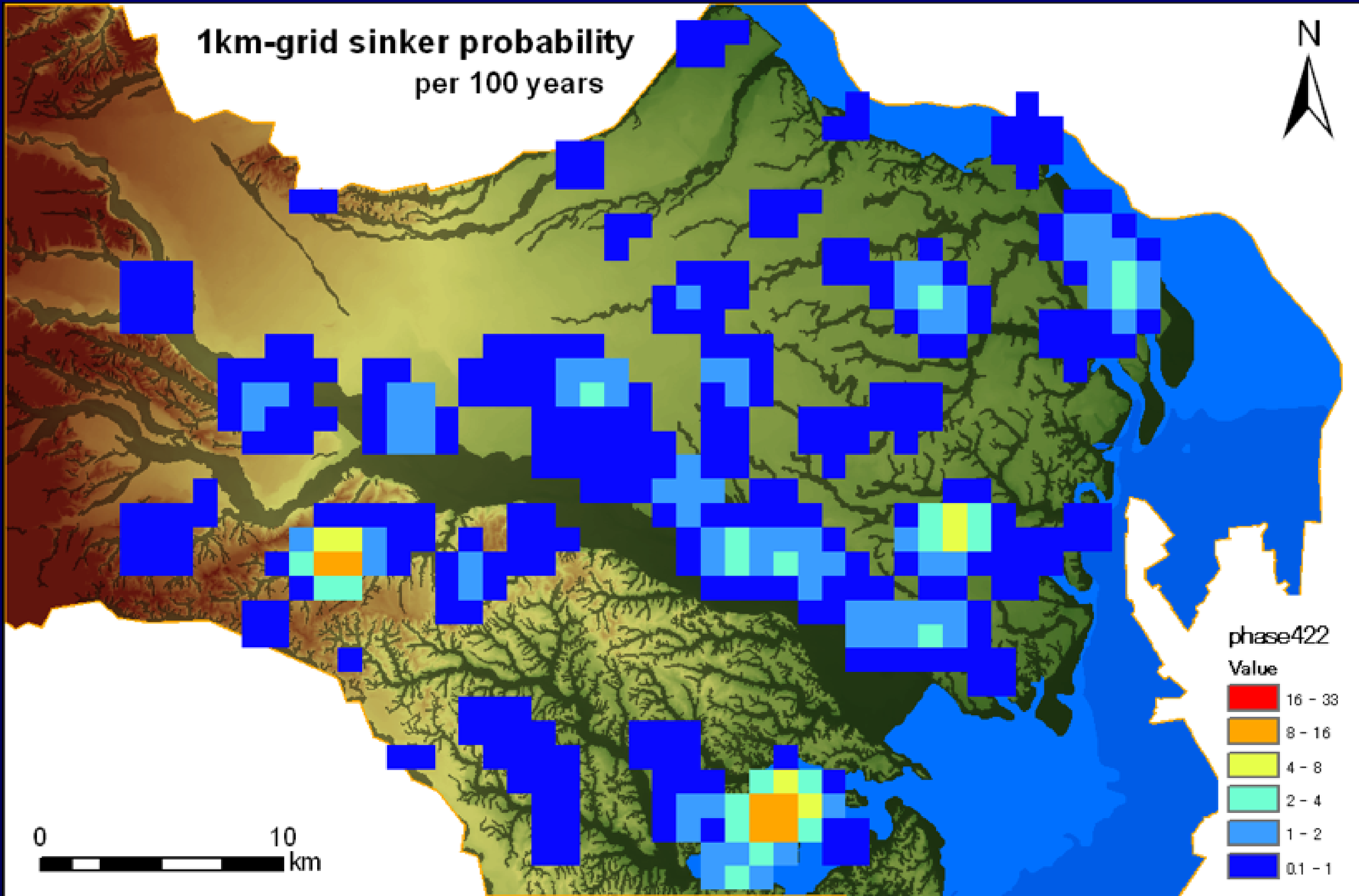
3480 cal. BC

Diachronic change of the distribution density of sinkers



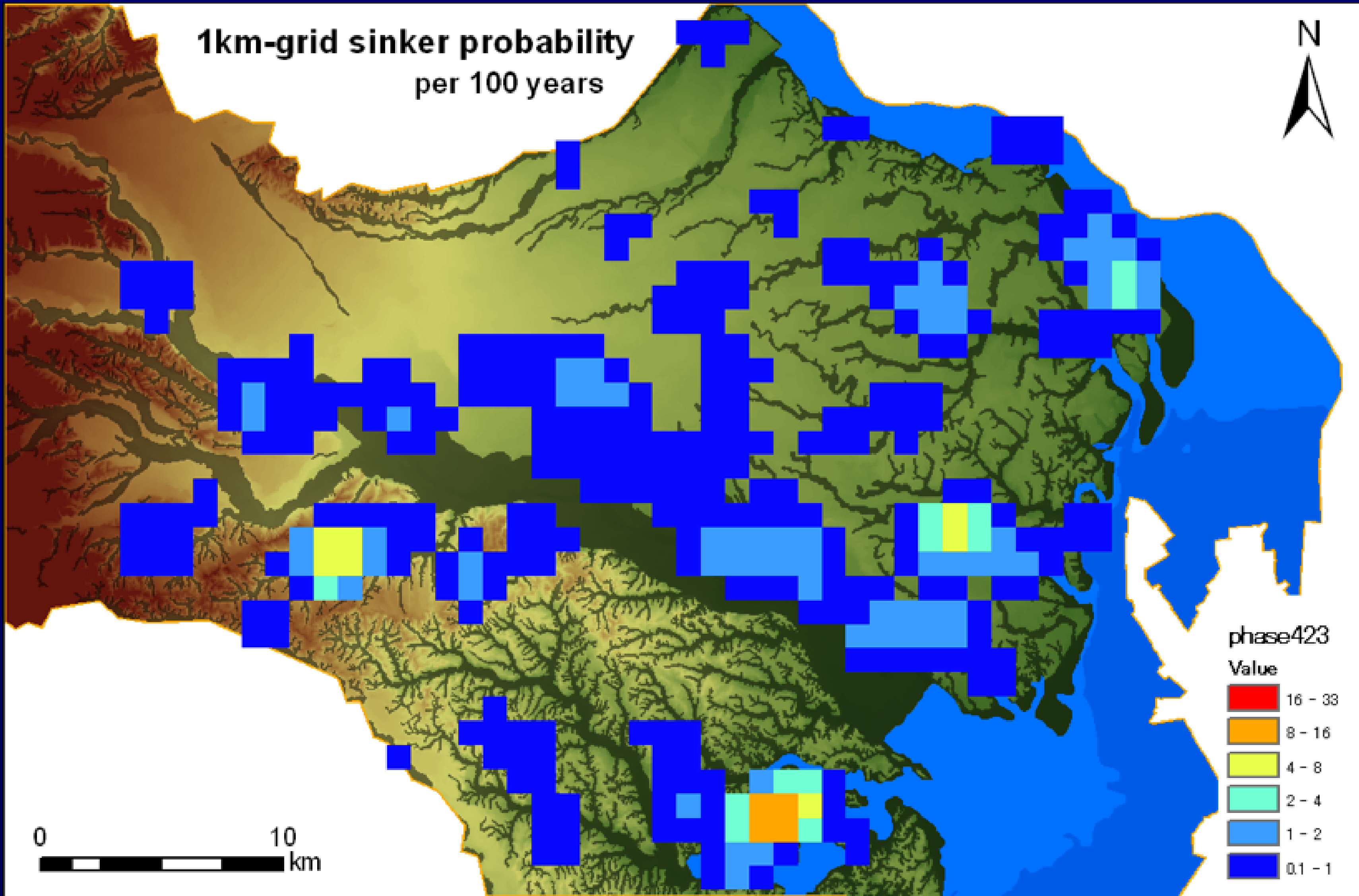
3380 cal. BC

Diachronic change of the distribution density of sinkers



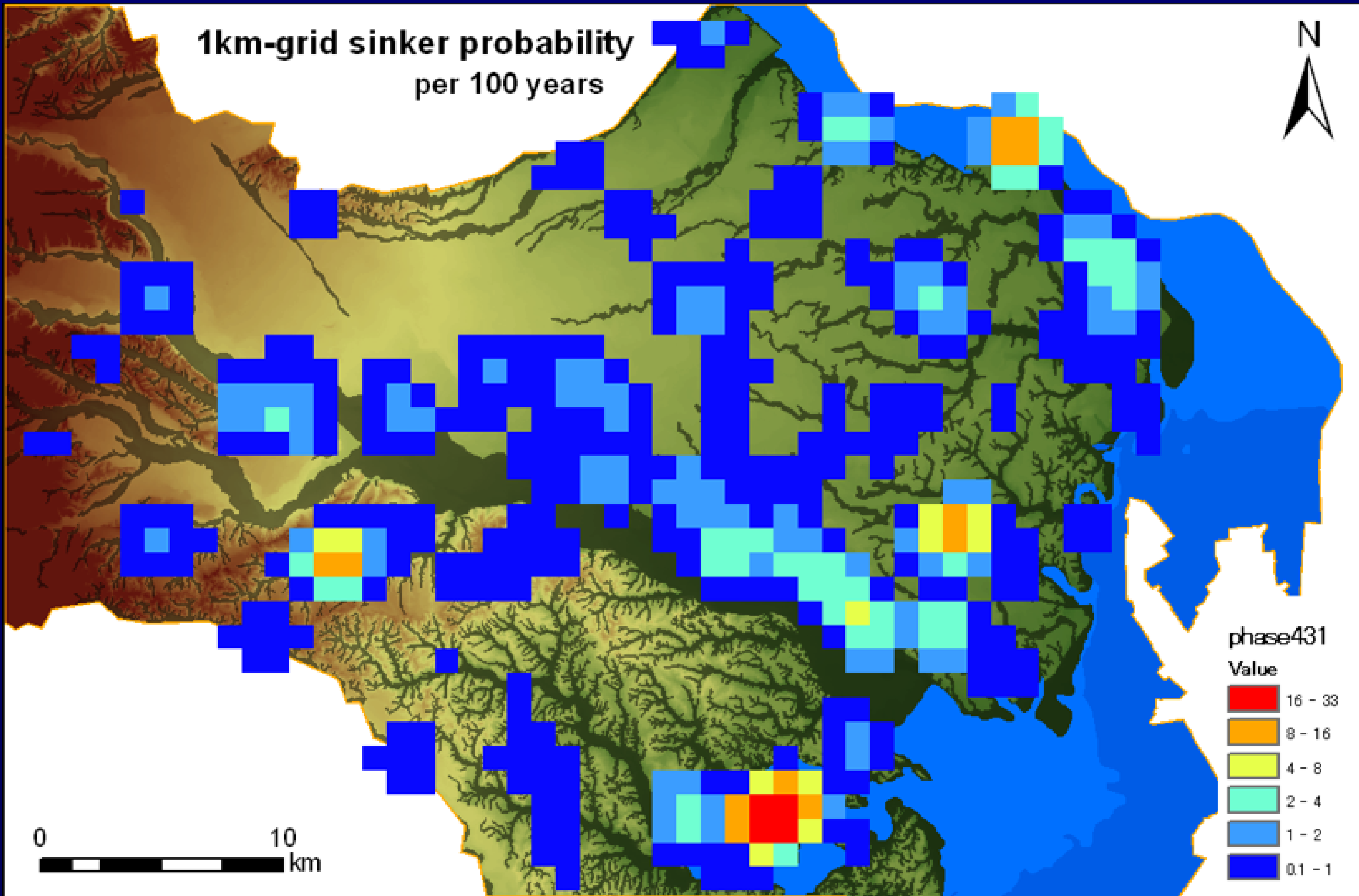
3230 cal. BC

Diachronic change of the distribution density of sinkers



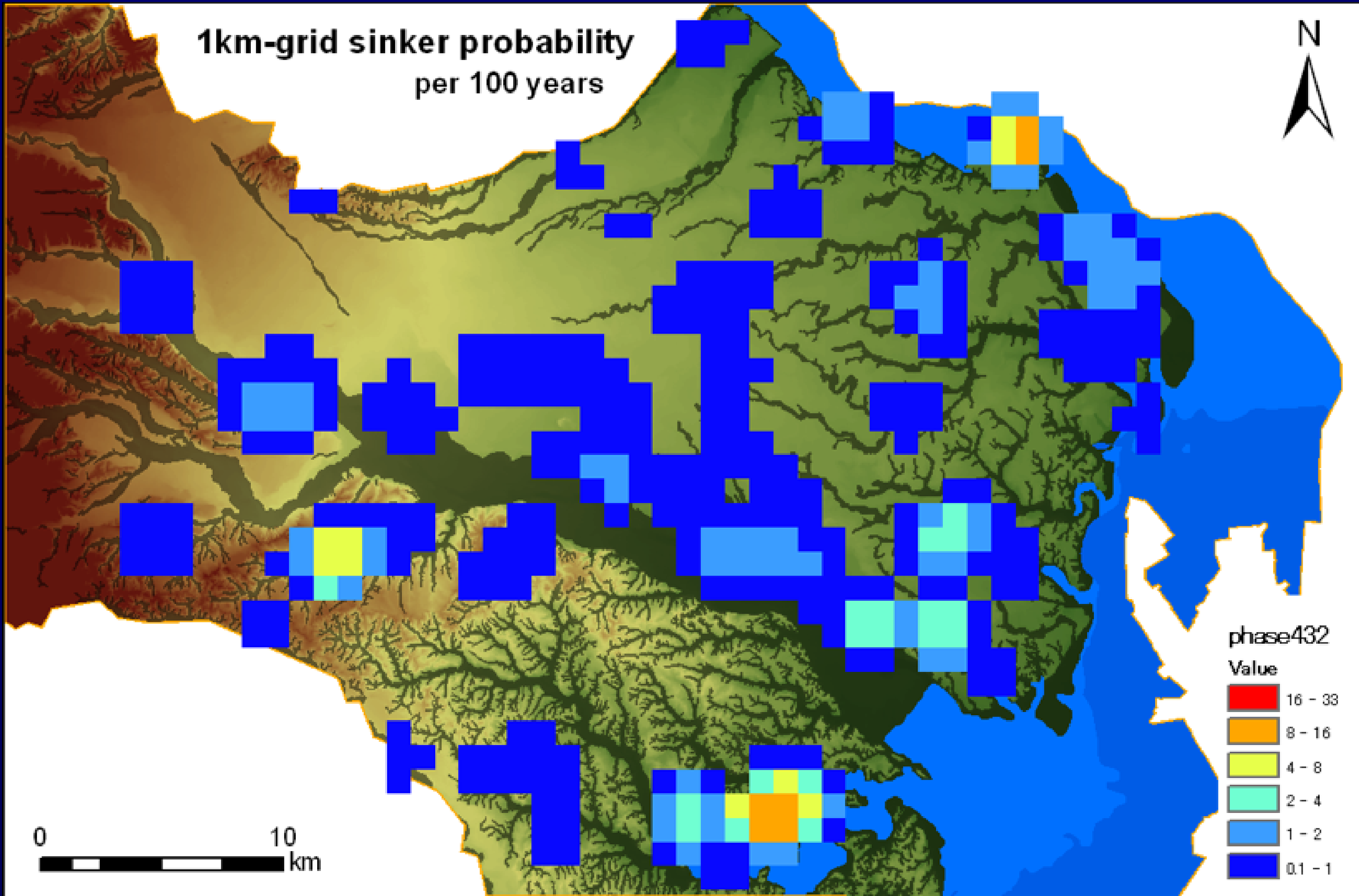
2990 cal. BC

Diachronic change of the distribution density of sinkers



