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Cellular Automata and Urban Development

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Published in:
NORDGI : Nordic Geographic Information

Publication date:
2006

Document Version
Publisher's PDF, also known as Version of record

Link to publication from Aalborg University

Citation for published version (APA):
Reinau, K. H. (2006). Cellular Automata and Urban Development. In P. Takala (Ed.), *NORDGI : Nordic Geographic Information: proceedings from the Nordic GIS Conference, Helsinki 2006* (pp. 75-80). National Land Survey of Finland. http://www.ginorden.org/arrangement/gikonferanser/the-18th-nordic-gis-conference-2006-in-helsinki-finland

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Cellular Automata and Urban Development

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The Nordic GIS Conference in Helsinki
2nd – 4th of October 2006

Sustainable Urban Development

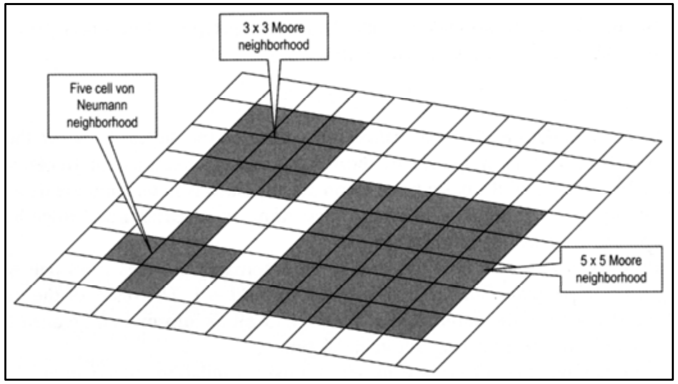
-Where are we going?

”In general, it is presently recognised that, in order to respond to the idea of sustainability, urban areas have to maintain an internal equilibrium balance between economic activity, population growth, infrastructure and services, pollution, waste, noise, etc in such a way that the urban system and its dynamics evolve internally in harmony, limiting, as much as possible, impacts on the natural environment” (Barredo et. al. 2004, p.65)

- **How will cities evolve in the future?**
  - 1950s: The first mathematical urban models.
  - 1990s: Urban models based on cellular automata.
- **Urban models based on Cellular Automata**
  - Method tested on more than 50 cases, but applications to real cities are still quite rare. Method mainly tested on relatively large American and European cities, such as San Francisco, Cincinnati and Dublin.
  - Not tested in a Danish context (fall 2005).
- **The research question: Can CA based urban models simulate the growth of relatively small Danish cities?**
  - Case study Herning (24757 inhabitants).
  - The consequence of scale?
  - Can CA based urban models simulate the dynamics that are the driving forces behind contemporary urban growth in post-industrial and post-modern cities?

What is Cellular Automata?

- Artificial Life
- *"An automaton is a machine that processes information, proceeding logically, inexorably performing its next action after applying data received from outside itself in light of instructions programmed within itself" (Torrens 2000, p. 15)*



Example: The dynamic simulated in the example is, that if a cell has 1 or more cells in its Moore neighborhood that are alive, then the cell will become alive in the next generation.

Starting point

		X		

1. generation

	X	X	X	
	X	X	X	
	X	X	X	

2. generation

X	X	X	X	X
X	X	X	X	X
X	X	X	X	X
X	X	X	X	X
X	X	X	X	X

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The dynamics simulated in the Herning model

- Trigger factors behind urban development:
  - Economy, Technology, Demography, Politics, Society, Culture and Environment

- Which of these “trigger factors” should be simulated?
  - The exemplary model in the CA literature is (White et. al. 1997)’s model of Cincinnati (1840-1960), which simulates dynamics described in classical economic location theory and classic urban theories.

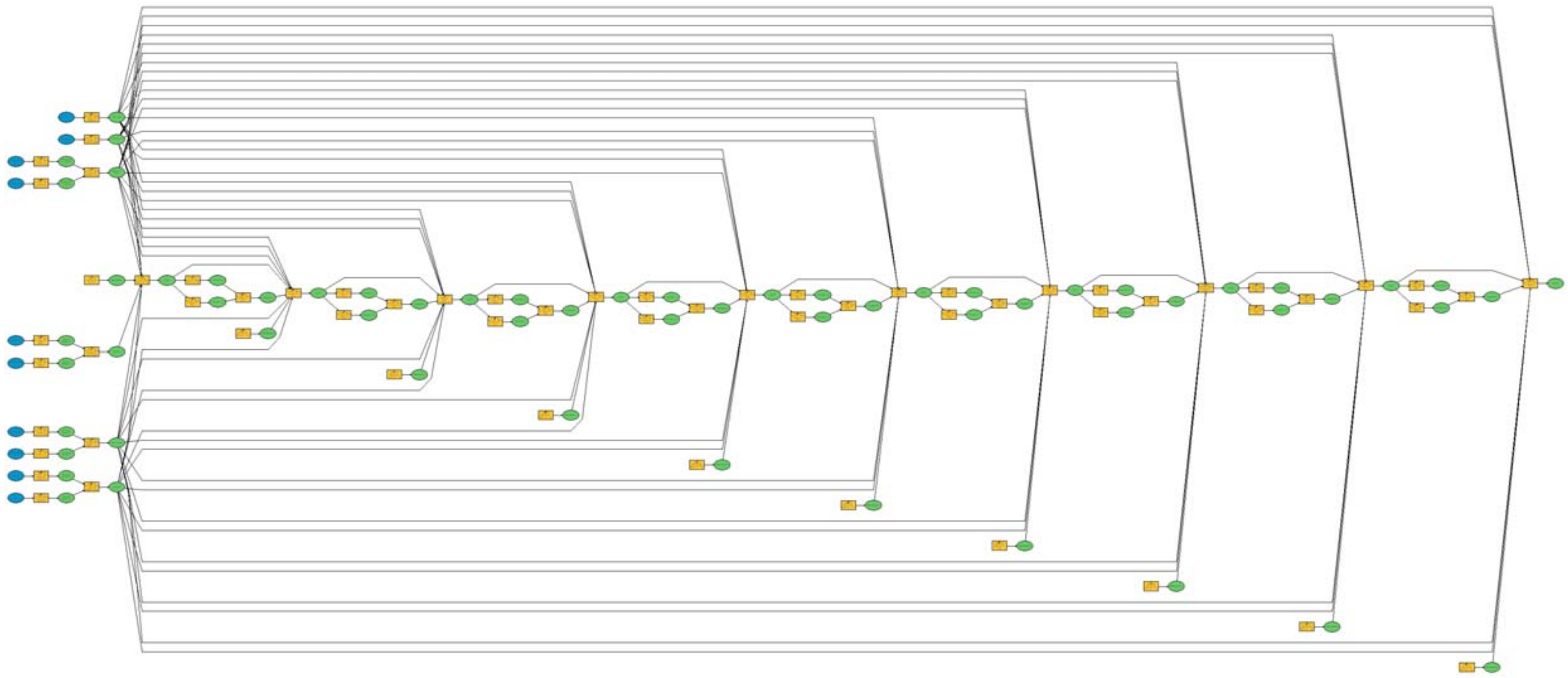
- From an industrial society to an information society!

- Is a model that simulates dynamics describes in classical economic location theory and classical urban theories capable of simulating the development of contemporary Danish cities?

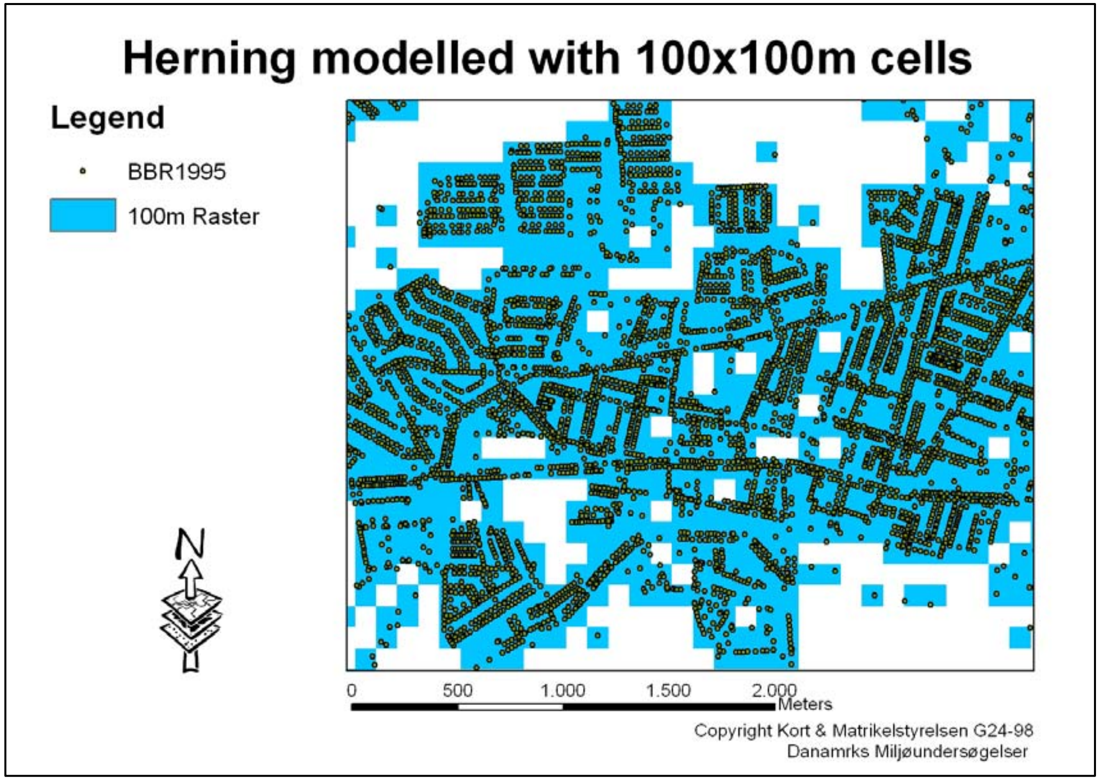
- The CA based model for Herning simulated three dynamics:
  - Buildings are build near existing buildings.
  - Buildings are build near infrastructure.
  - Some barriers have slowed development in some areas.

The CA model of Herning

- Programmed in Modelbuilder in ArcGIS 9.0
- Uses 7 rastermodels as input: “Herning 1900”, “Road”, “Railway”, “Railway Station”, “Wetlands”, “Lake” and “Stochastic variable”.

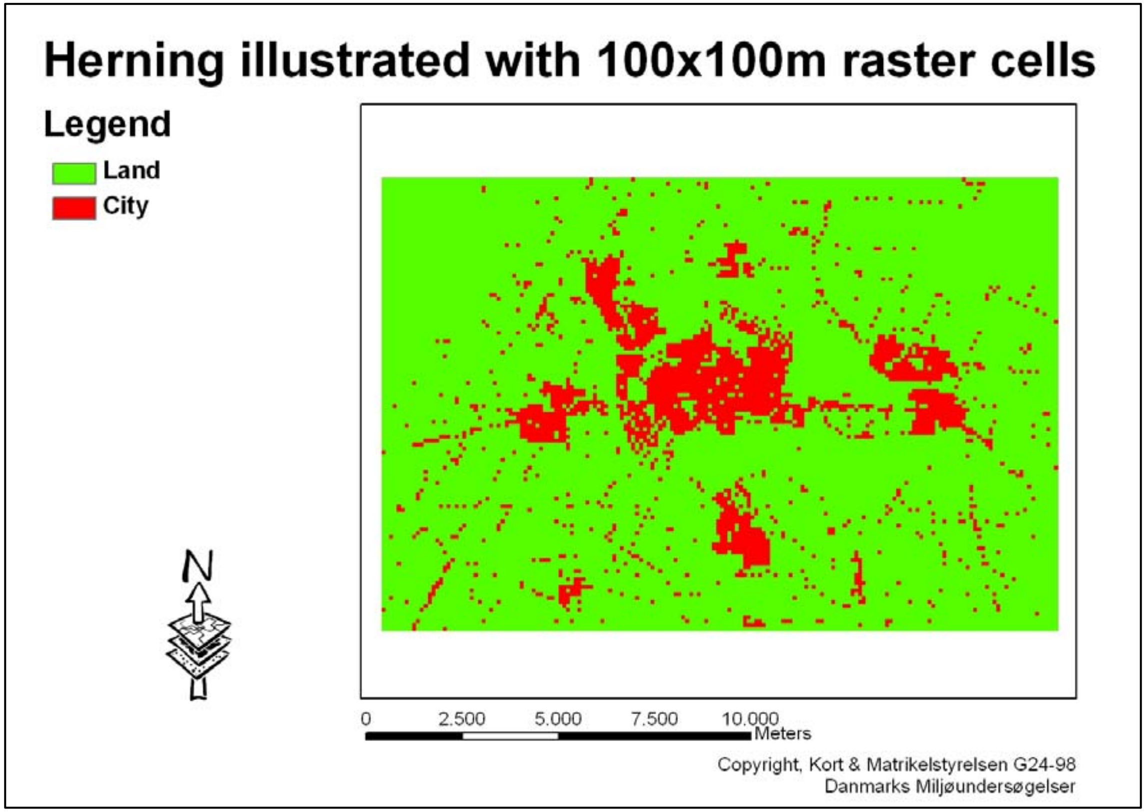


The development of Herning



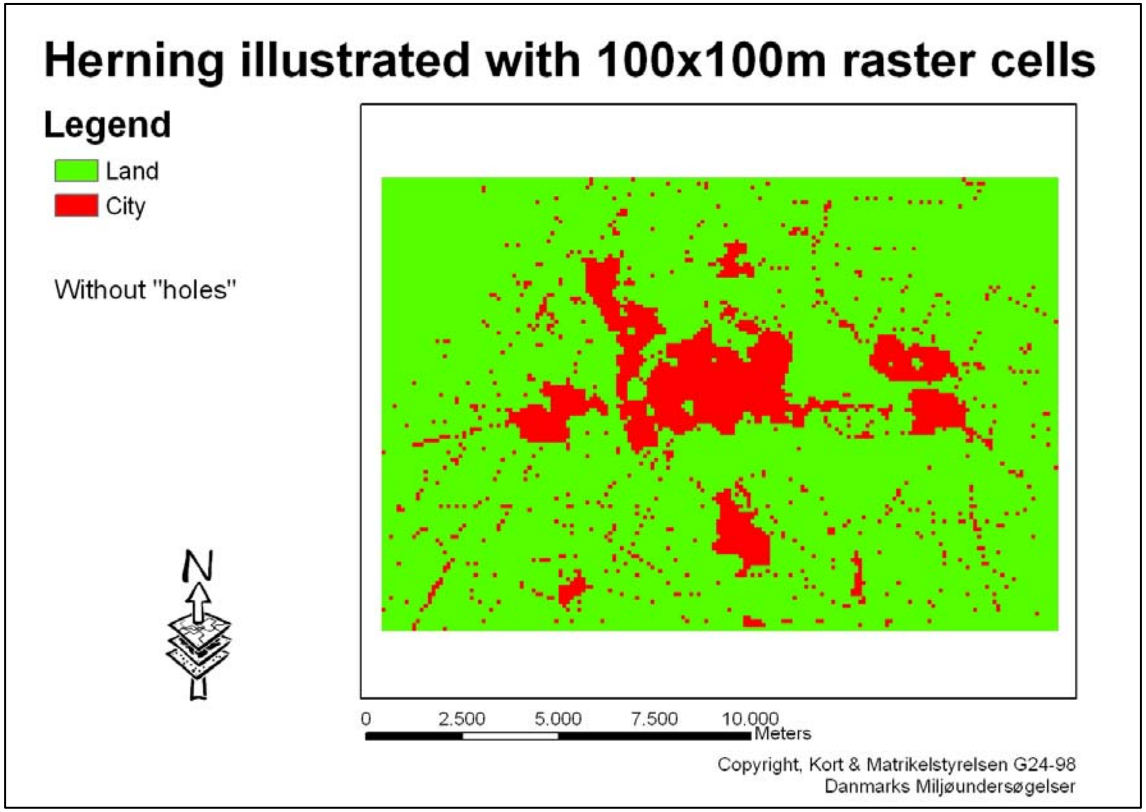
- Bygnings og BoligRegister, BBR (Buildings and housing register)
  - Vectorpointmodel containing information about the location of buildings and some of their attributes. Buildings constructed before a given date can be identified.
  - Problem: Demolished buildings "invisible"!
  - Vector point model converted to raster model with 100x100m cells by "features to raster" operation, showing "urban areas".

The development of Herning



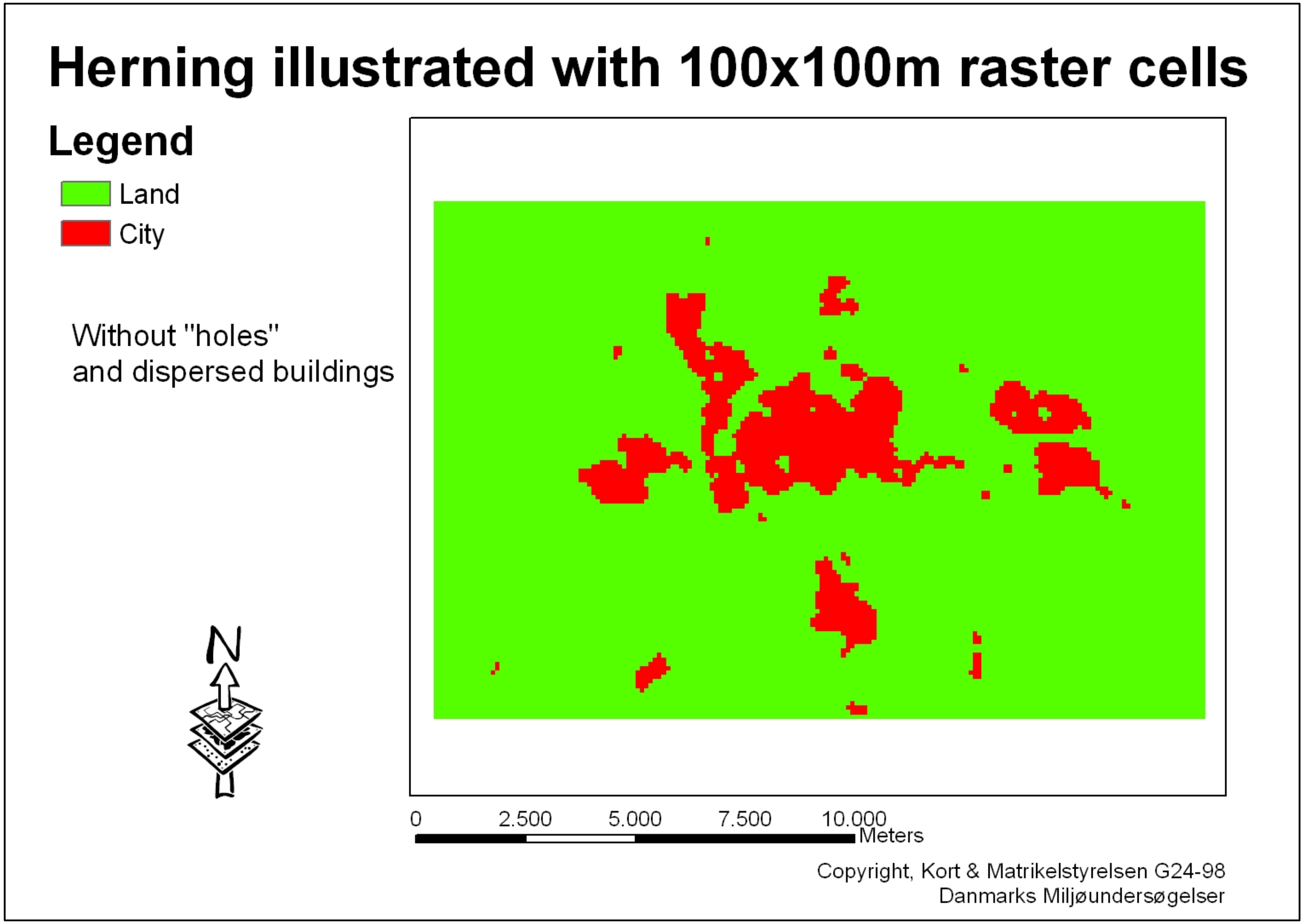
- "Holes" in the citymodel closed with the following Map Algebra expression:
  - Con(([Rastermodel] == 1), 1, (Con((focalsum([Rastermodel], rectangle, 3, 3) > 4), 1, 0)))

The development of Herning



- Dispersed "urban areas" in the citymodel deleted with the following Map Algebra expression:
  - Con(([Rastermodel] == 0), 0, (Con((focalsum([Rastermodel], rectangle, 3, 3) < 5), 0, 1)))

The development of Herning



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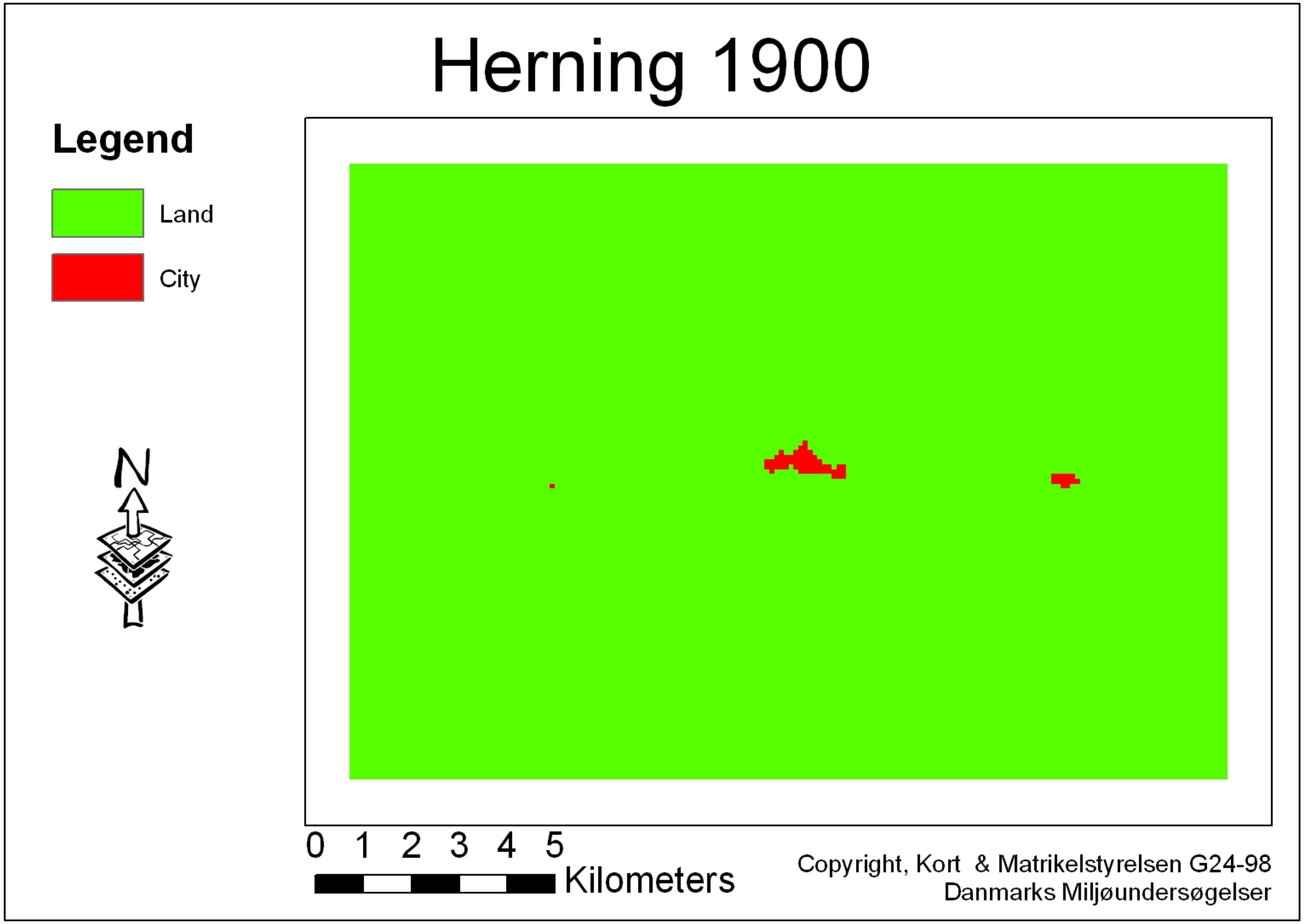

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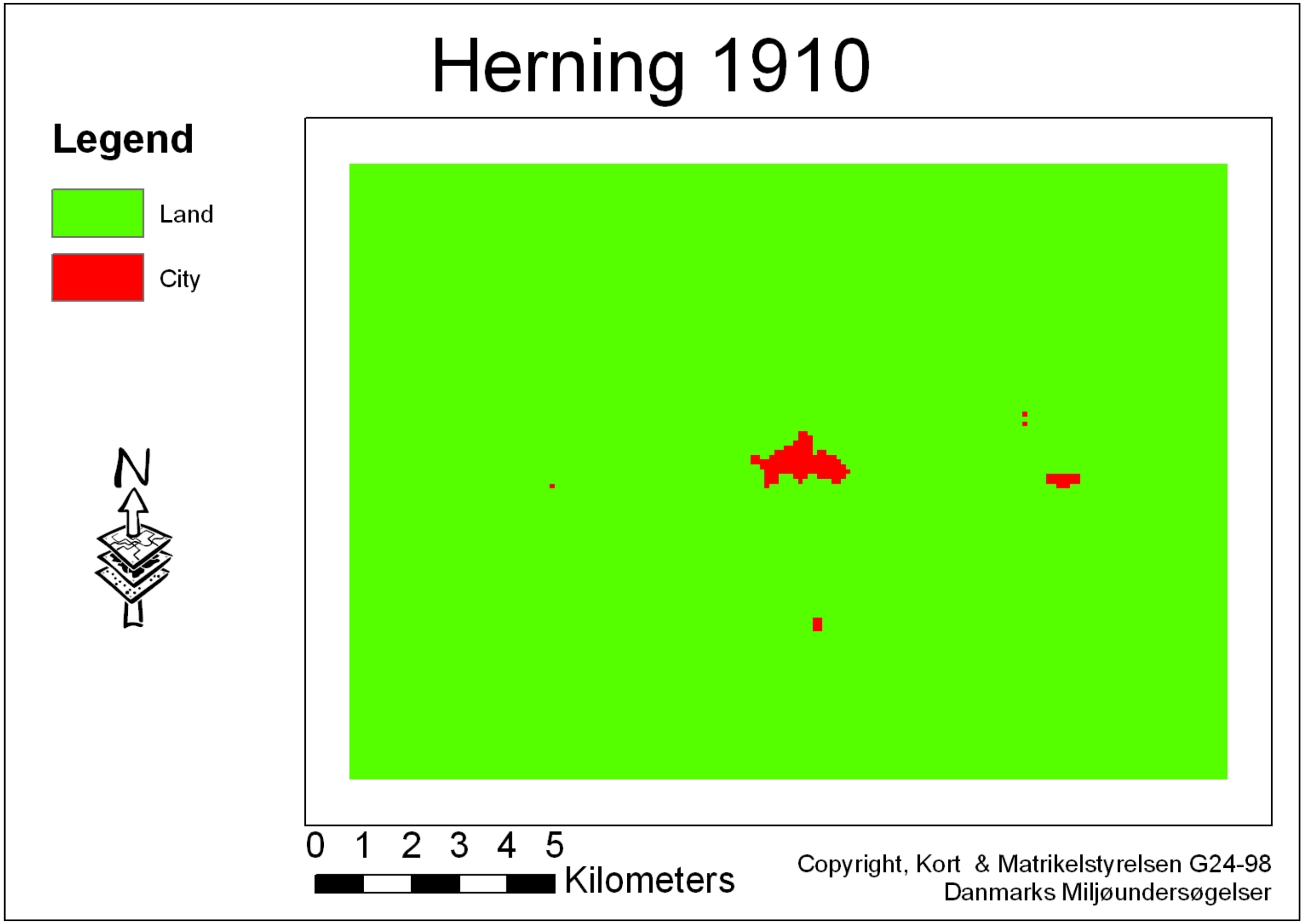

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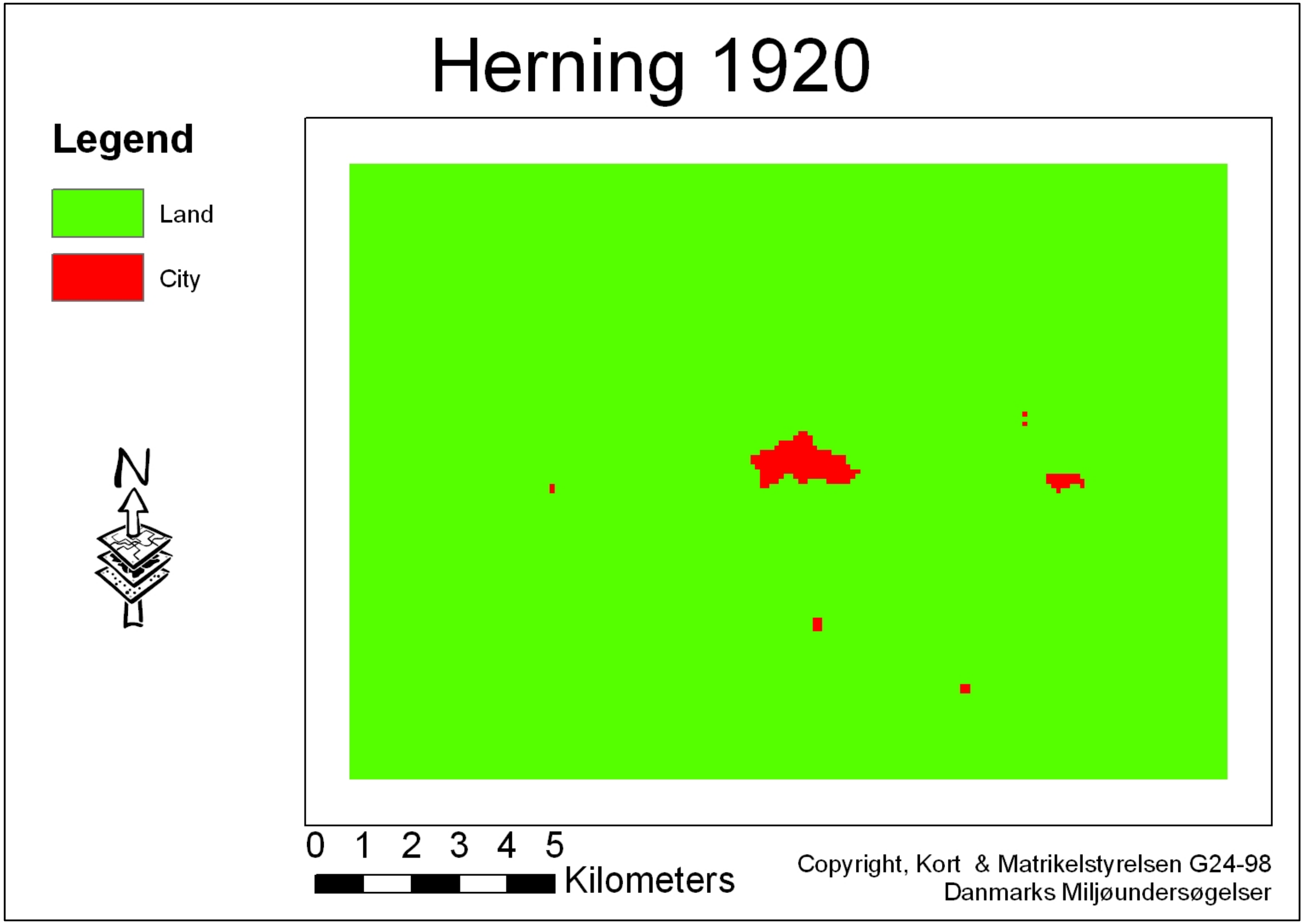

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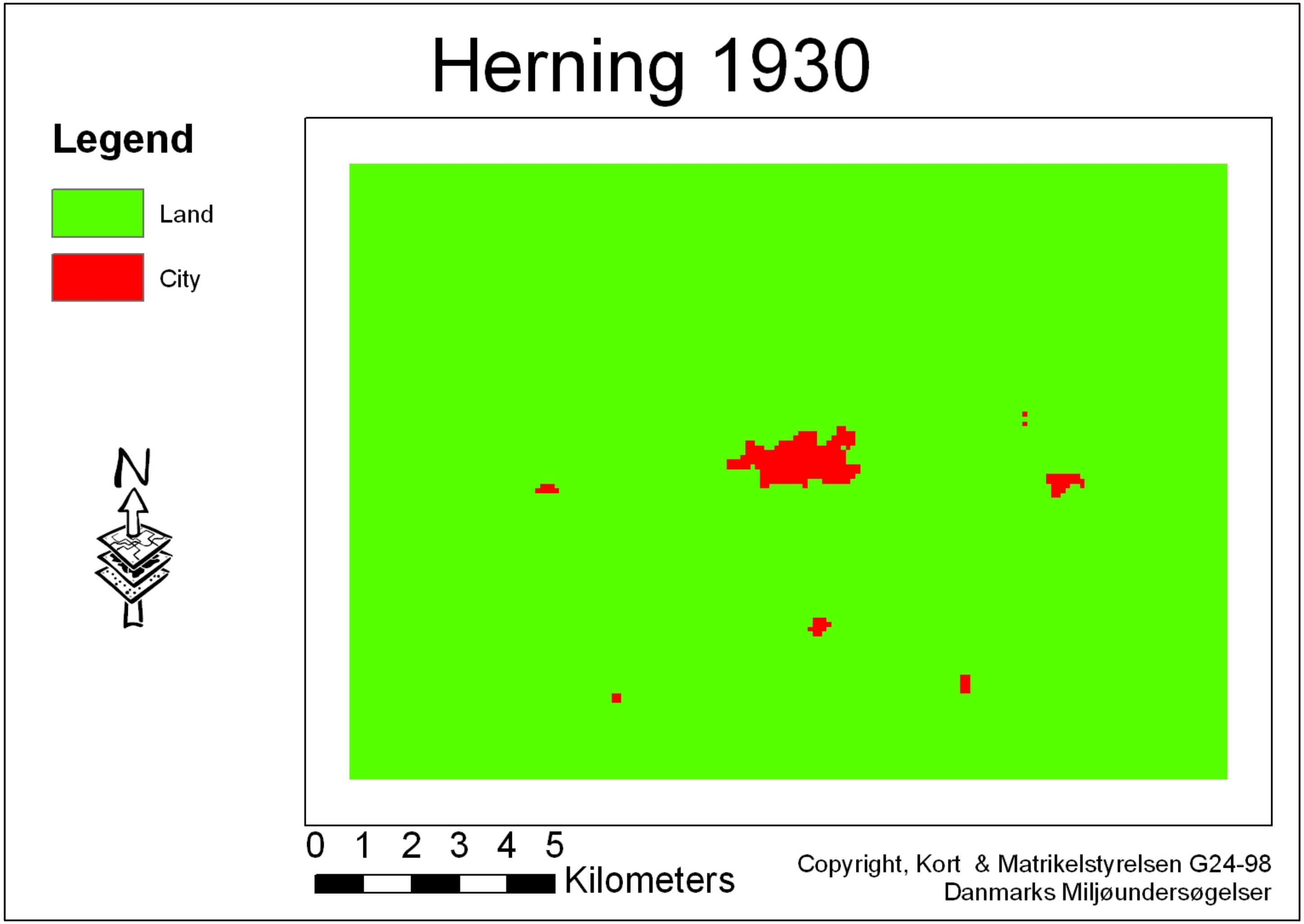