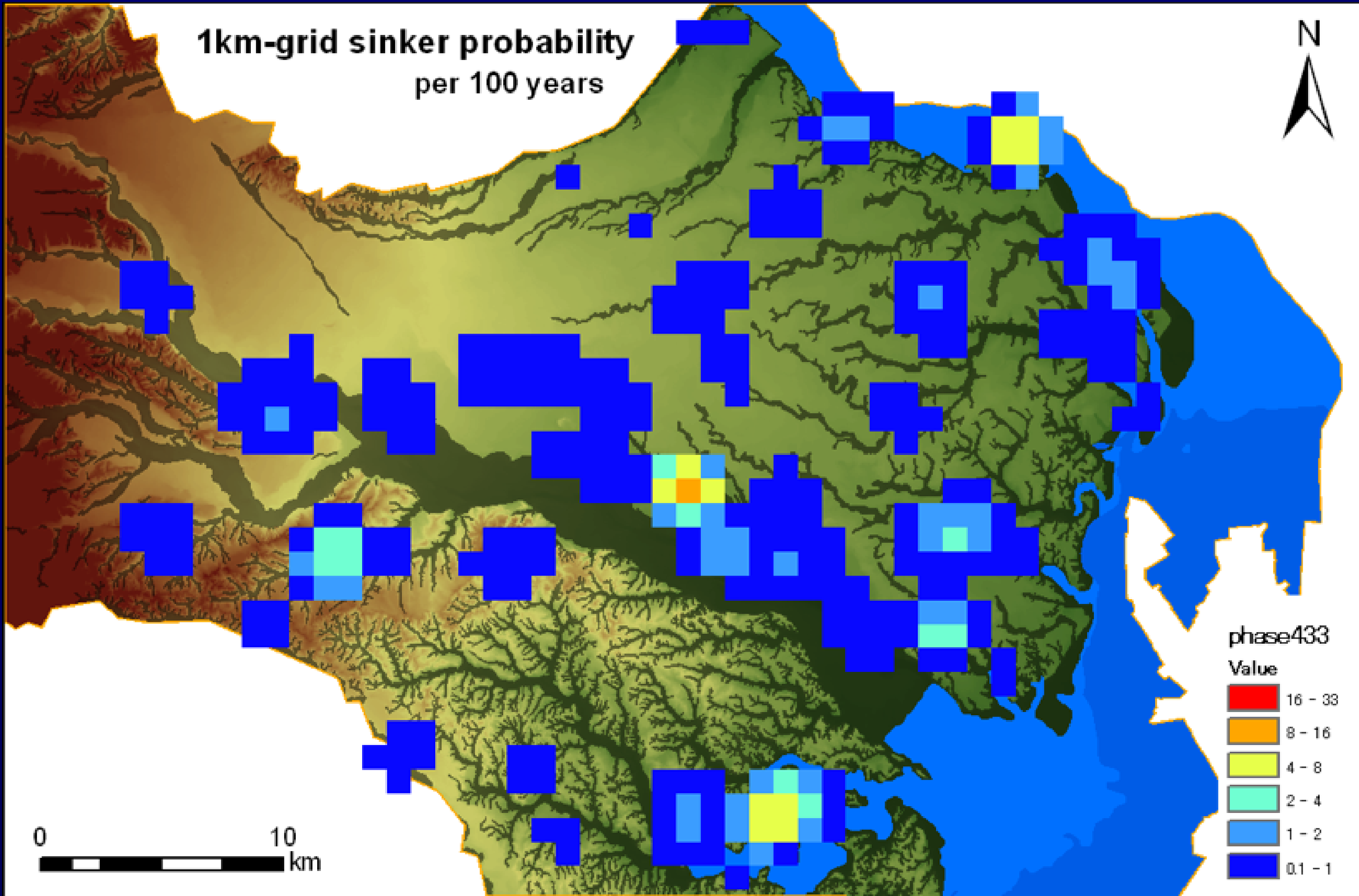
2900 cal. BC

Diachronic change of the distribution density of sinkers



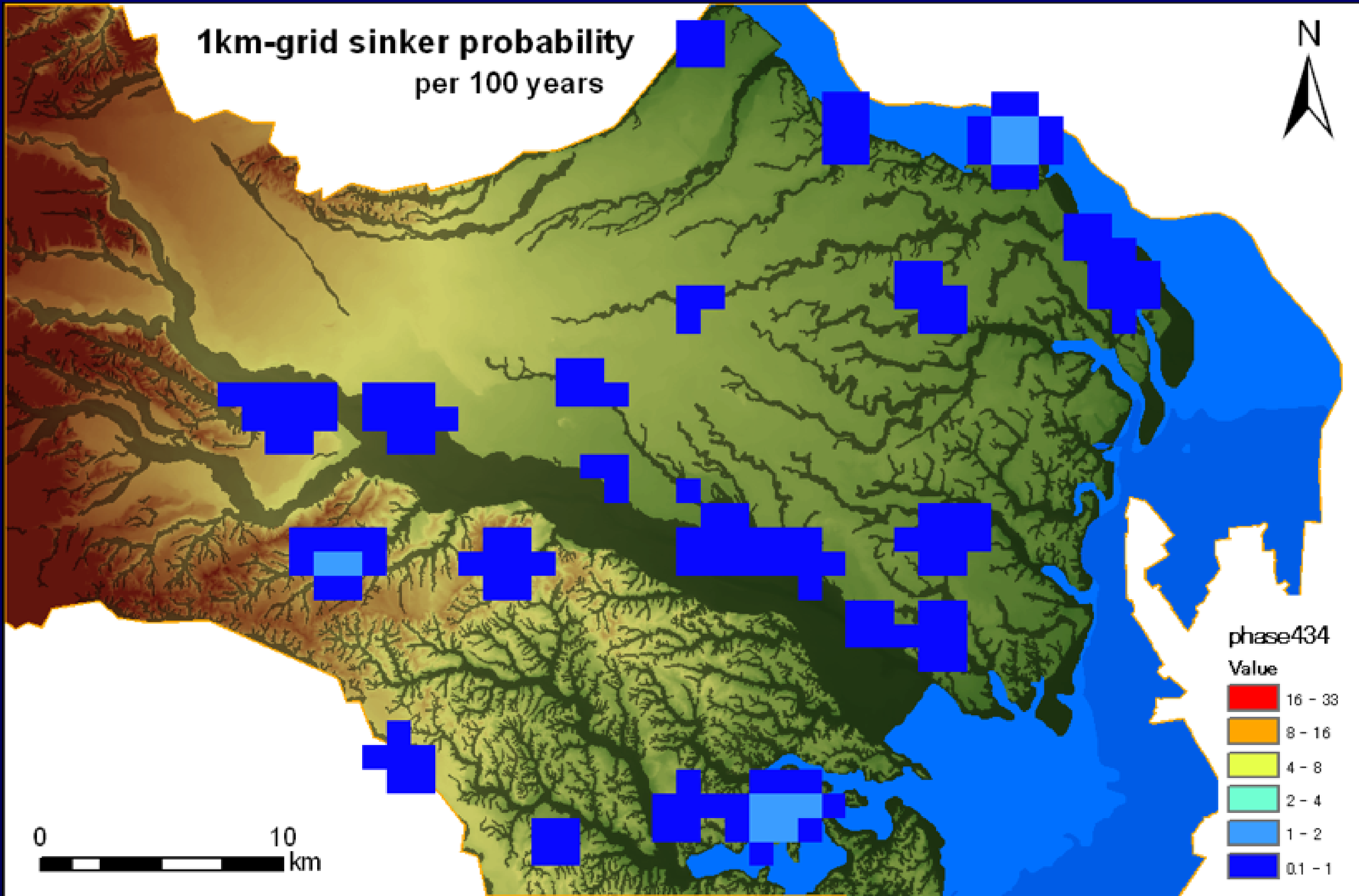
2810 cal. BC

Diachronic change of the distribution density of sinkers



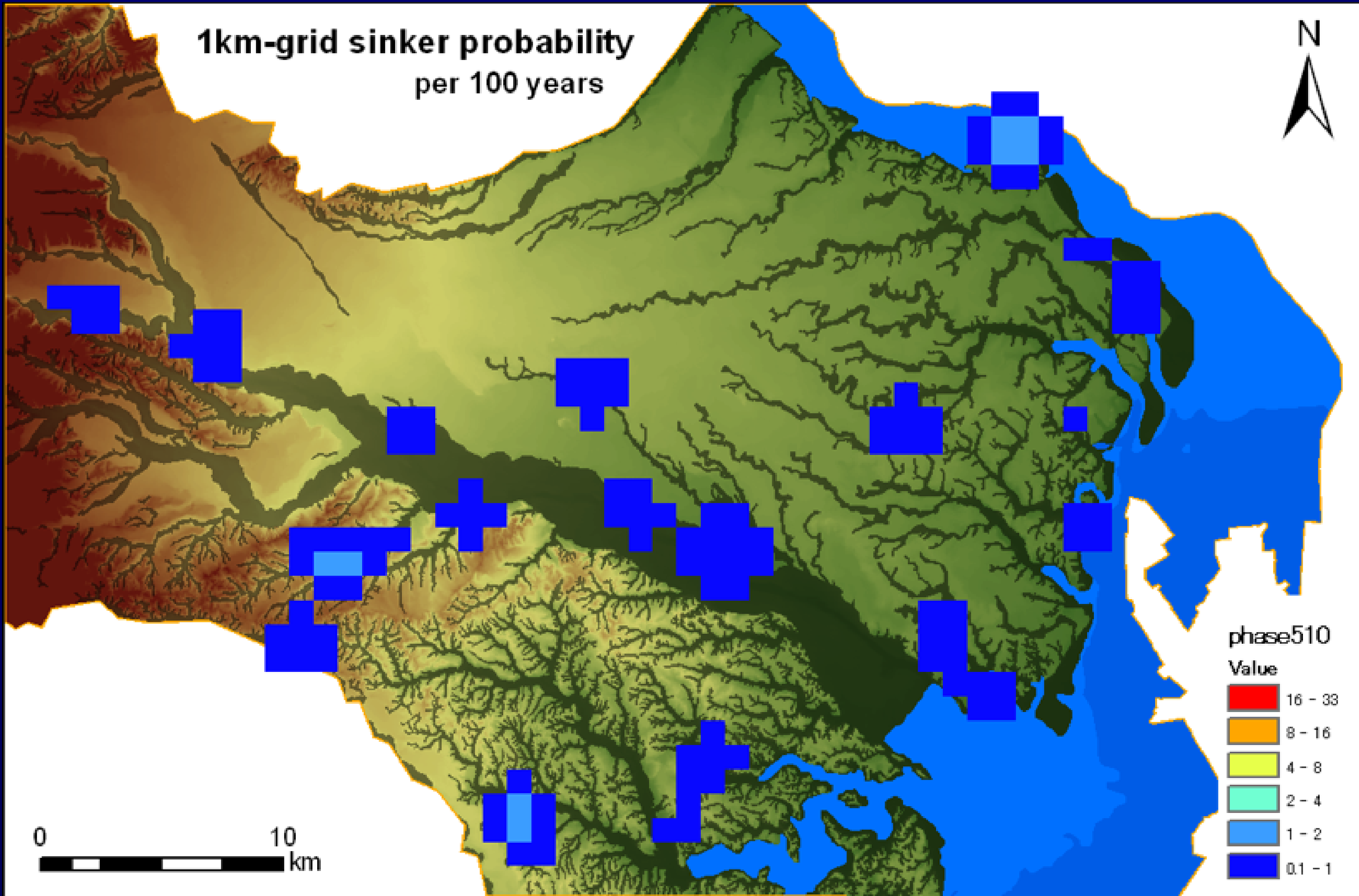
2660 cal. BC

Diachronic change of the distribution density of sinkers



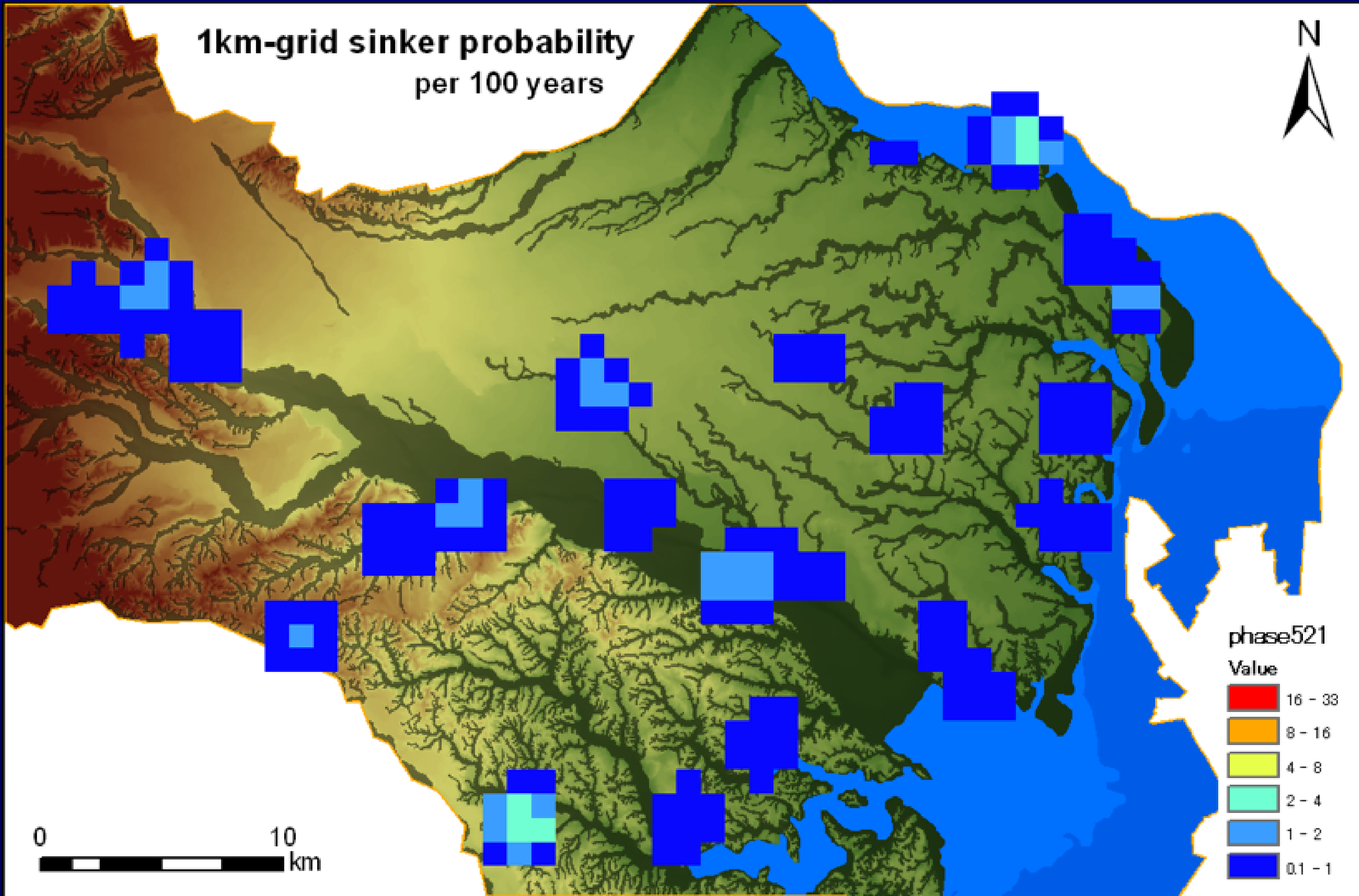
2520 cal. BC

Diachronic change of the distribution density of sinkers



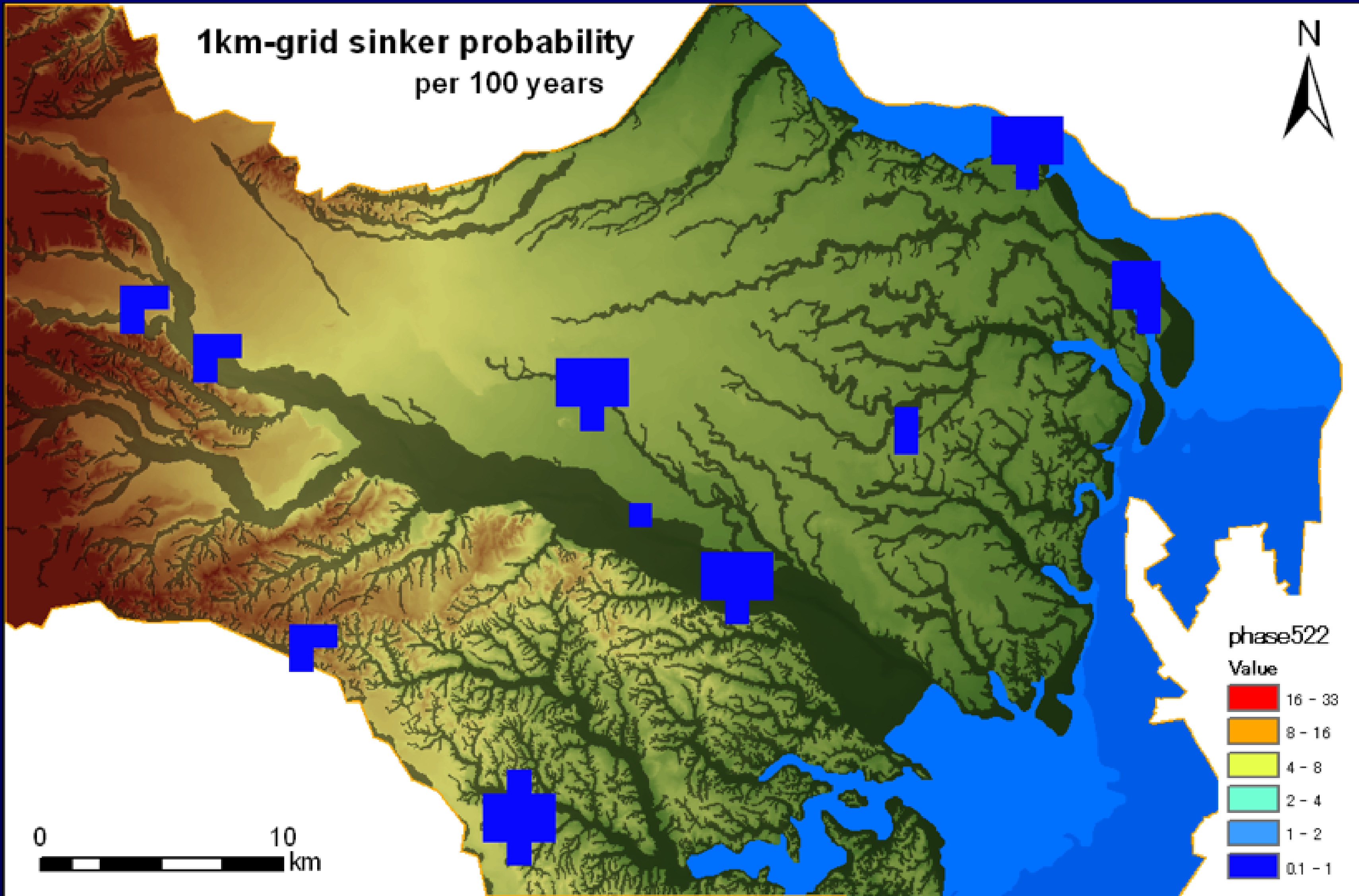
2410 cal. BC

Diachronic change of the distribution density of sinkers



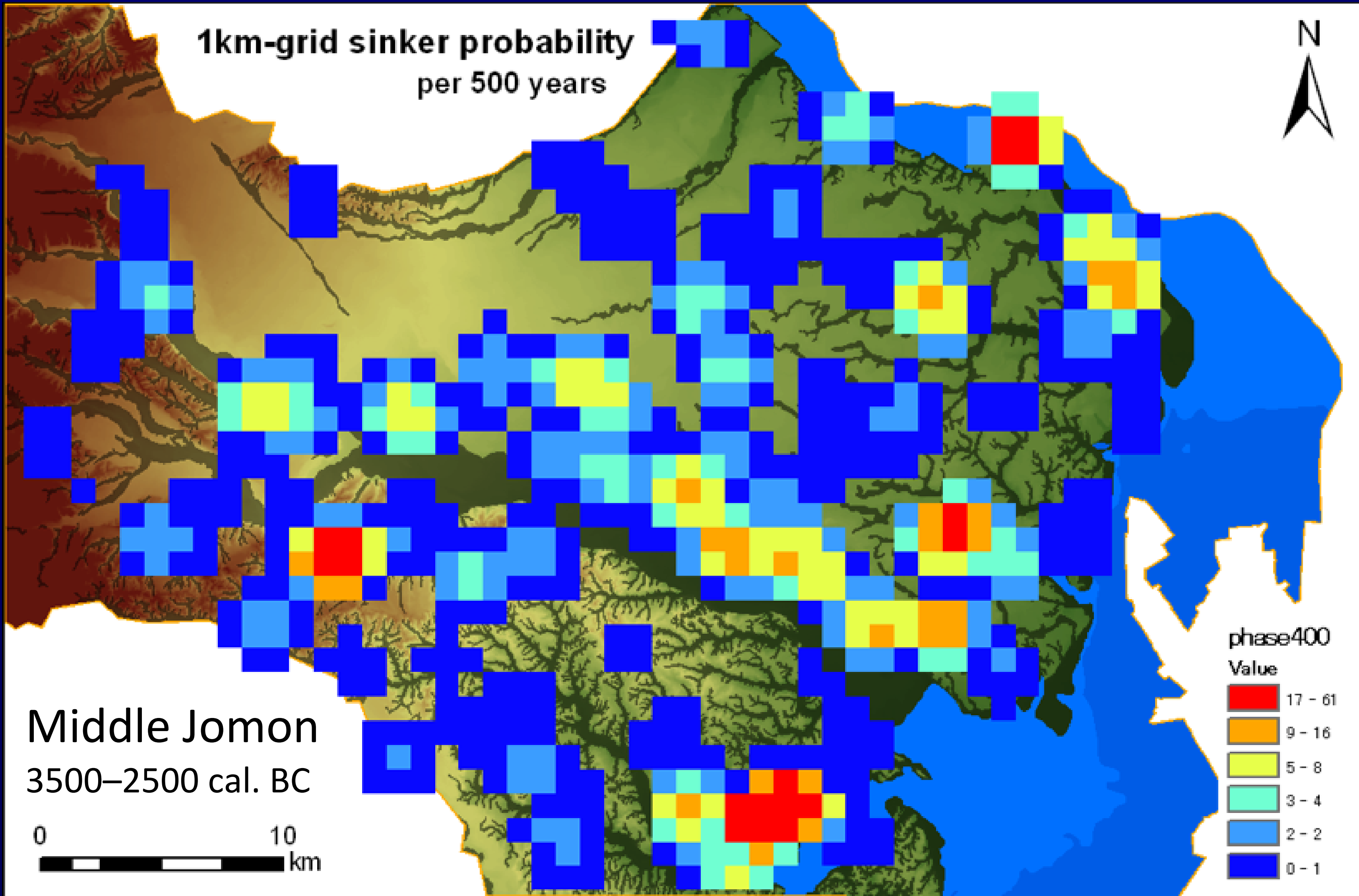
2280 cal. BC

Diachronic change of the distribution density of sinkers



2100 cal. BC

Standardized distribution density of sinkers



High-density areas are observed on the coast and along the riverbanks.

Building a new cost model

- Travels in the past should be evaluated using energy-related units (calories) rather than time-related ones (speed and hours), because time may have been perceived differently in different societies and different time periods.
- A new data-driven energy-based travel-cost model:

$$E_{[\text{kcal}]} = 1.05 * W_{[\text{kg}]} * METs * T_{[\text{hour}]}$$

- MET (Metabolic Equivalents) is an index of exercise intensity.
- $T = D_{[\text{km}]} / V_{[\text{km/hr}]} = 0.001 / V$
- For *V*, overland travel (walking) and waterway (canoe) are distinguished from each other.