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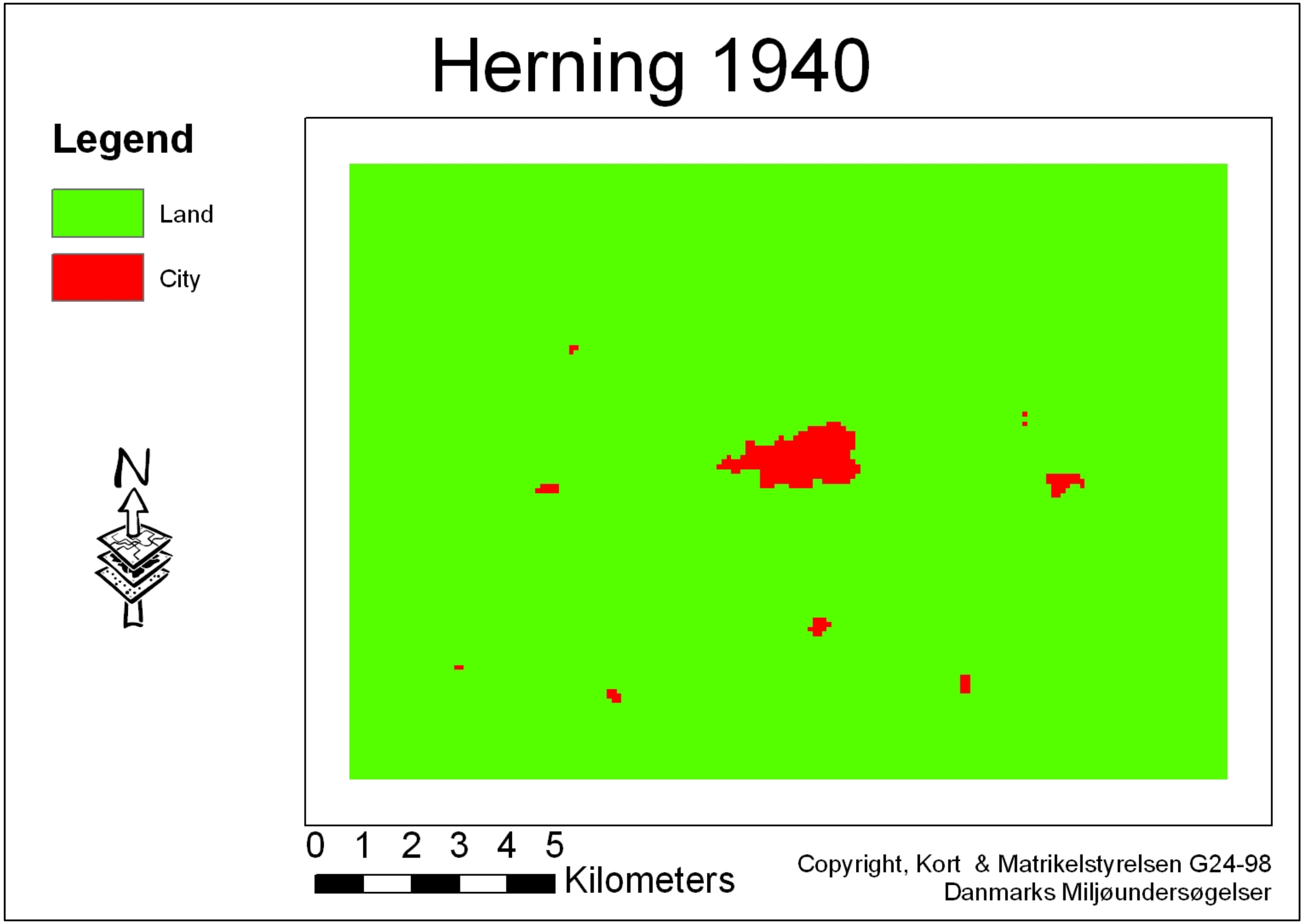

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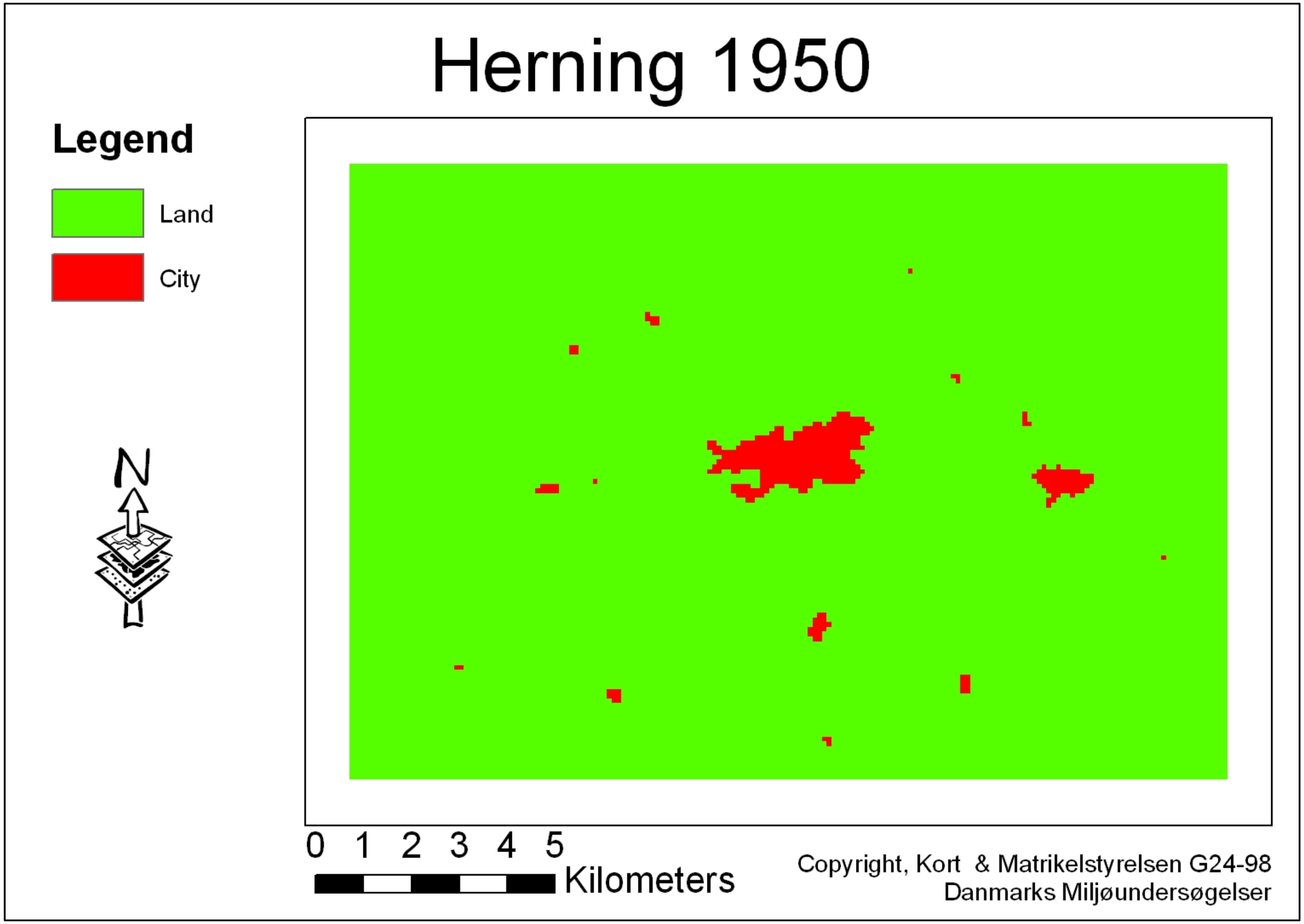

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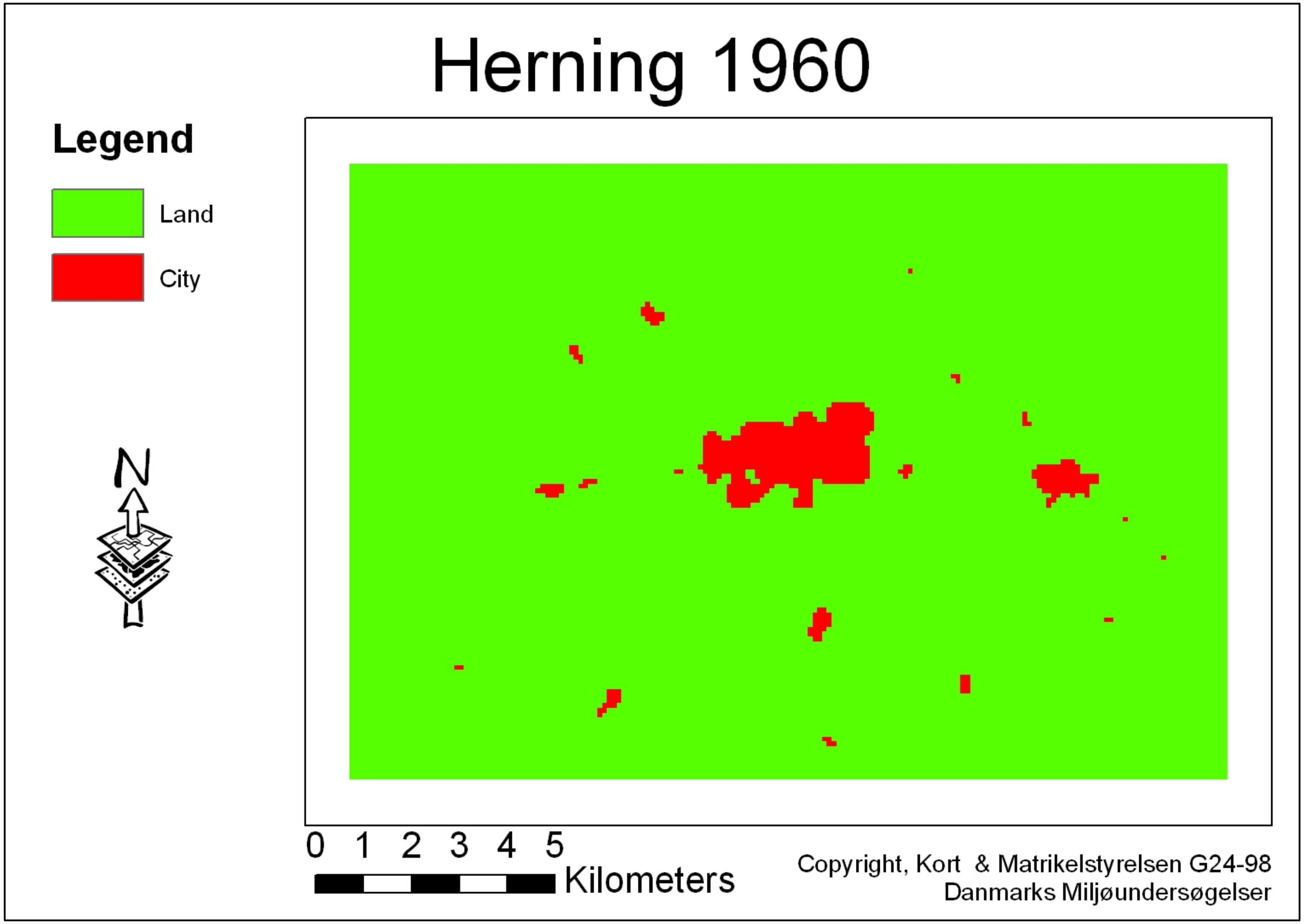
The development of Herning



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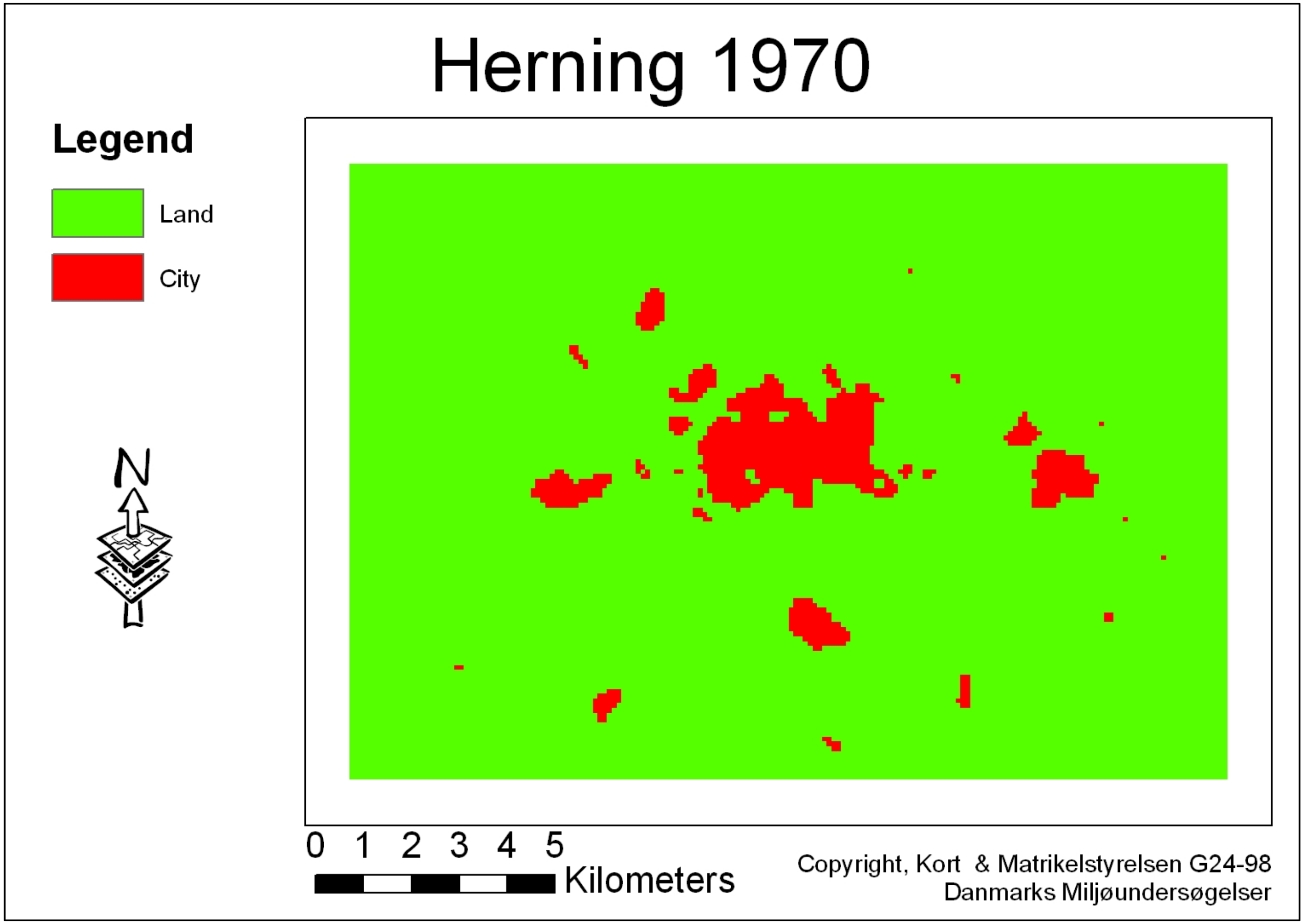

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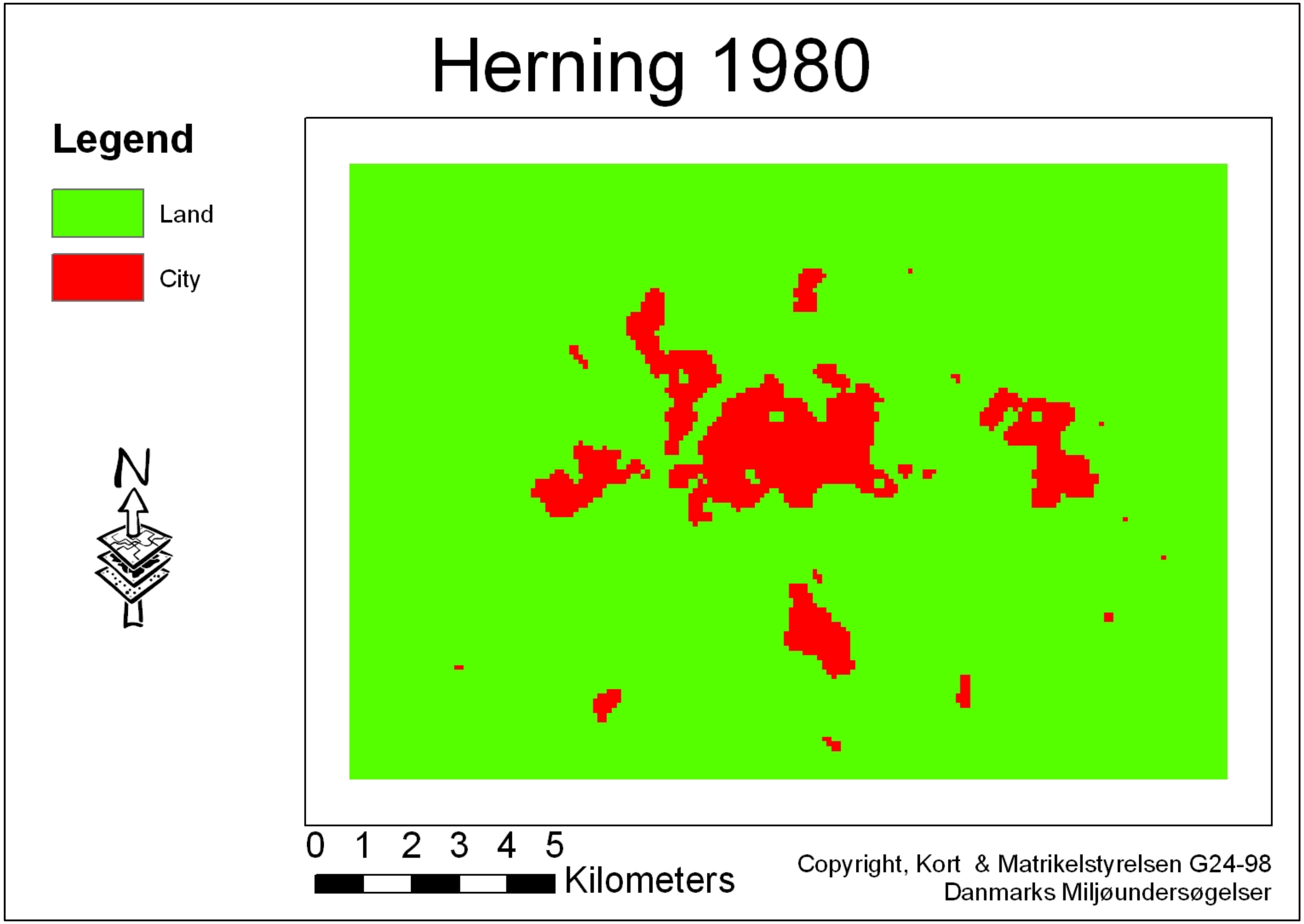