Body weight of a Jomon fisherman

Typical Jomon fishermen

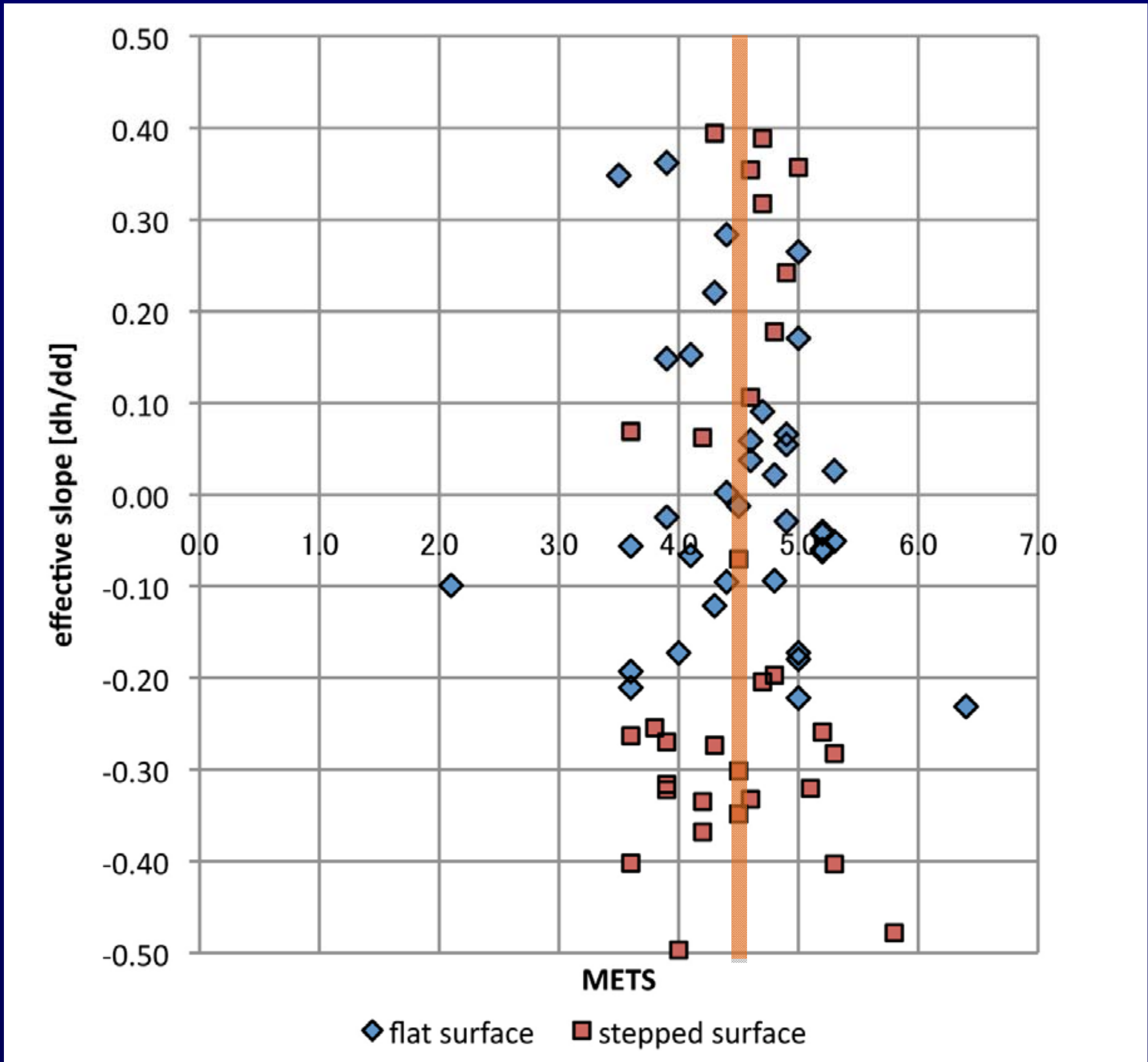
- 20 years old
- 160 cm tall
- BMI (Body Mass Index) = 22
- Then, the normal weight is
  1.6 * 1.6 * 22 = <u>56.32kg</u>

$E = 1.05 * W * METS * T$

Walking experiment in the study area

- A walking experiment was conducted in a nature trail in the study area in order to determine the parameters of METs and time.
- MET values were recorded by means of a digital pedometer with an accelerated velocity sensor (TANITA Calorism).
- Walking speed were calculated by means of a handy GPS receiver (Garmin GPSMAP 60CSx).

Result 1: METs



METs in the experiment

MAX: 6.4 METs

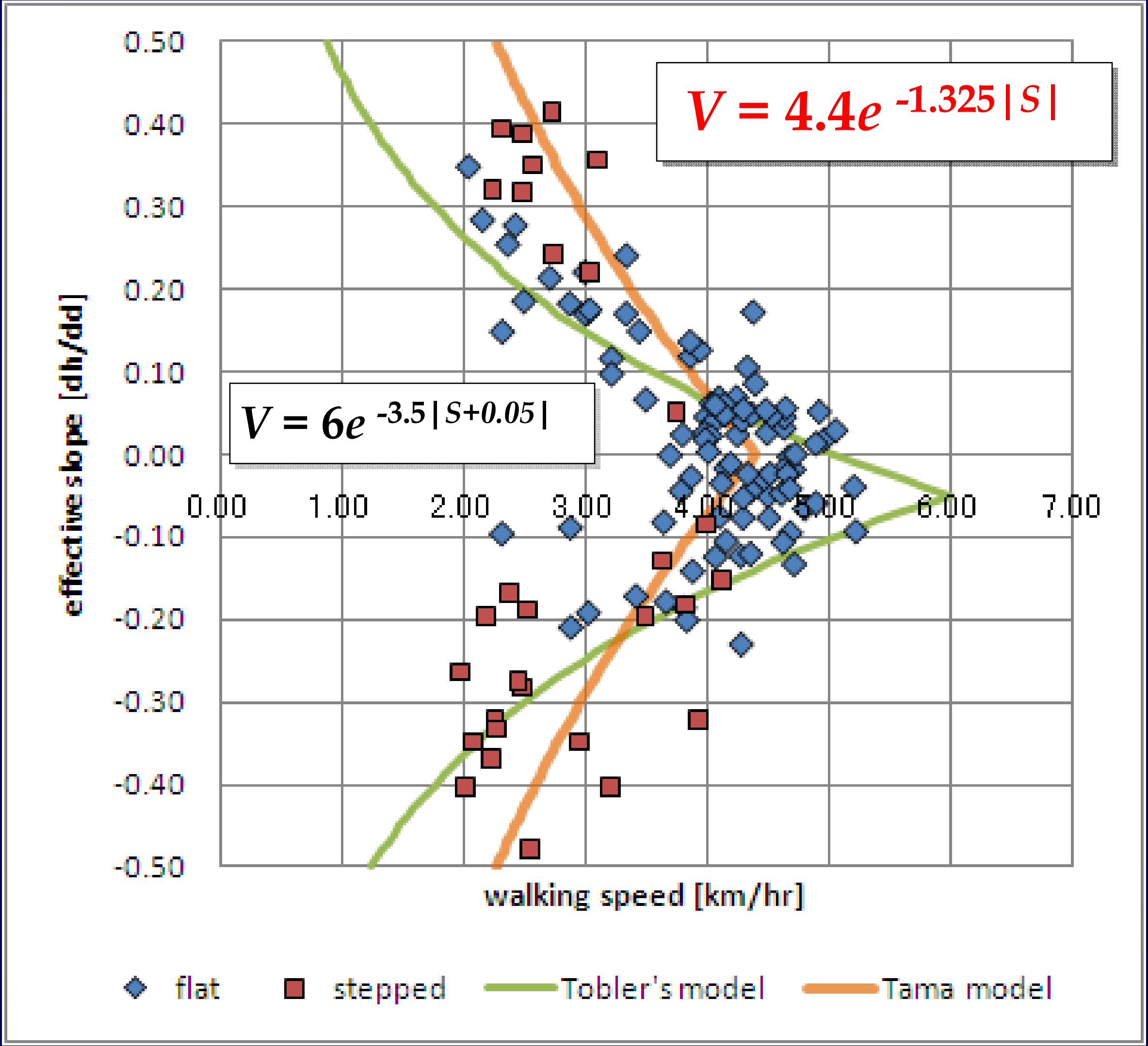
MEAN: 4.5 METs

MIN: 2.1 METs

STDEV: 0.66

∴ 4.5 METs is allocated for the cost model.

Result 2: walking speed



$$V = a*e^{-b|S-c|}$$

Slope class	MEAN	STDEV
0.23 to 0.42	2.52	0.38
0.14 to 0.23	3.12	0.55
0.06 to 0.14	3.92	0.40
0.04 to 0.06	4.33	0.32
0.00 to 0.04	4.40	0.44
–0.04 to 0.00	4.40	0.40
–0.08 to –0.04	4.37	0.38
–0.14 to –0.08	4.06	0.78
–0.22 to –0.14	3.26	0.65
–0.48 to –0.22	2.66	0.73

Canoeing METs and speed

- ACSM allocates (in average) 6.0 METs to canoeing.
- Cruising speed of a dugout canoe is assumed to be 5km/hr.

If $S \geq 0$ (upstream), then $V = 5 - 3.6\ U$ (≥ 1)

else if $S < 0$ (downstr.), then $V = 5 + 3.6\ U$

where *U* is cross-sectional average flow velocity [m/s].

- Manning's formula to calculate *U*:

$$U = R^{2/3} * I^{1/2} / n \approx 43.68\sqrt{|S|}$$

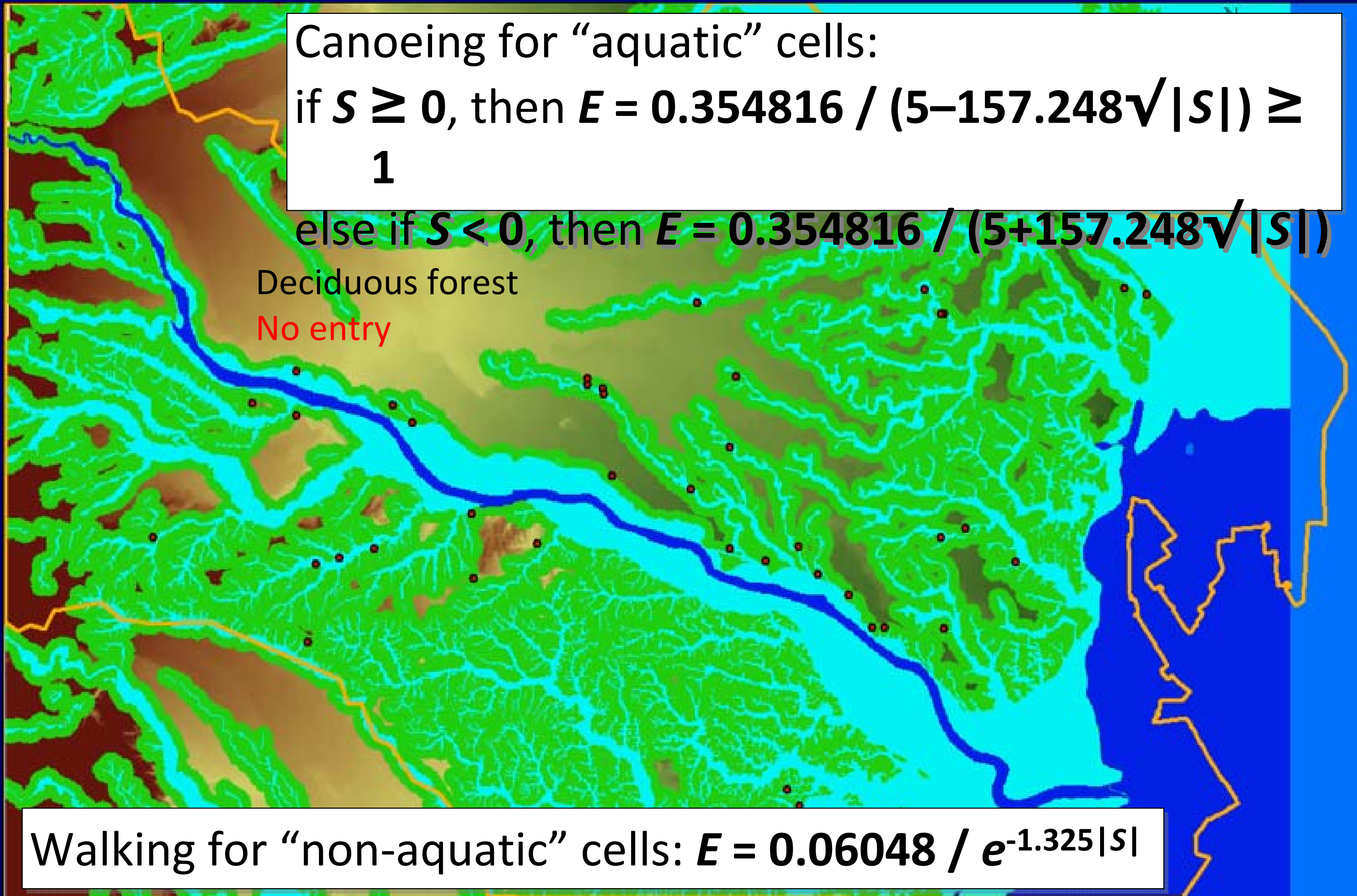
where *R* is hydraulic radius (=1.5) [m], *I* is energy grade line slope (=*S*), *n* is roughness coefficient (=0.03).

“Aquatic” and “non-aquatic” zones

Canoeing for “aquatic” cells:

if $\boldsymbol{S \geq 0}$, then $\boldsymbol{E = 0.354816 / (5 - 157.248\sqrt{|S|}) \geq 1}$

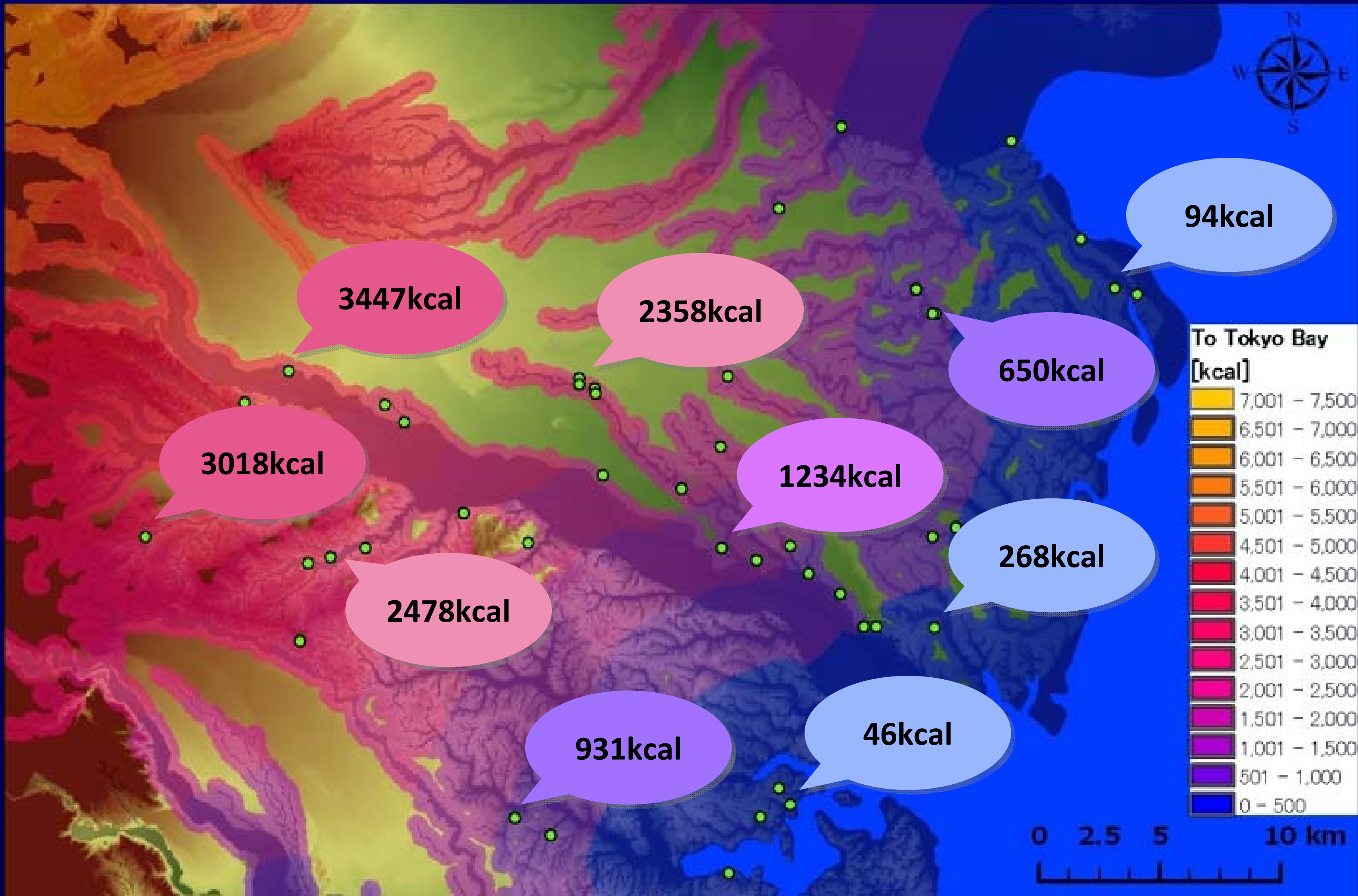
else if $\boldsymbol{S < 0}$, then $\boldsymbol{E = 0.354816 / (5 + 157.248\sqrt{|S|})}$



Walking for “non-aquatic” cells: $\boldsymbol{E = 0.06048 / e^{-1.325|S|}}$

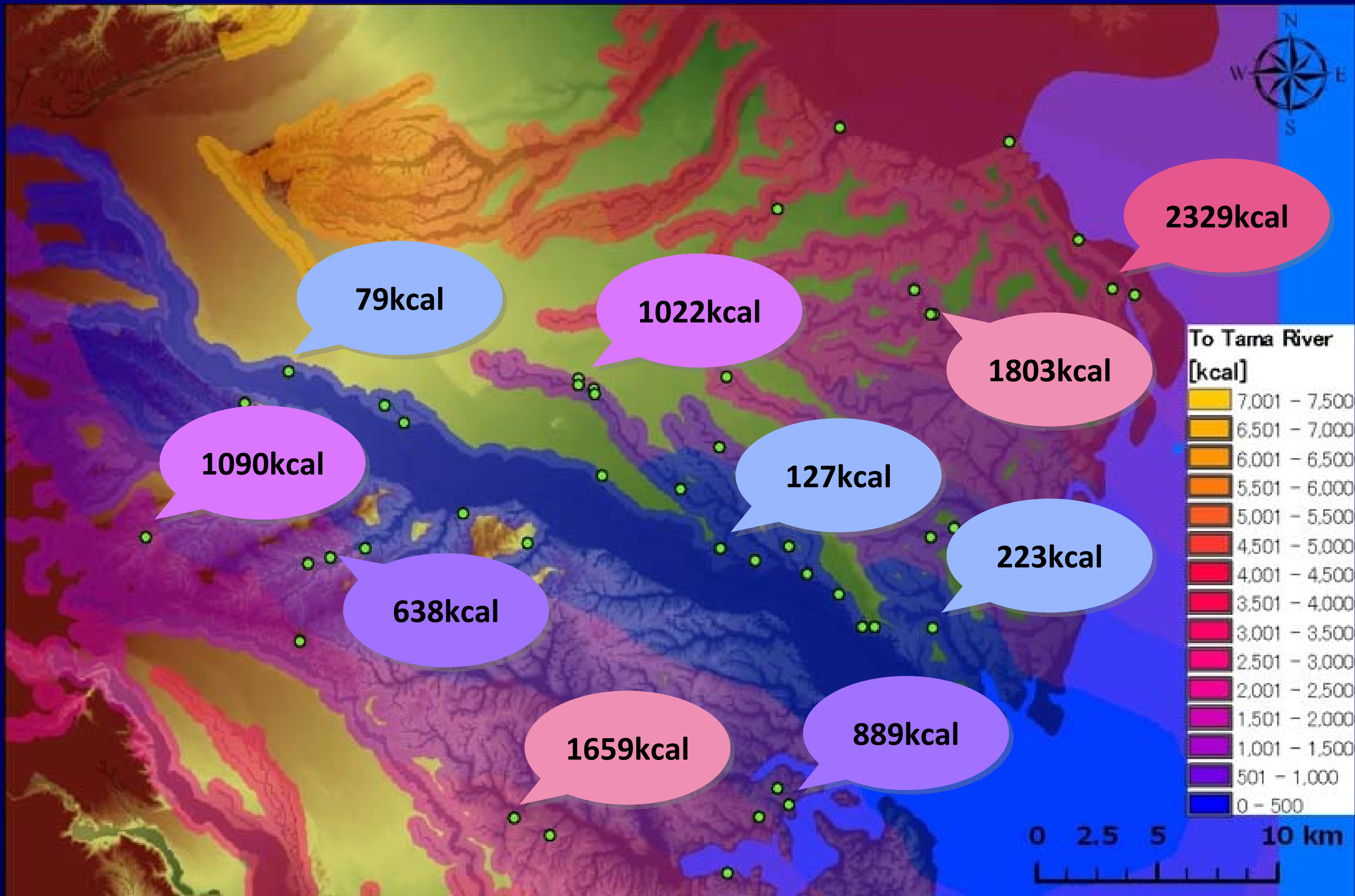
Non-aquatic walking area is confined to 400m inland from the lowland.