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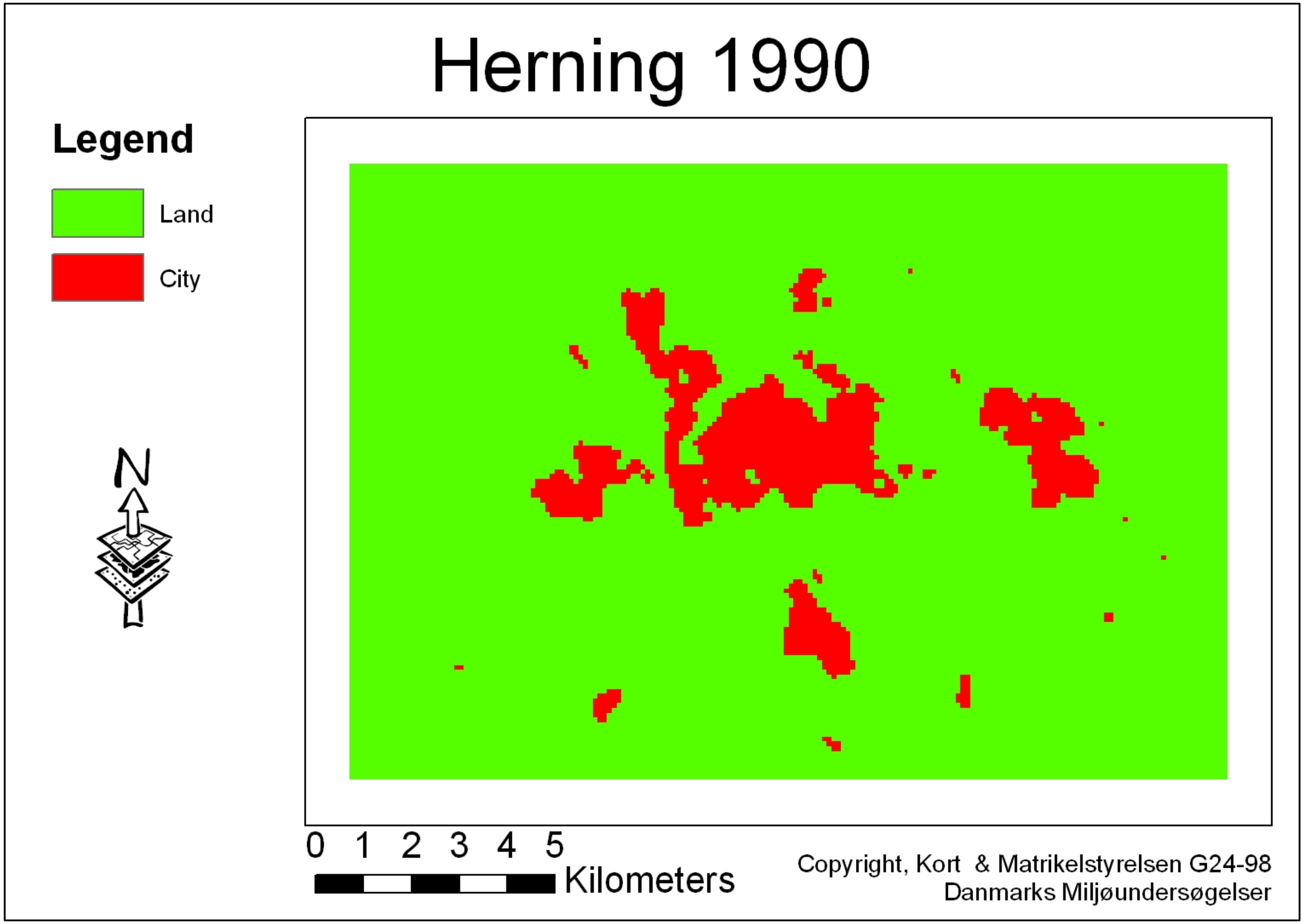

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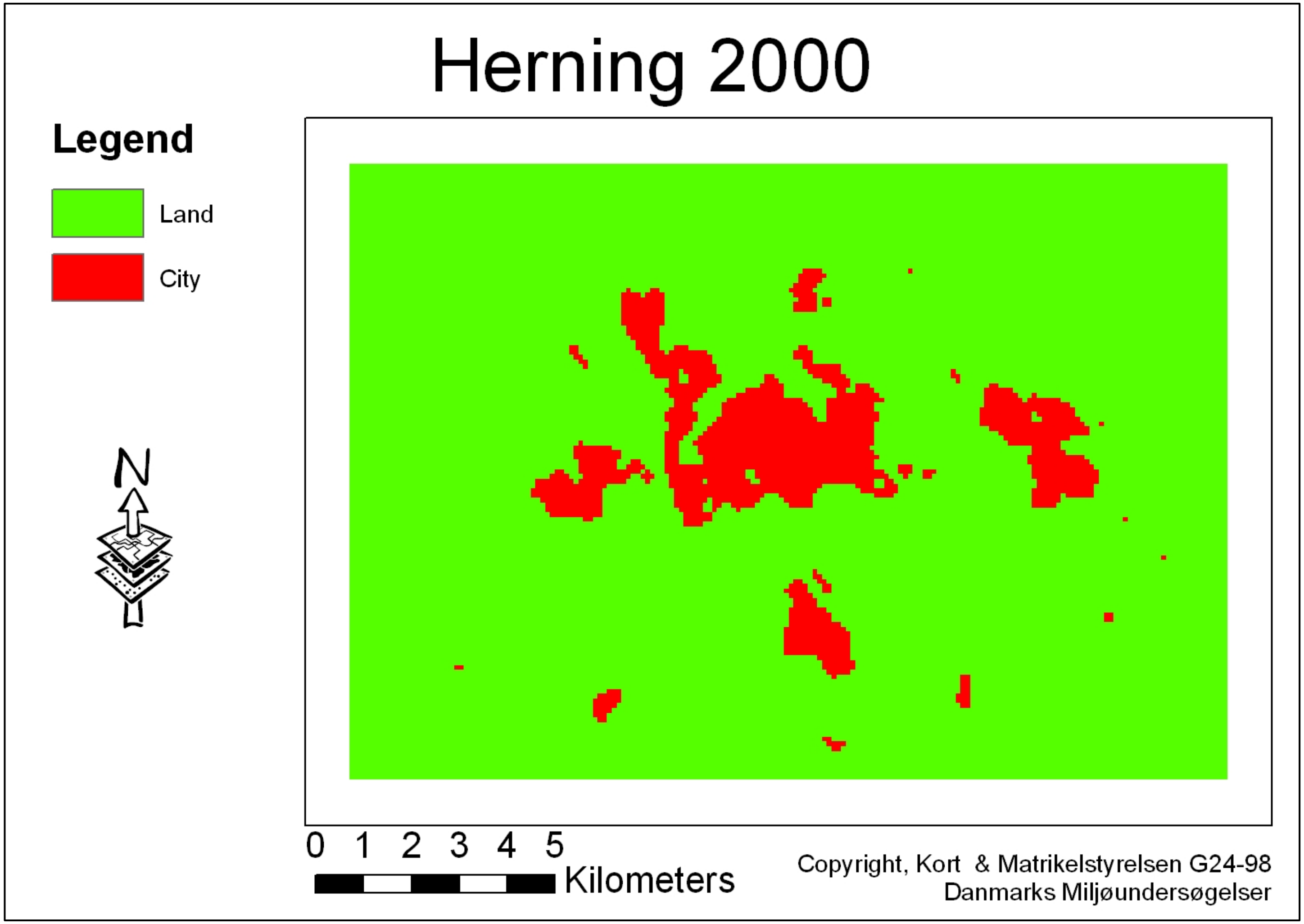
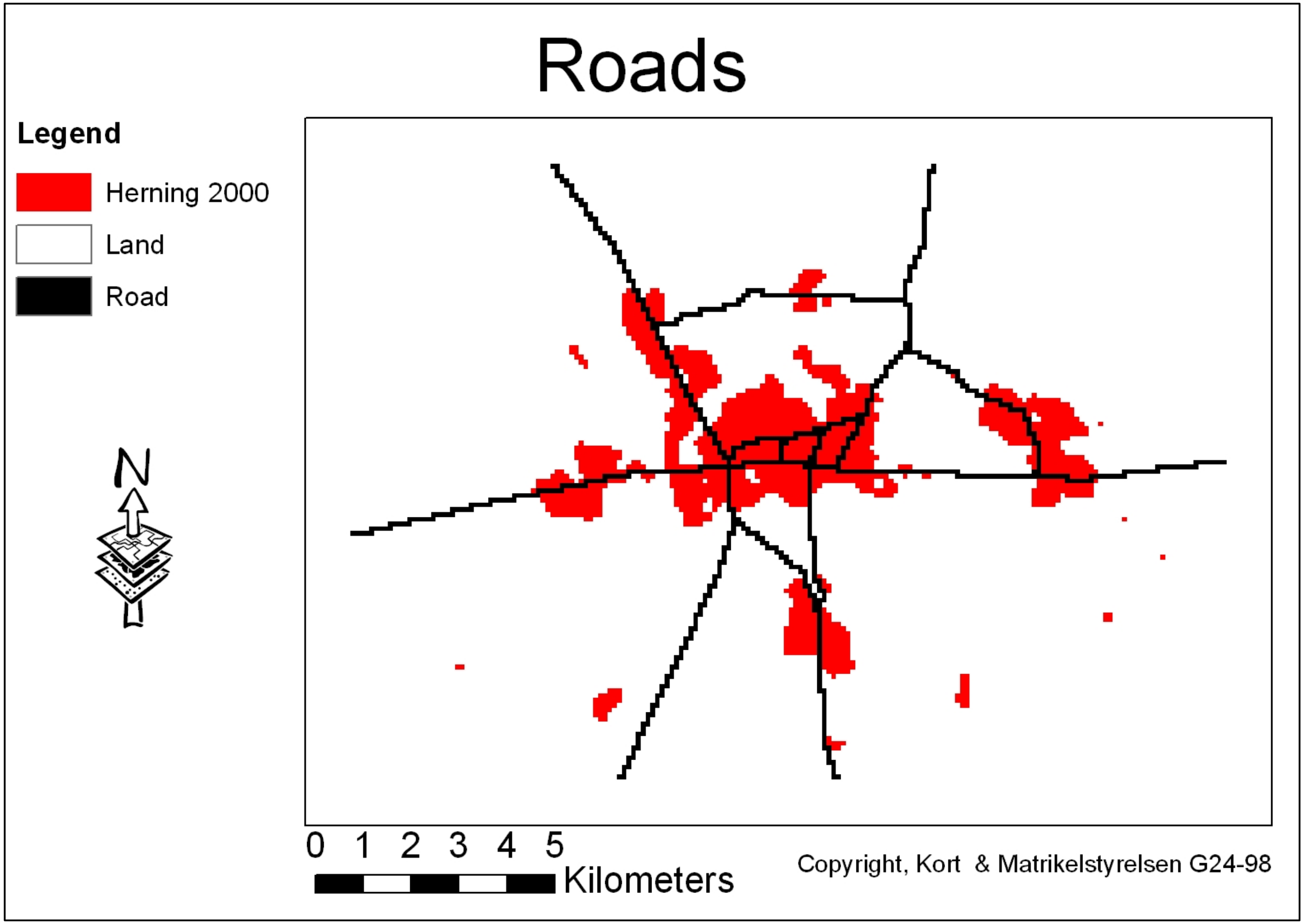
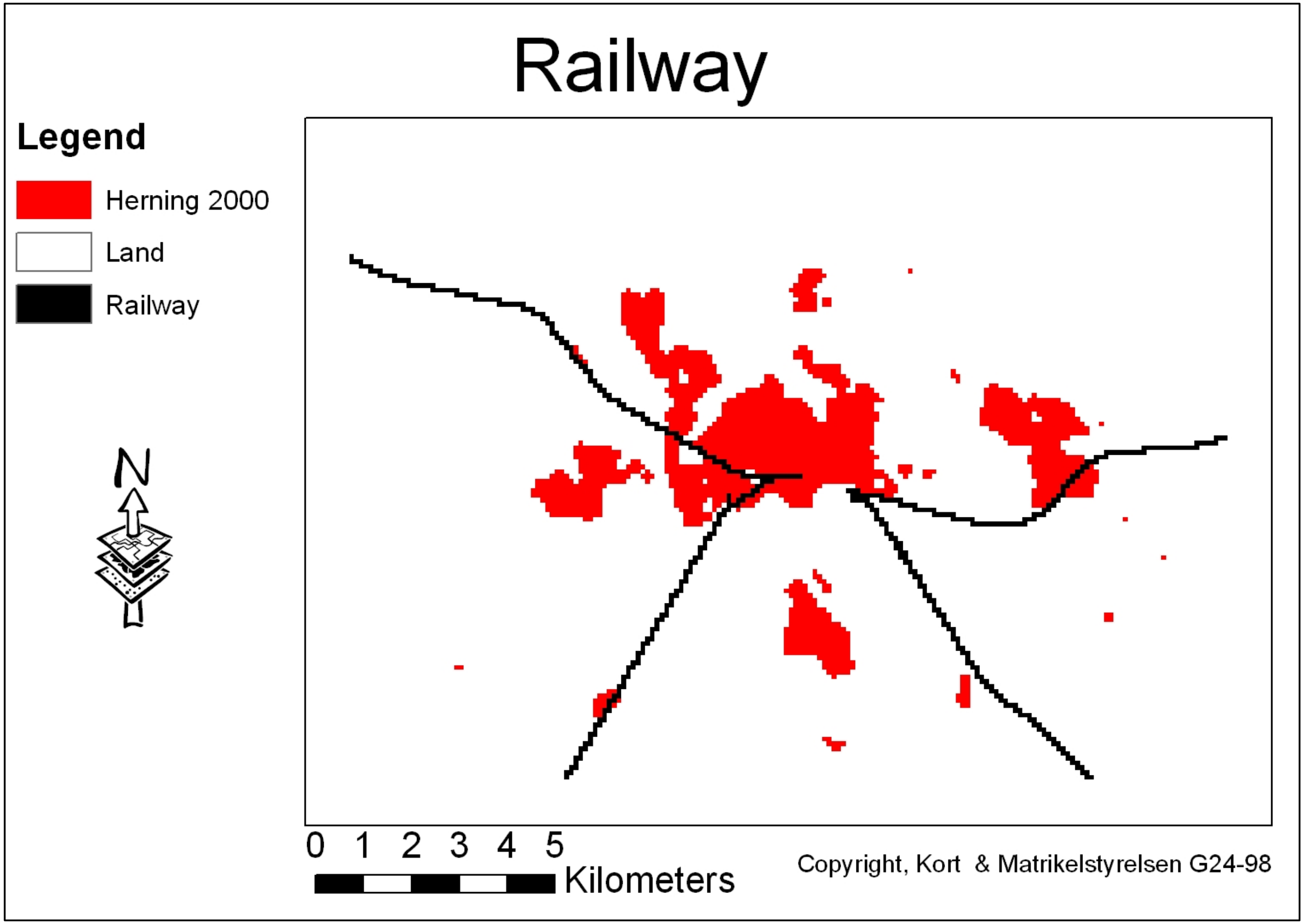


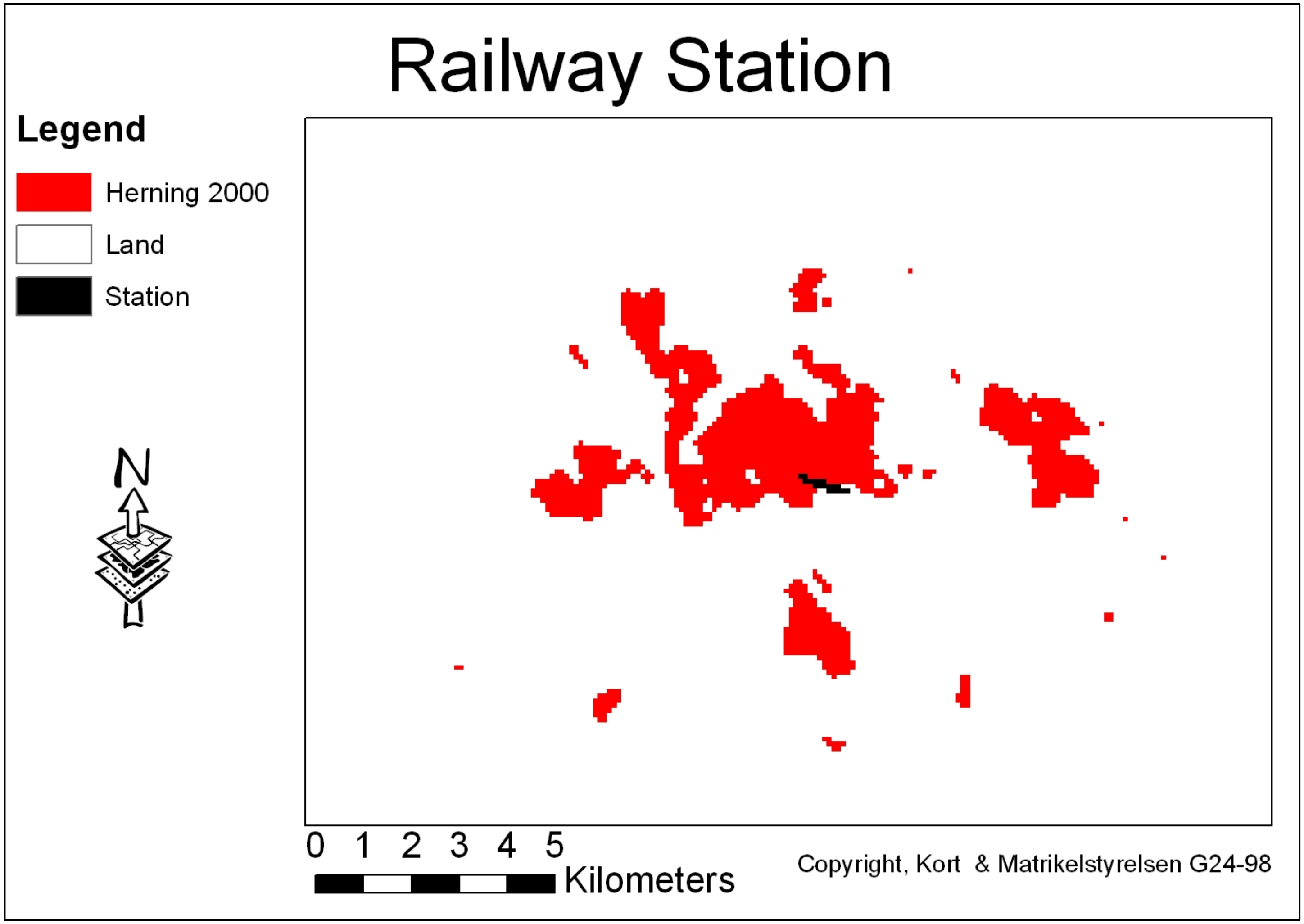
CA based model of Herning
- The Road model



CA based model of Herning
- The Railway model

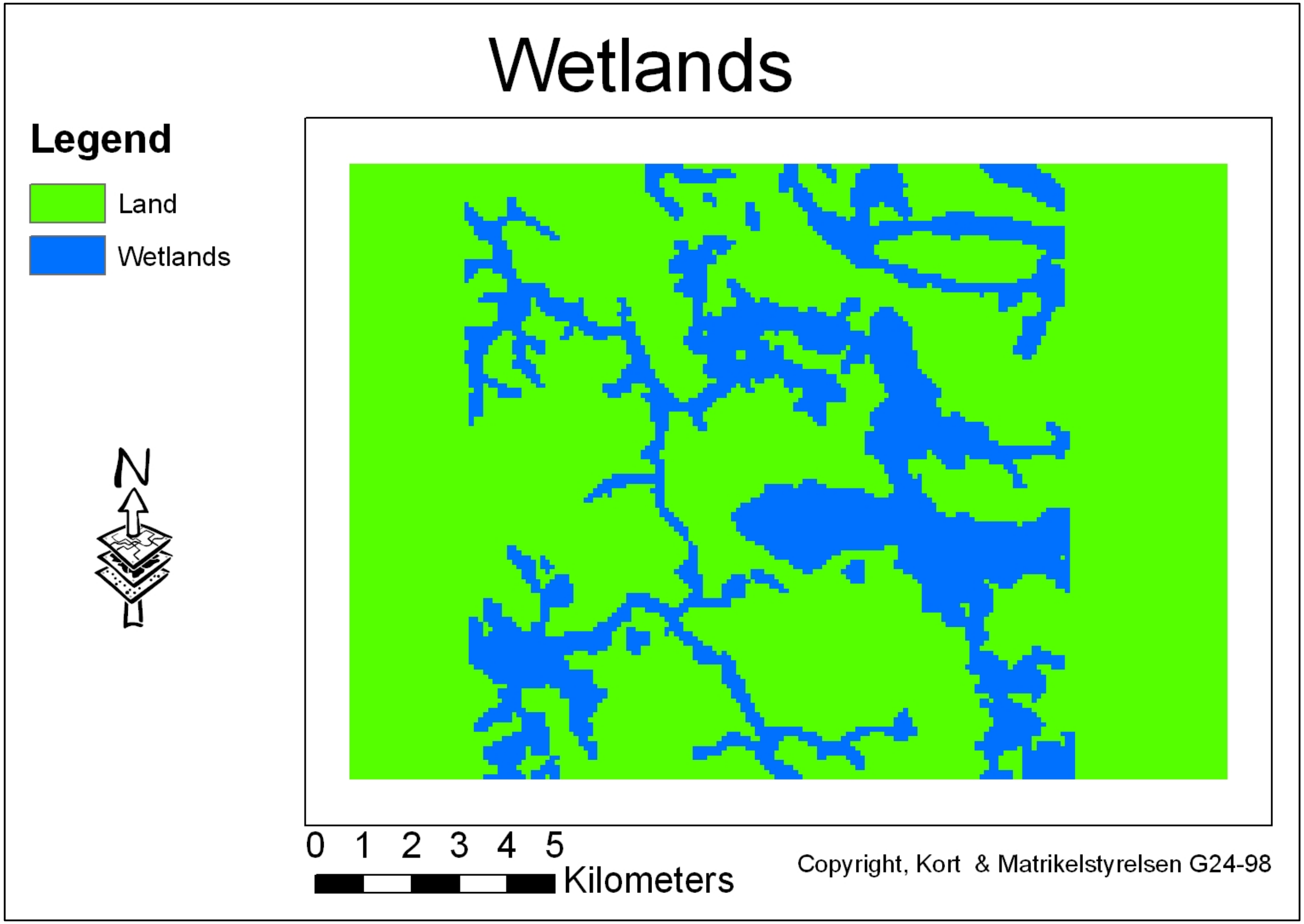


CA based model of Herning
- The Railway Station model

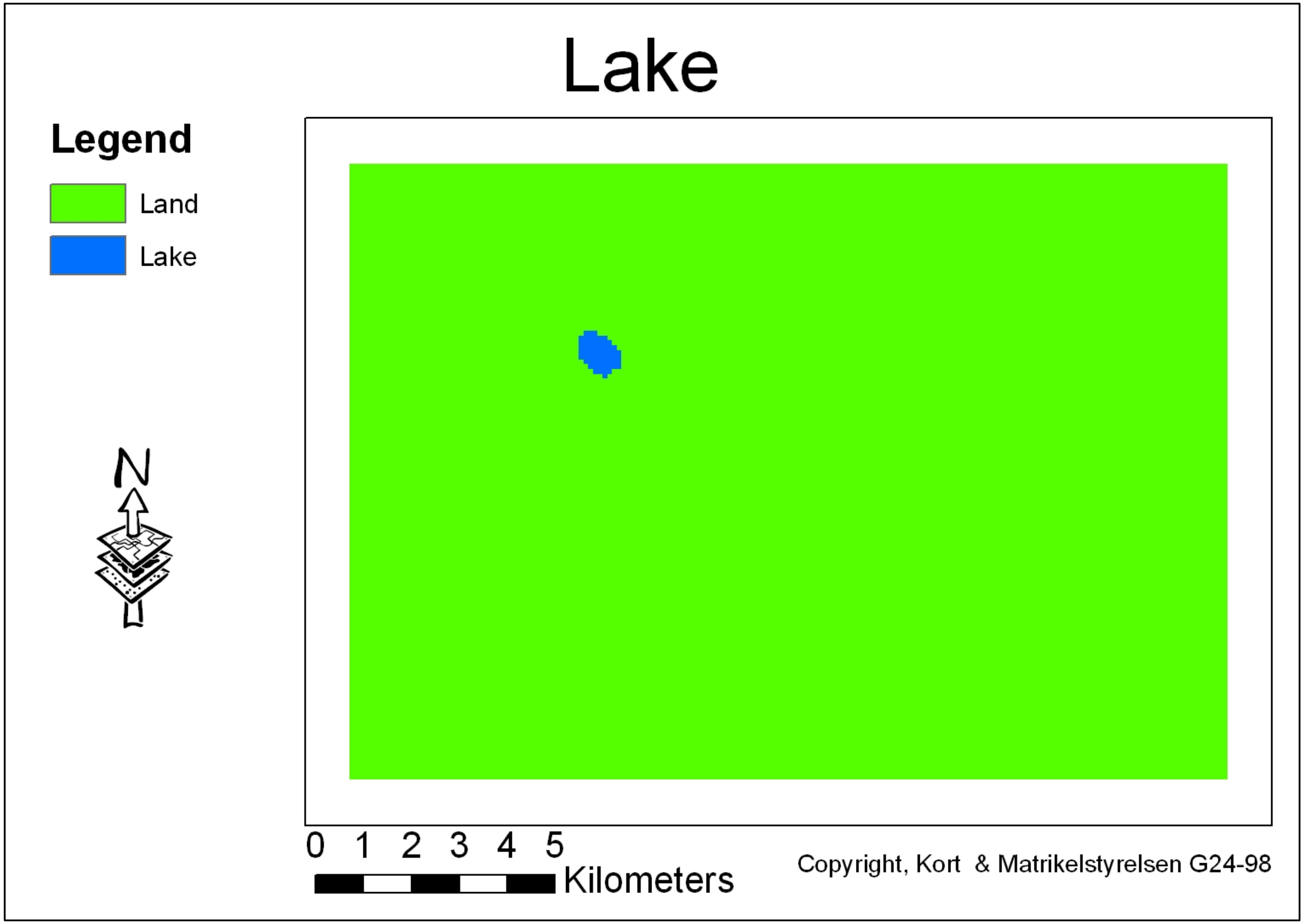


CA based model of Herning

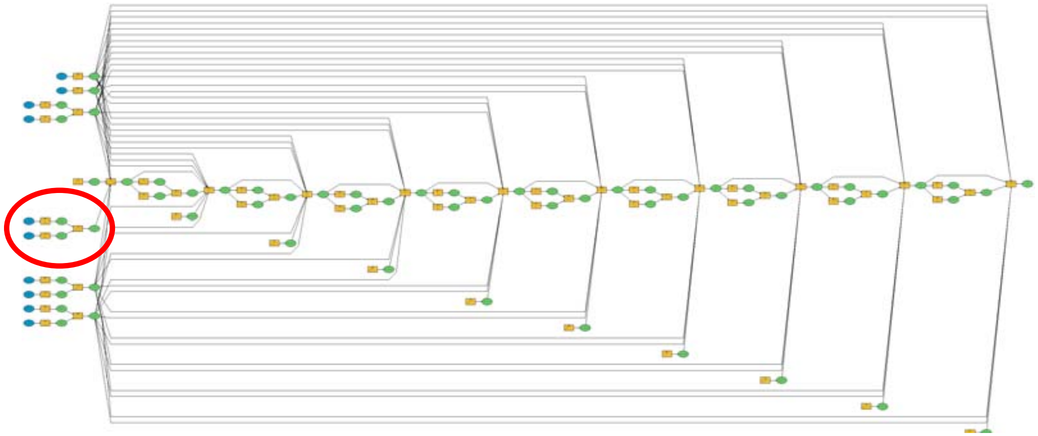
- The Wetlands model

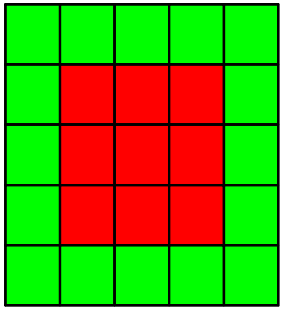


CA based model of Herning
- The Lake model

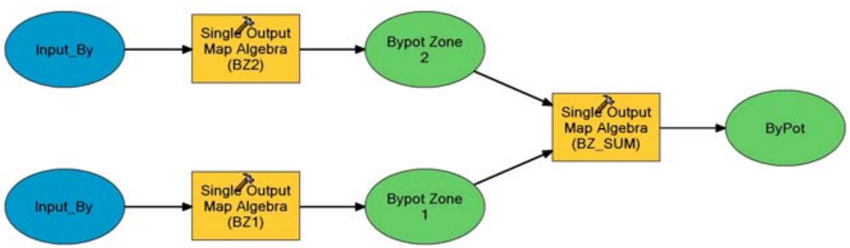


How does the models work?



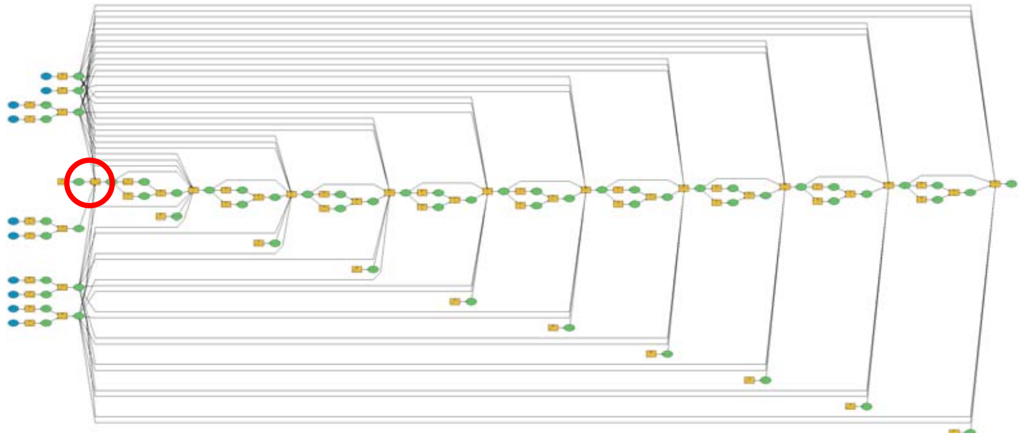


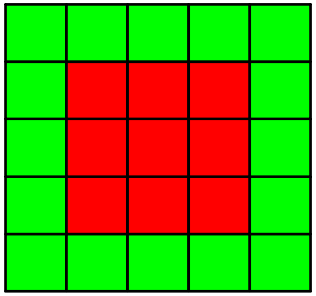
Extended Moore Neighbourhood



- Calculation of potential deriving from each input model, City as example
  - City Zone 1 Map Algebra Expression:
    - focalsum([Input_City], rectangle, 3, 3) * 0.2
  - City Zone 2 Map Algebra Expression:
    - focalsum([Input_City], irregular, D:\CA_GIS\z2kernel.txt) * 0.1
  - City Potential = City Zone 1 + City Zone 2

How does the models work?





Extended Moore Neighbourhood

- Map Algebra expression for calculation of city-cells after 1. generation
  - Con ((((Input_City] > 0.5) OR ((([Random] / 2) + [CityPot] + [RoadPot] + [WetlandsPot] + [LakePot] + [RailwayPot] + [RailwayStationPot]) > 2.0))), 1, 0)

Model	Weight inner zone of Neighbourhood	Weight outer zone of Neighbourhood
City	0,3	0,15
Road	0,2	0,1
Railway Station	0,2	0,1
Railway	-0,2	-0,1
Barriers with constant effect on development		
Wetlands	-2	
Lake	-2	
Size of stochastic variable 0 < X < 0,5		
Potential needed for city development: 2.0		