Round-trip energetic expenditure to Paleo-Tokyo Bay



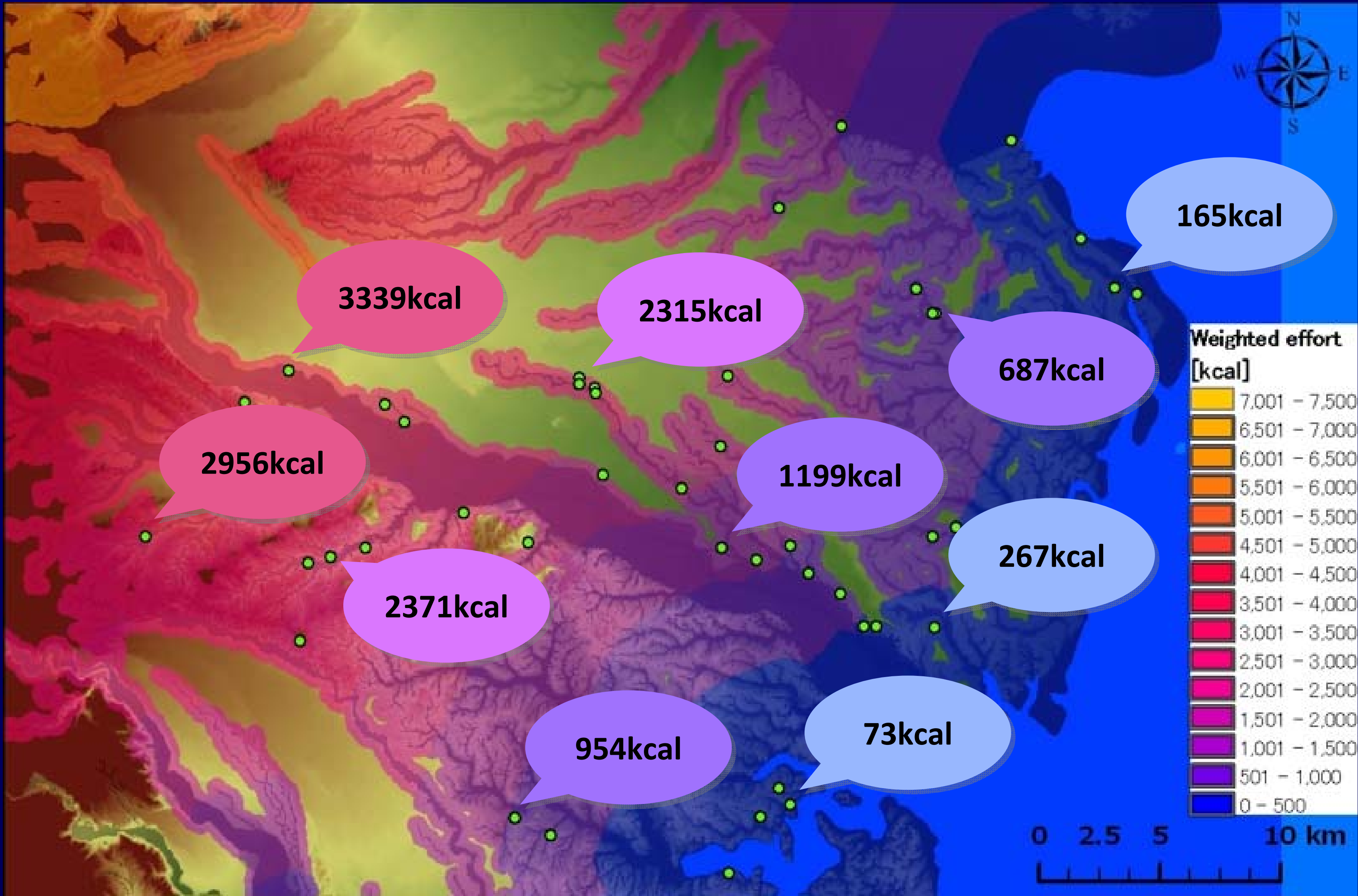
The cumulative cost increases when going inland.

Round-trip energetic expenditure to the Tama River



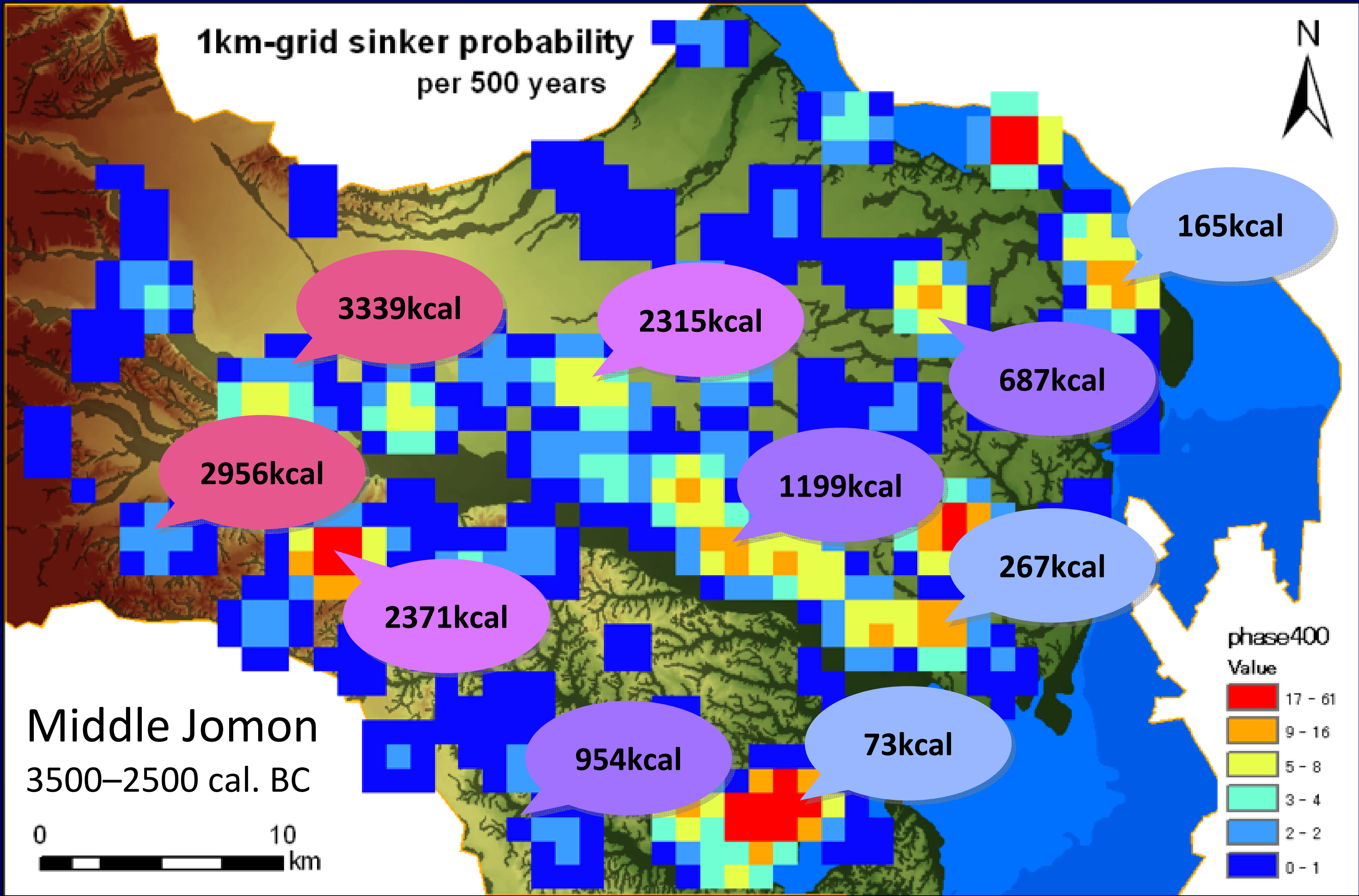
The cumulative cost increases when going away from the river valley.

Weighted access effort to the aquatic resources



96% of the potential fish catch is allocated for Paleo-Tokyo Bay.

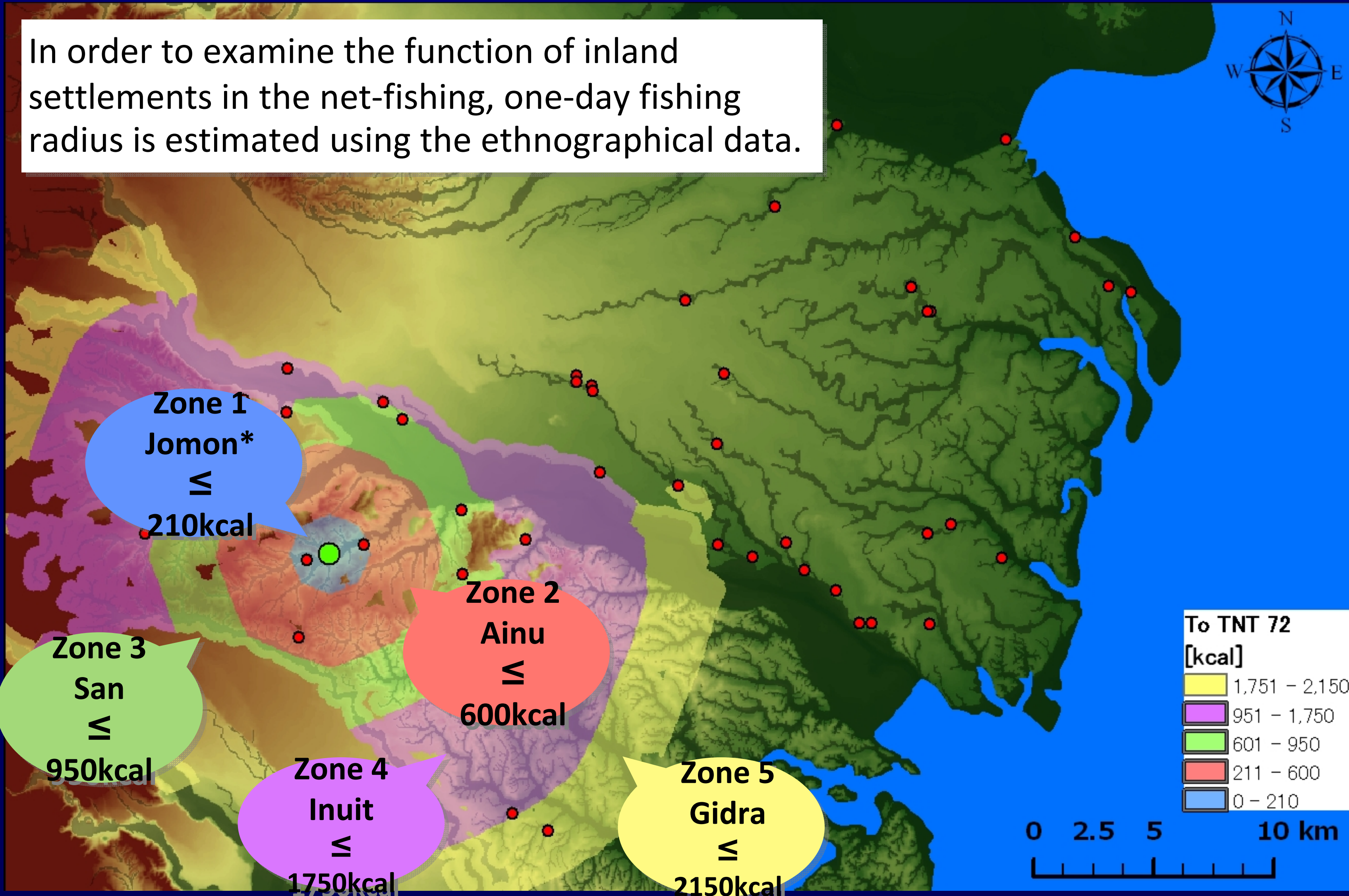
The access effort compared with the sinker density