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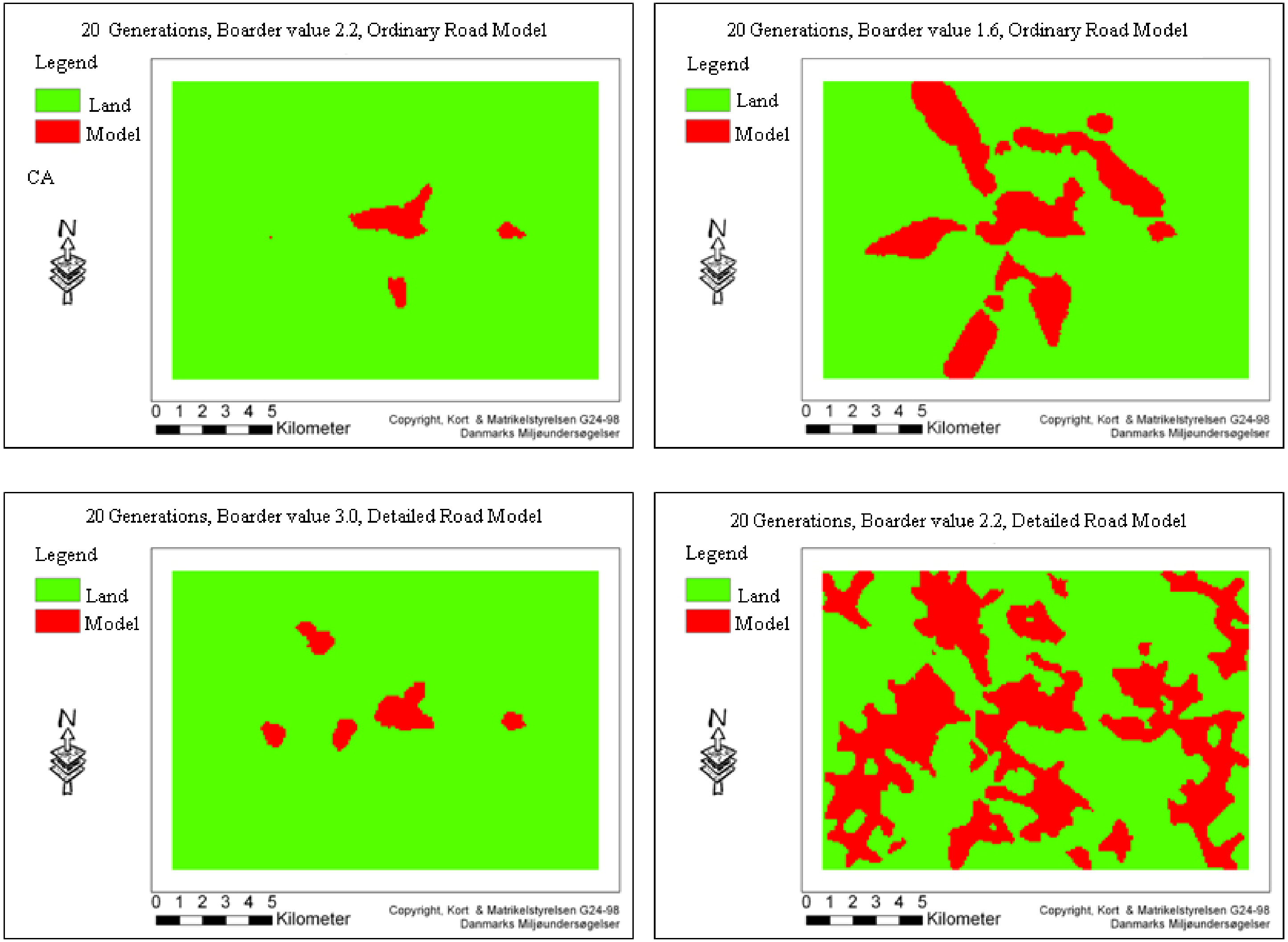
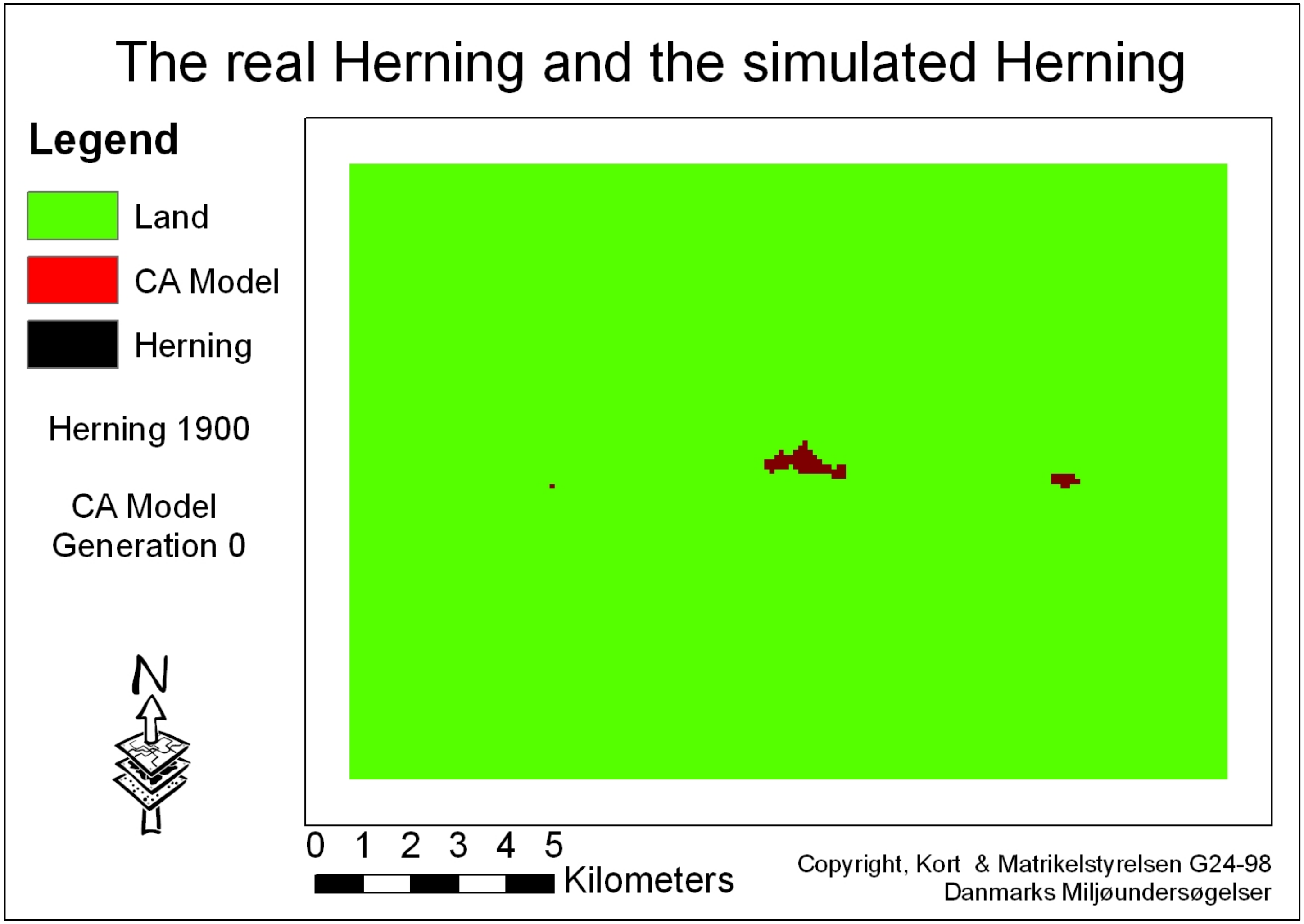
Calibration of weights and boarder values



The simulation of Herning



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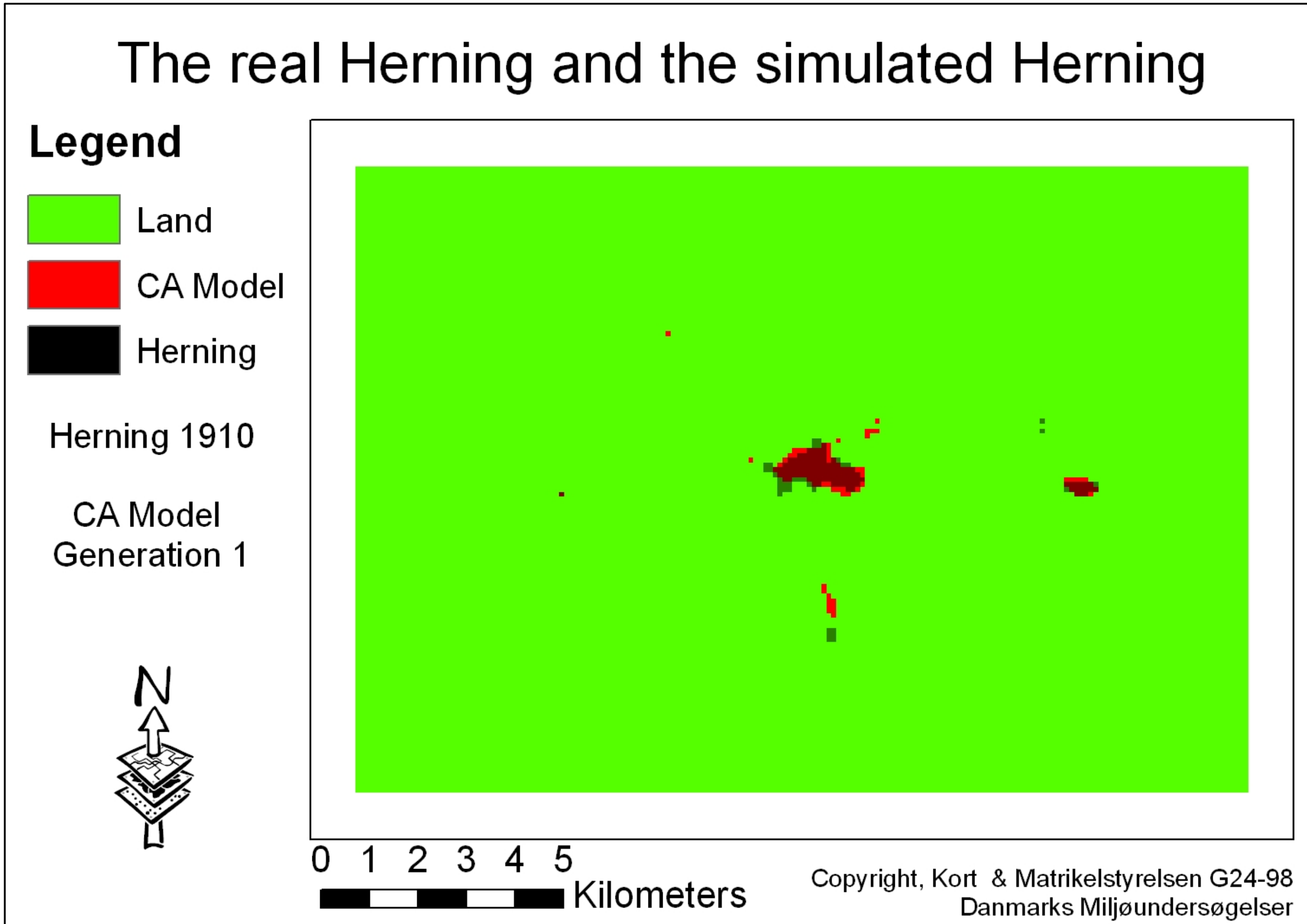

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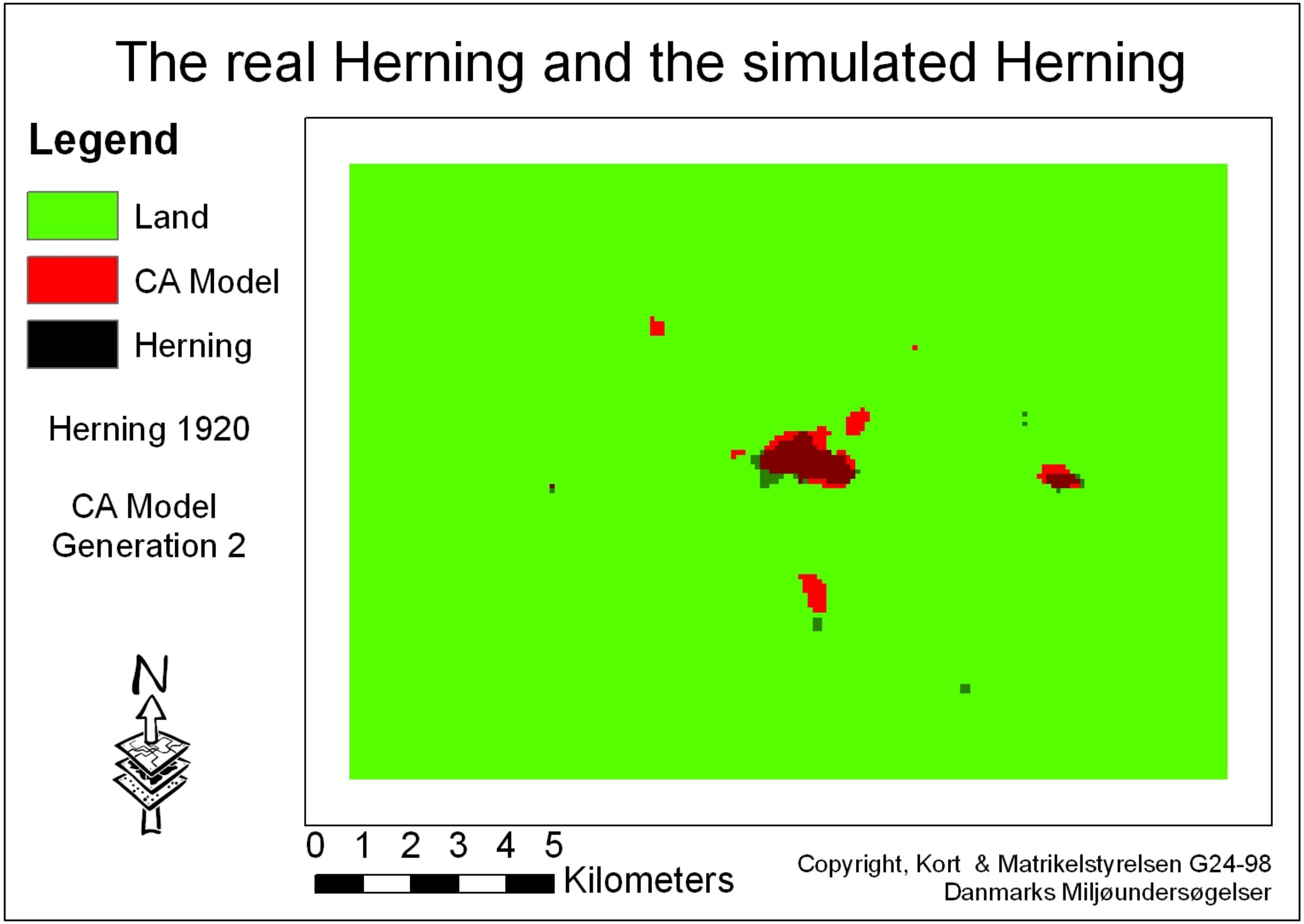

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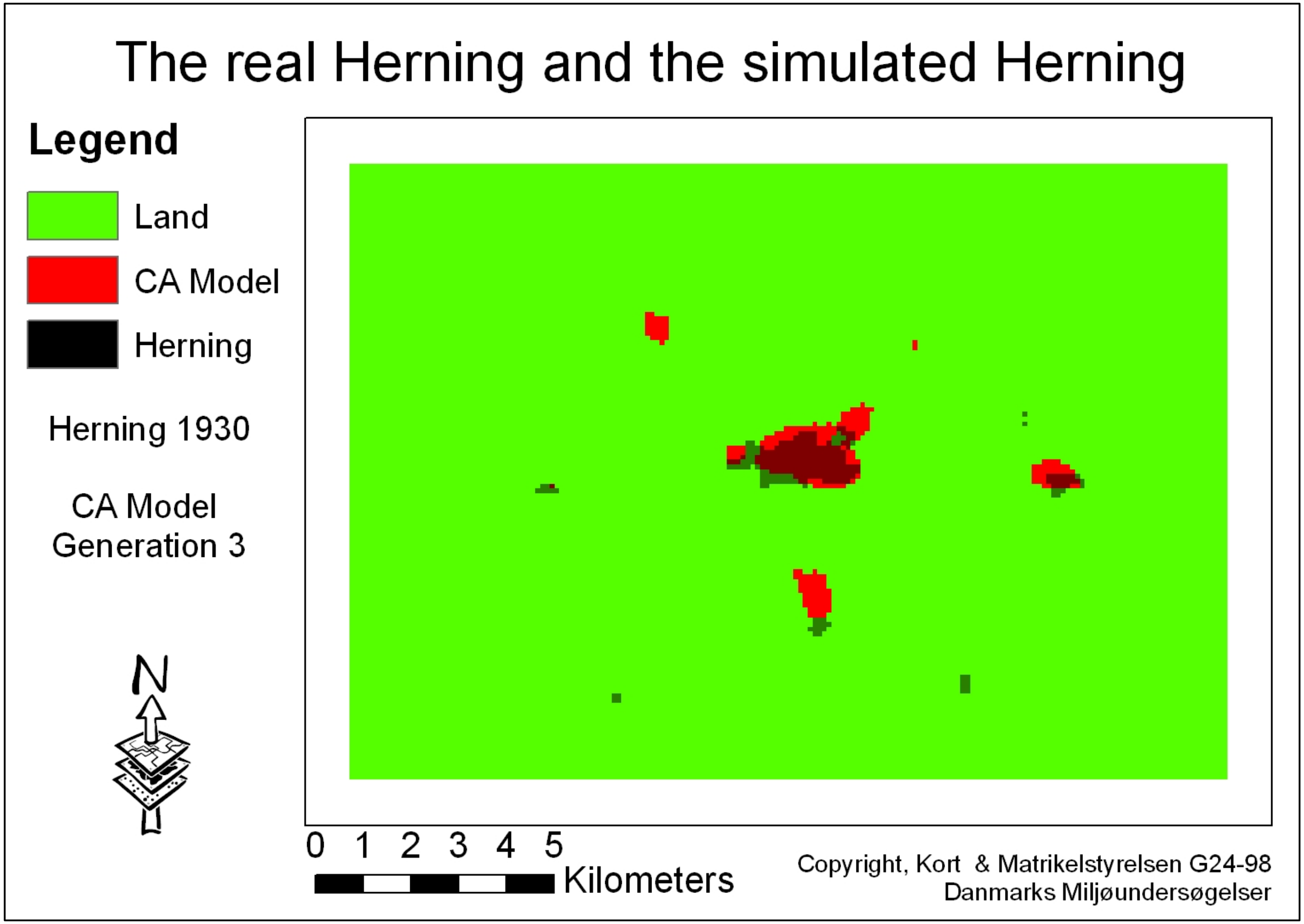

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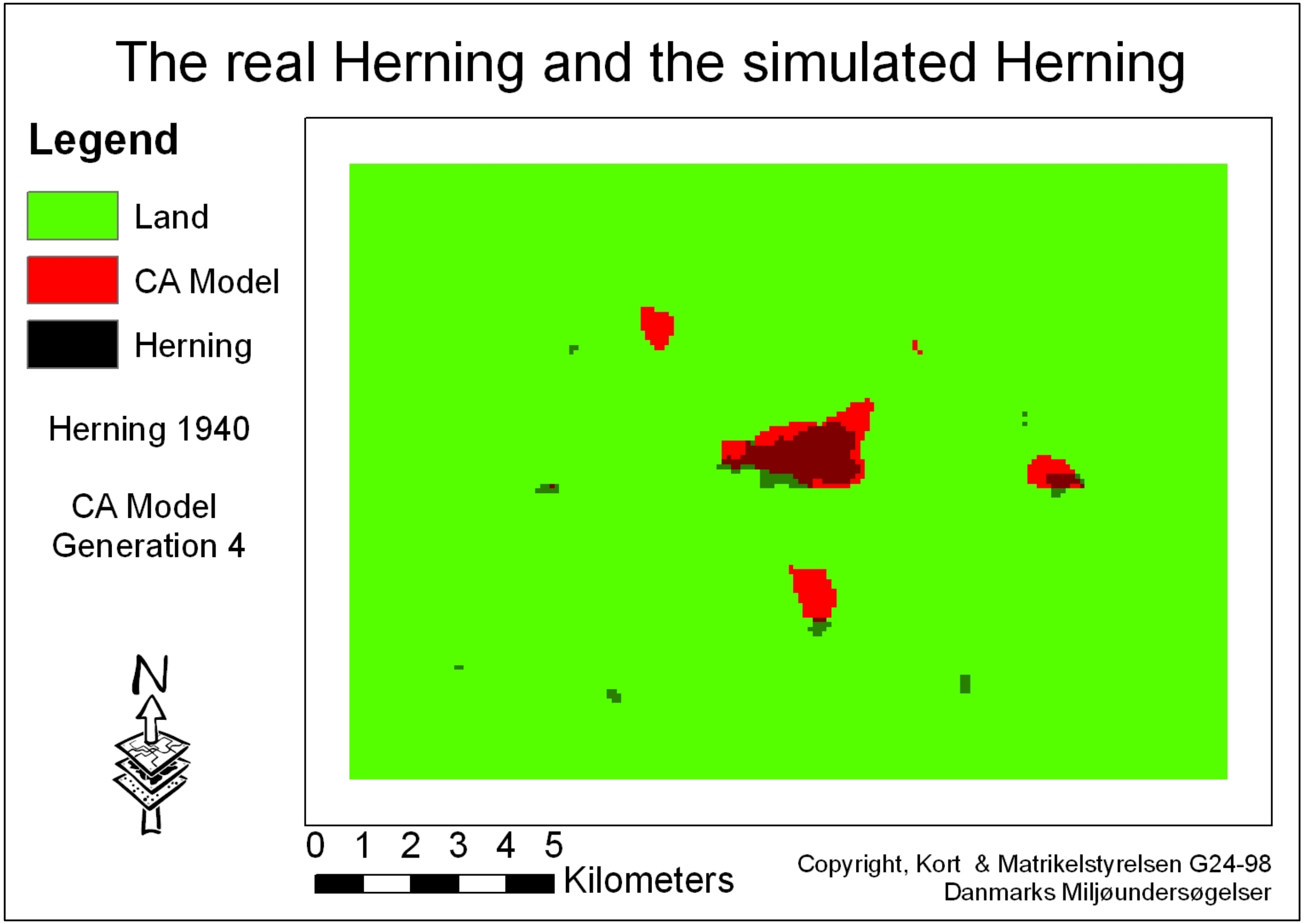

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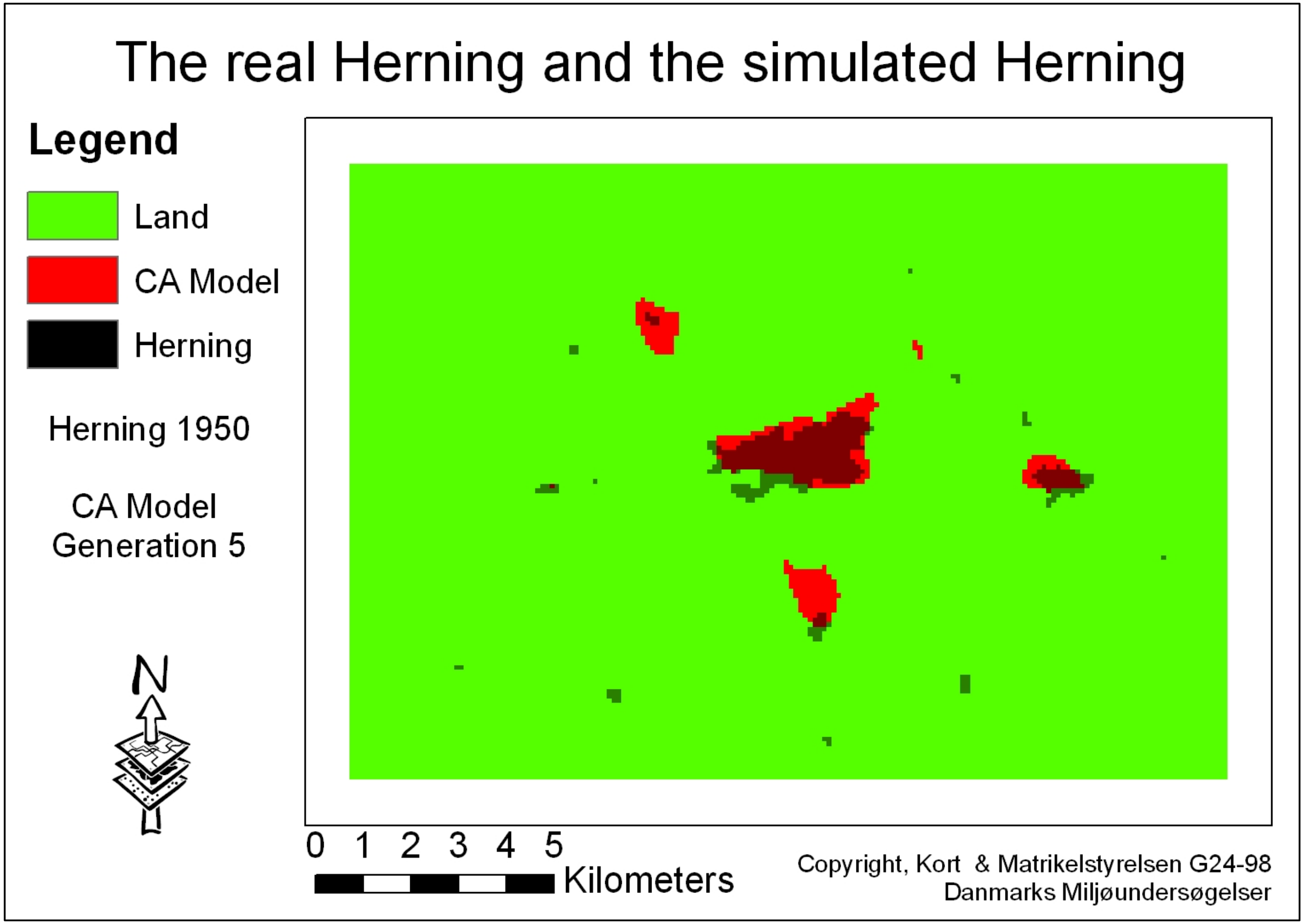

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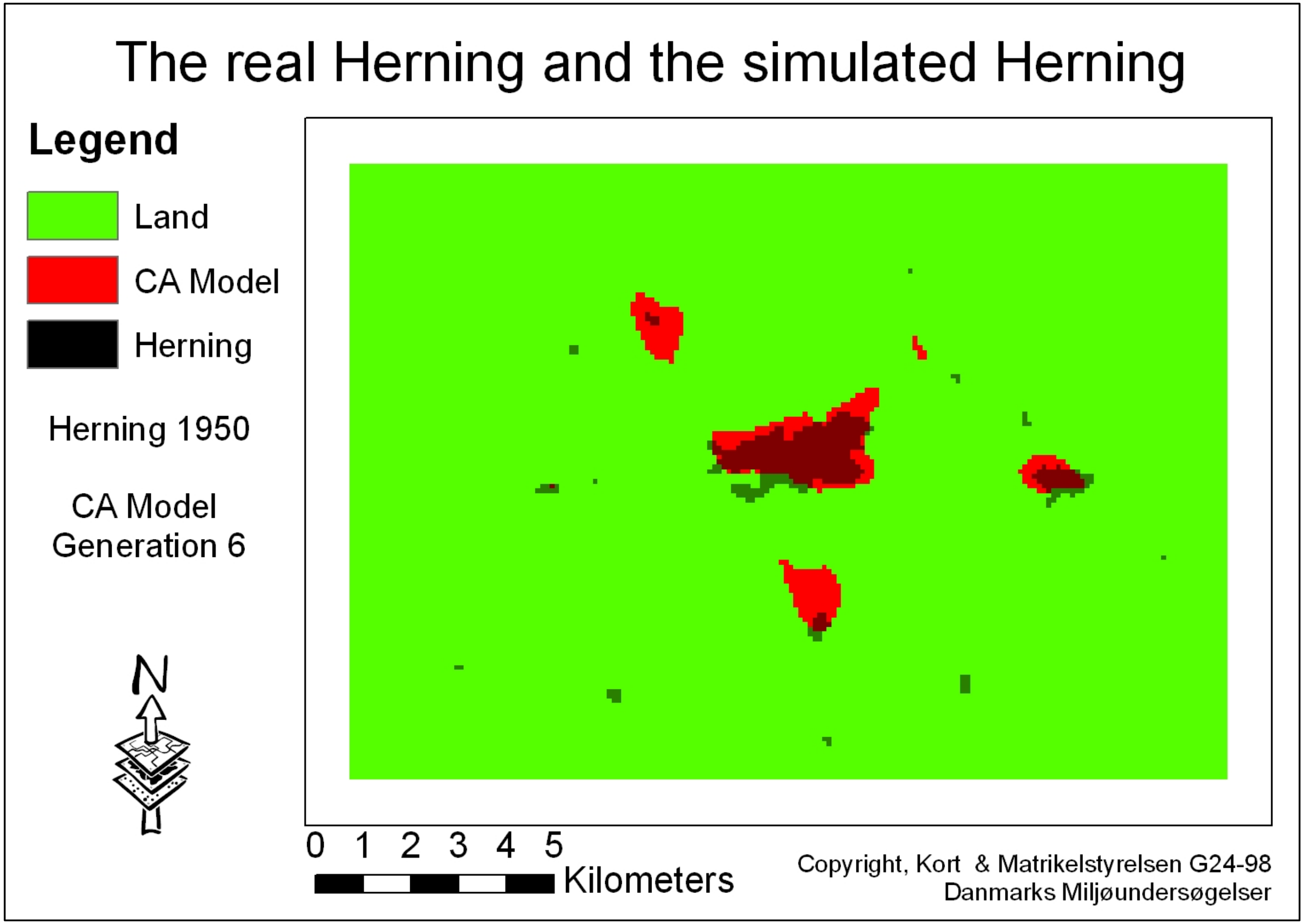

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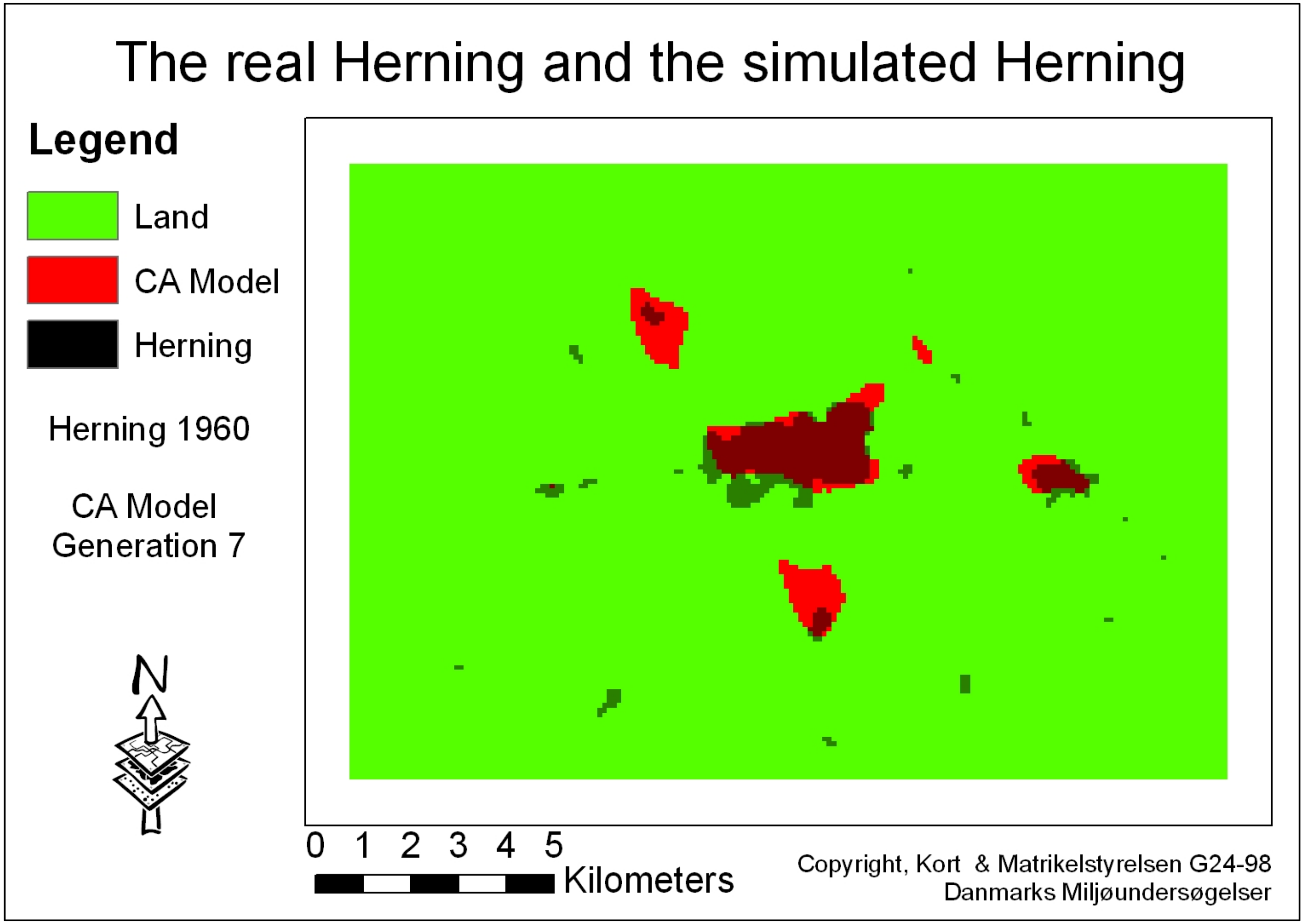

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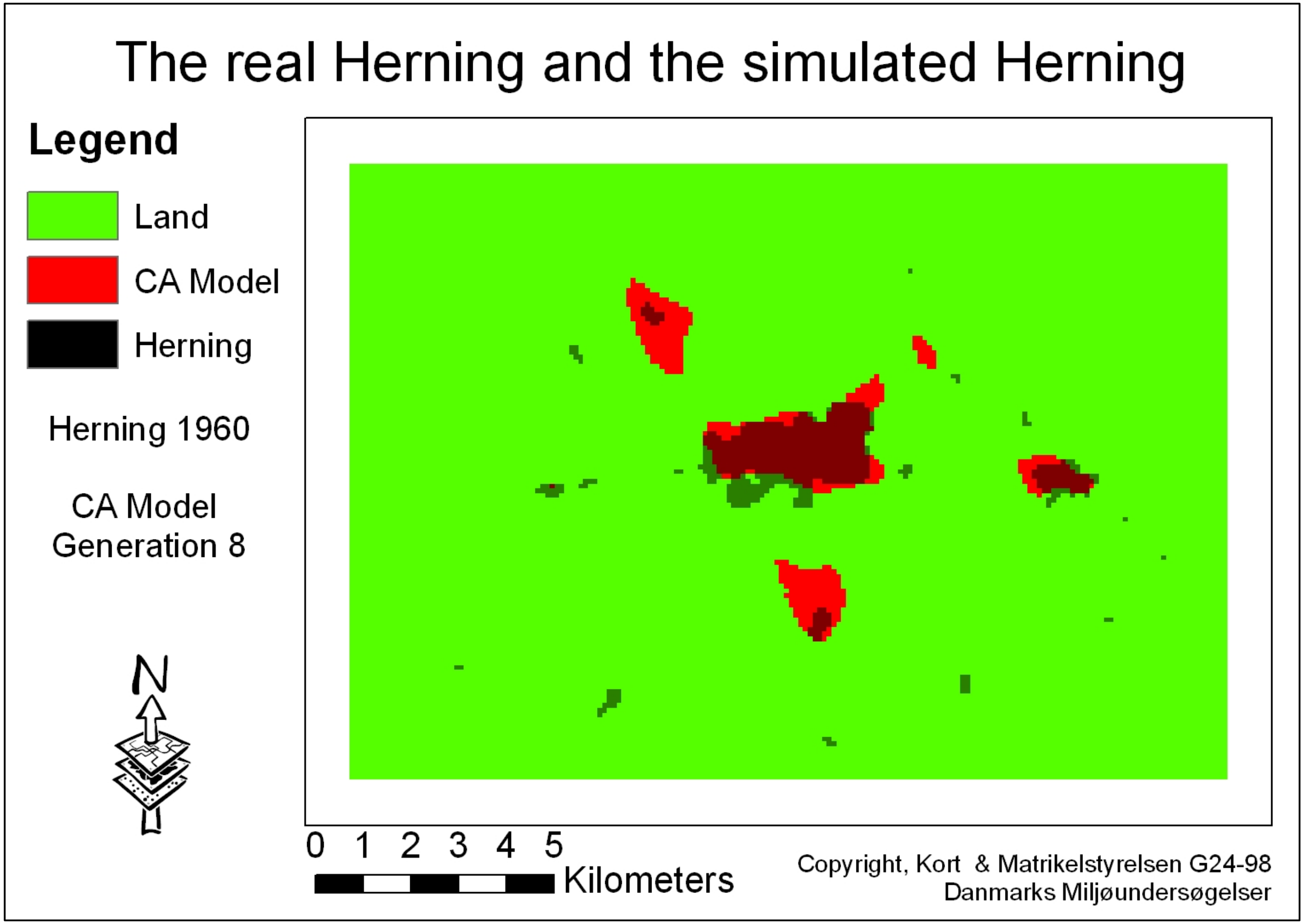