Some inland sites also had the highest potential for net-fishing.

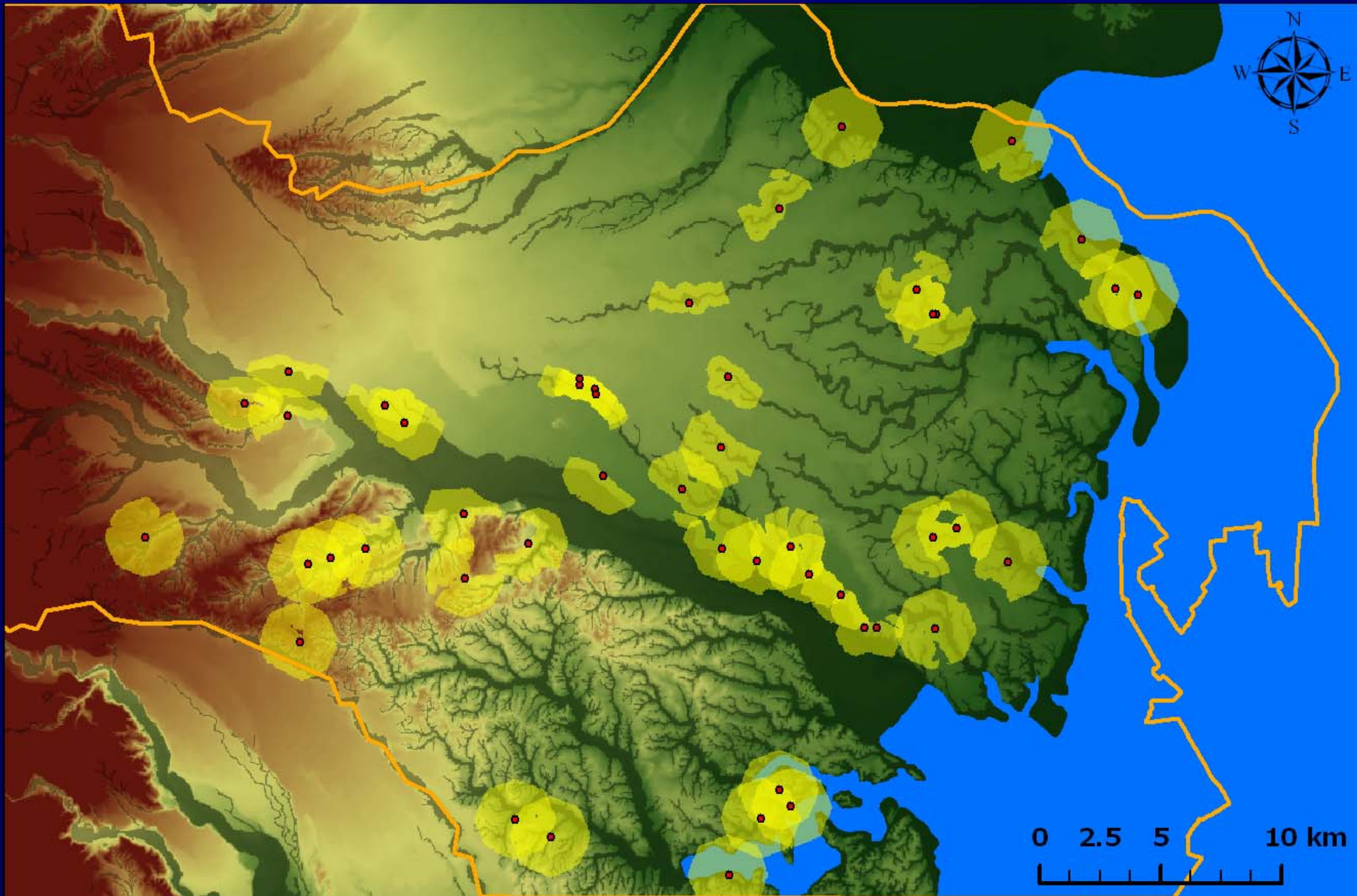
One-day fishing radii

In order to examine the function of inland settlements in the net-fishing, one-day fishing radius is estimated using the ethnographical data.



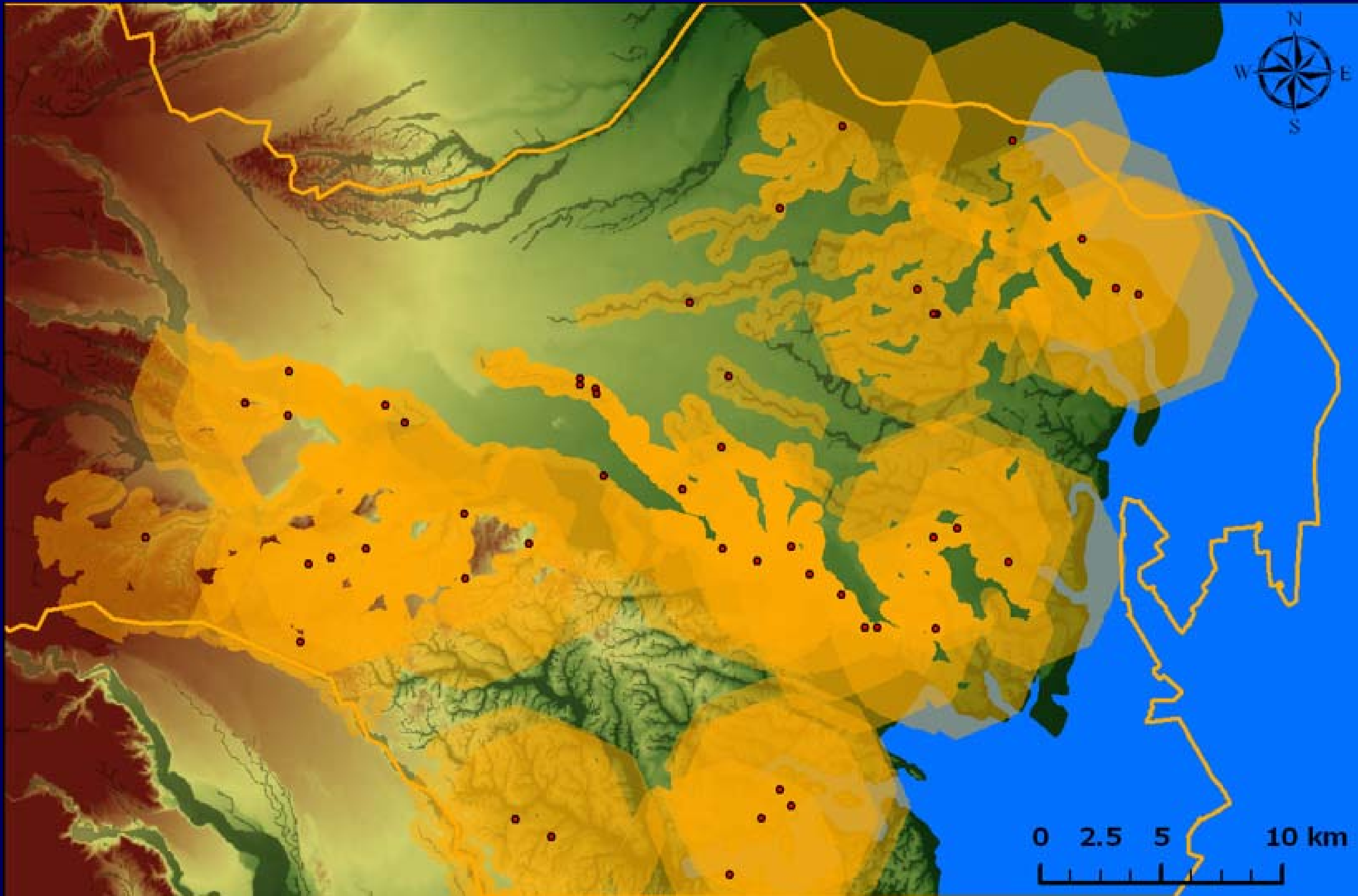
Zones 1–5 of the Middle Jomon settlement of Tama New Town 72

One-day fishing radii (Zone 1) ≤ 210 kcal/day



Zone 1 is too small to access the bay area.

One-day fishing radii (Zone 2) ≤ 600 kcal/day



Zone 2 could cover most of the river valleys and coastal areas.

Conclusion

- This study has developed a new energy-based travel-cost model for simulating the spatial radius of human activities. The parameters of the model should be customized for specific cultural and environmental contexts of the research subject.
- In the case study, the one-day fishing radii indicated that the Jomon fishermen would seasonally move from the inland settlements to the coastal zone to conduct intensive net-fishing.
- The reliability of the model should continuously be improved by crosschecking with updated archaeological and environmental datasets.

Thank you for your kind attention!