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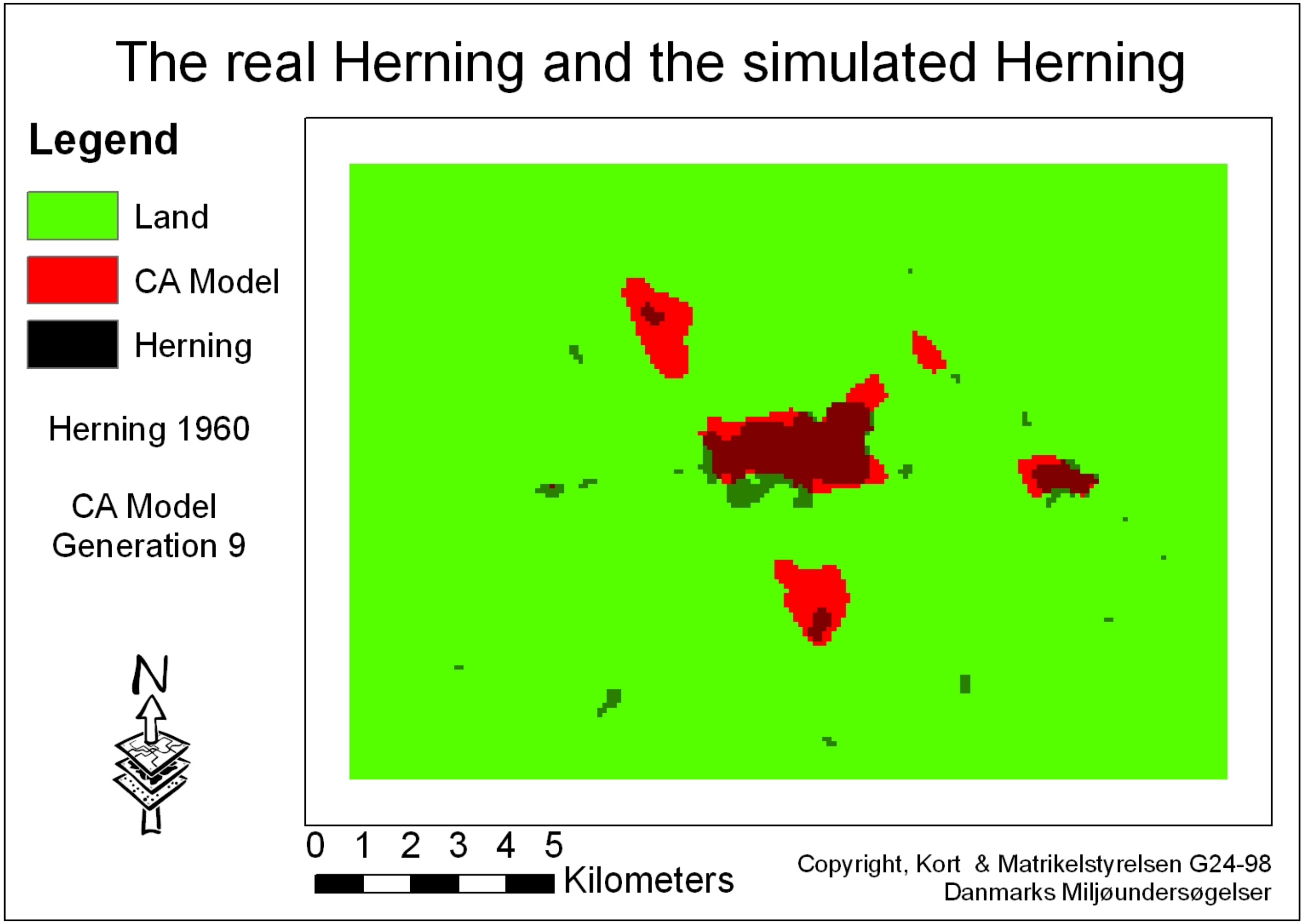

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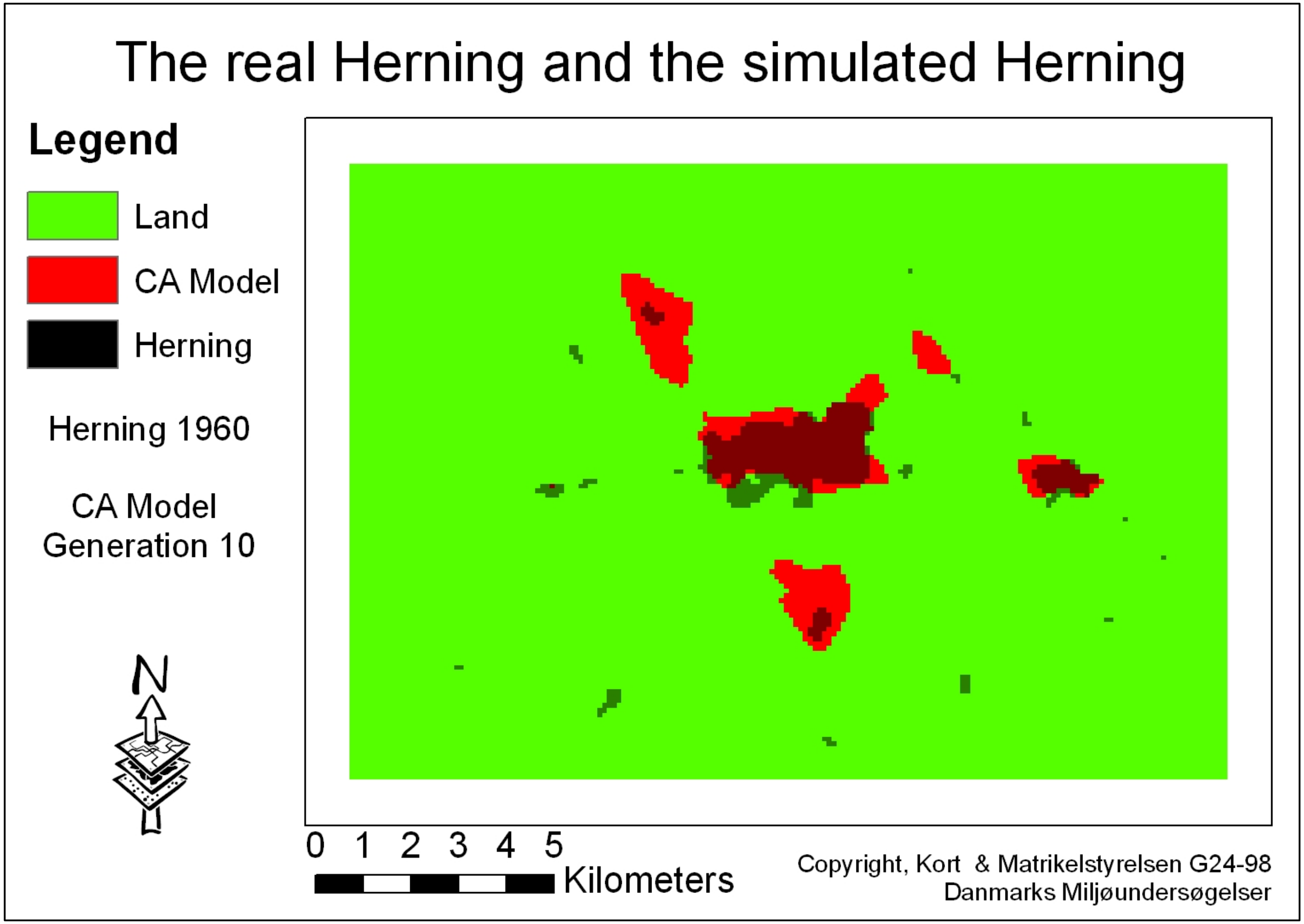

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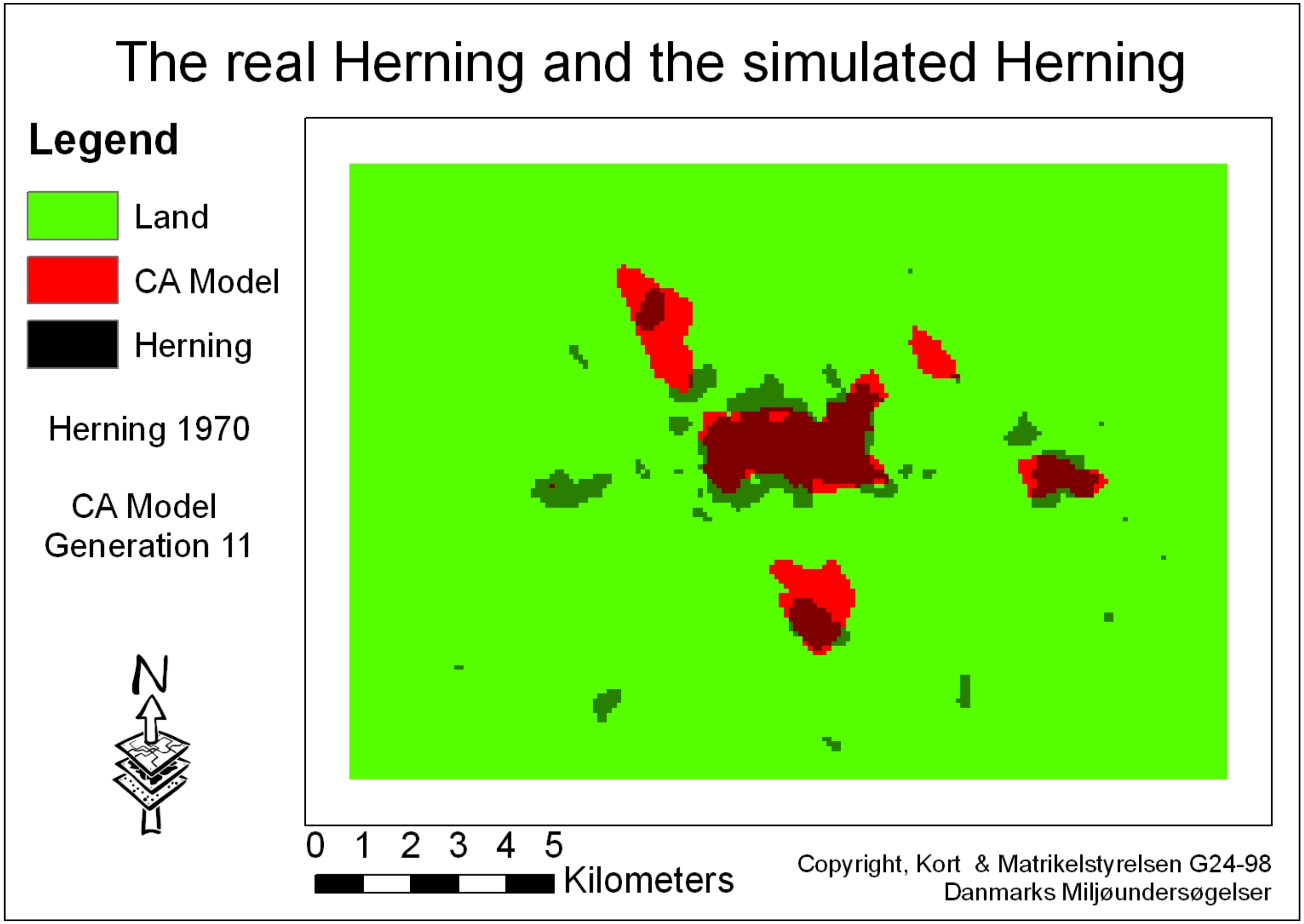

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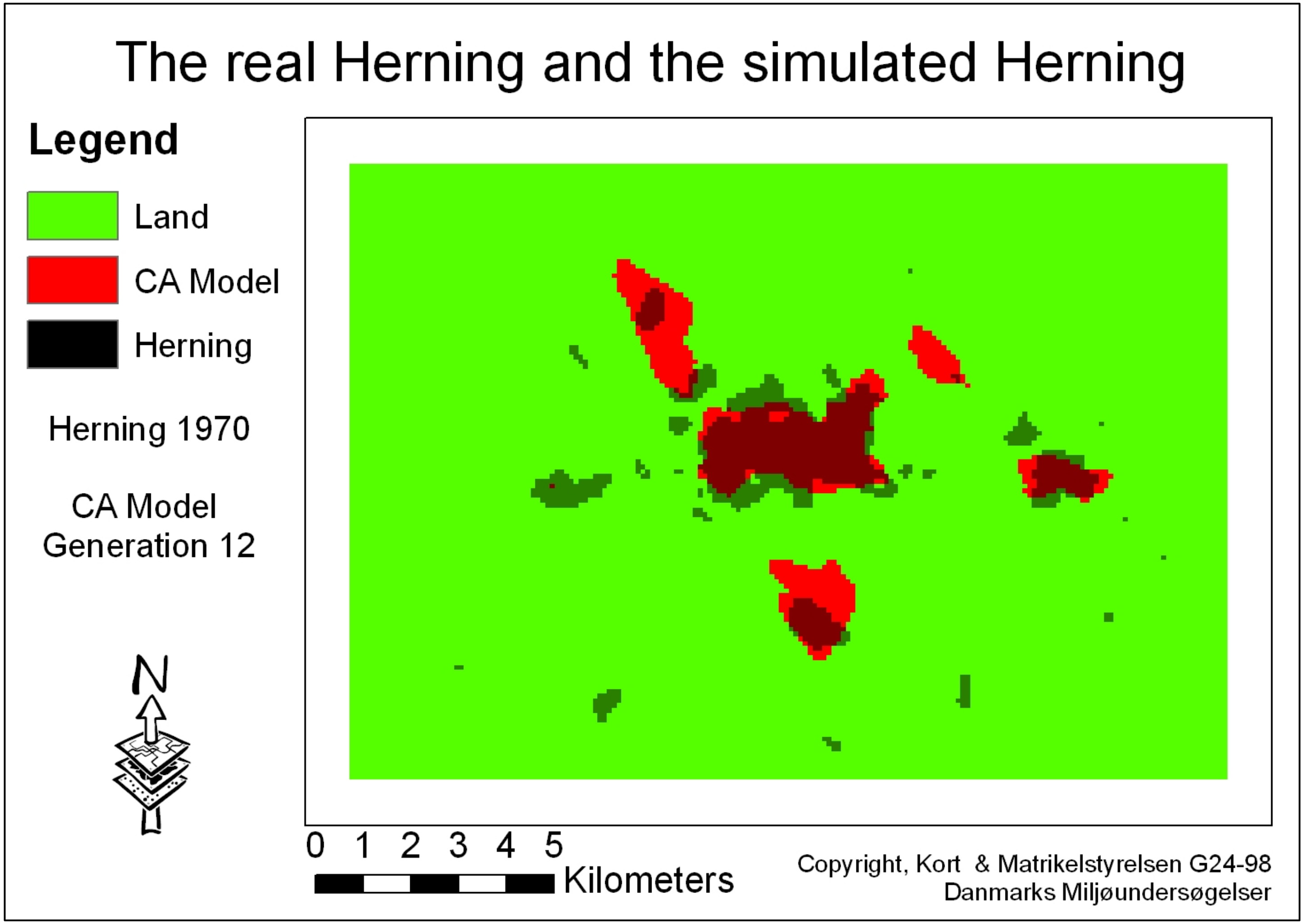

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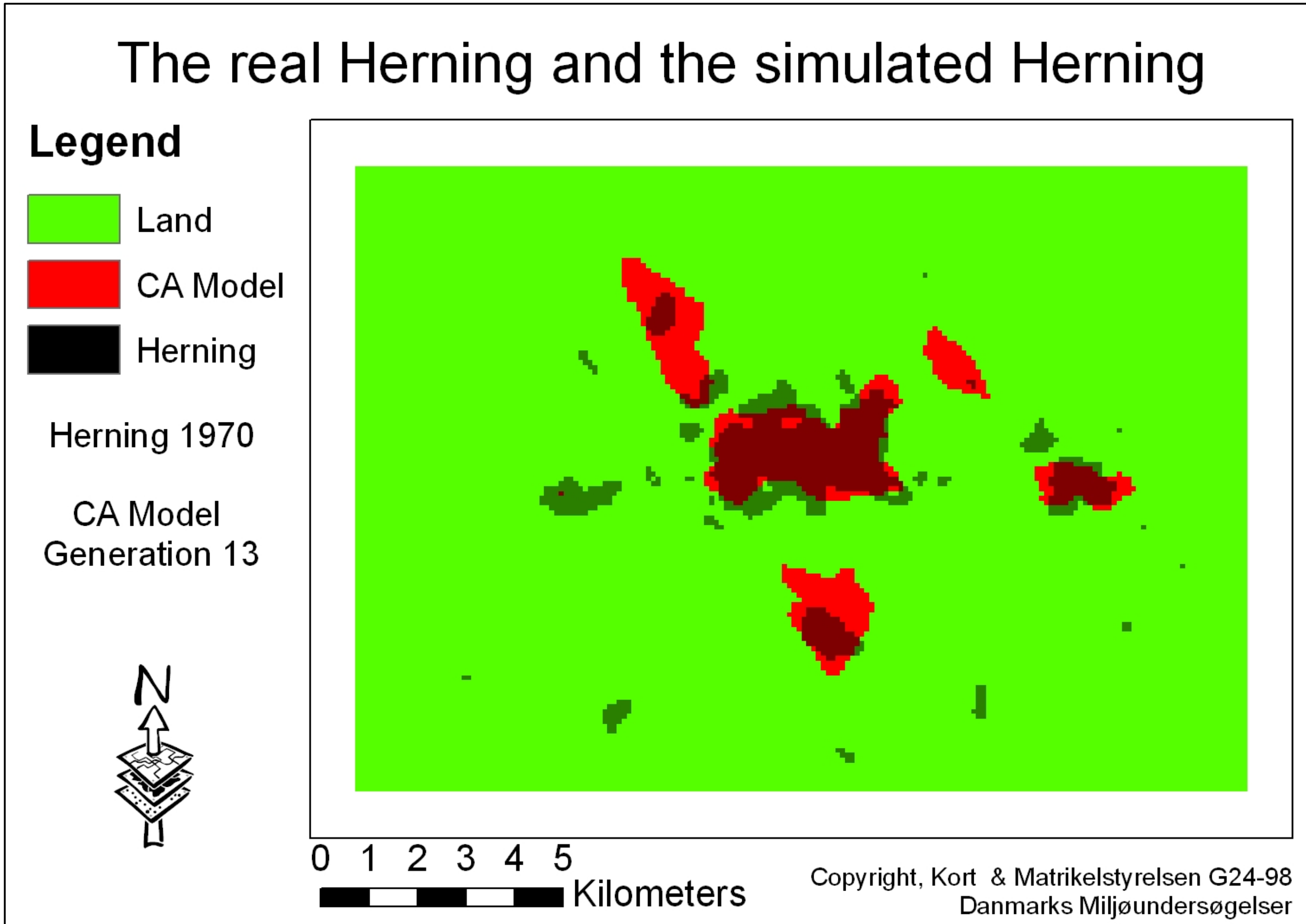

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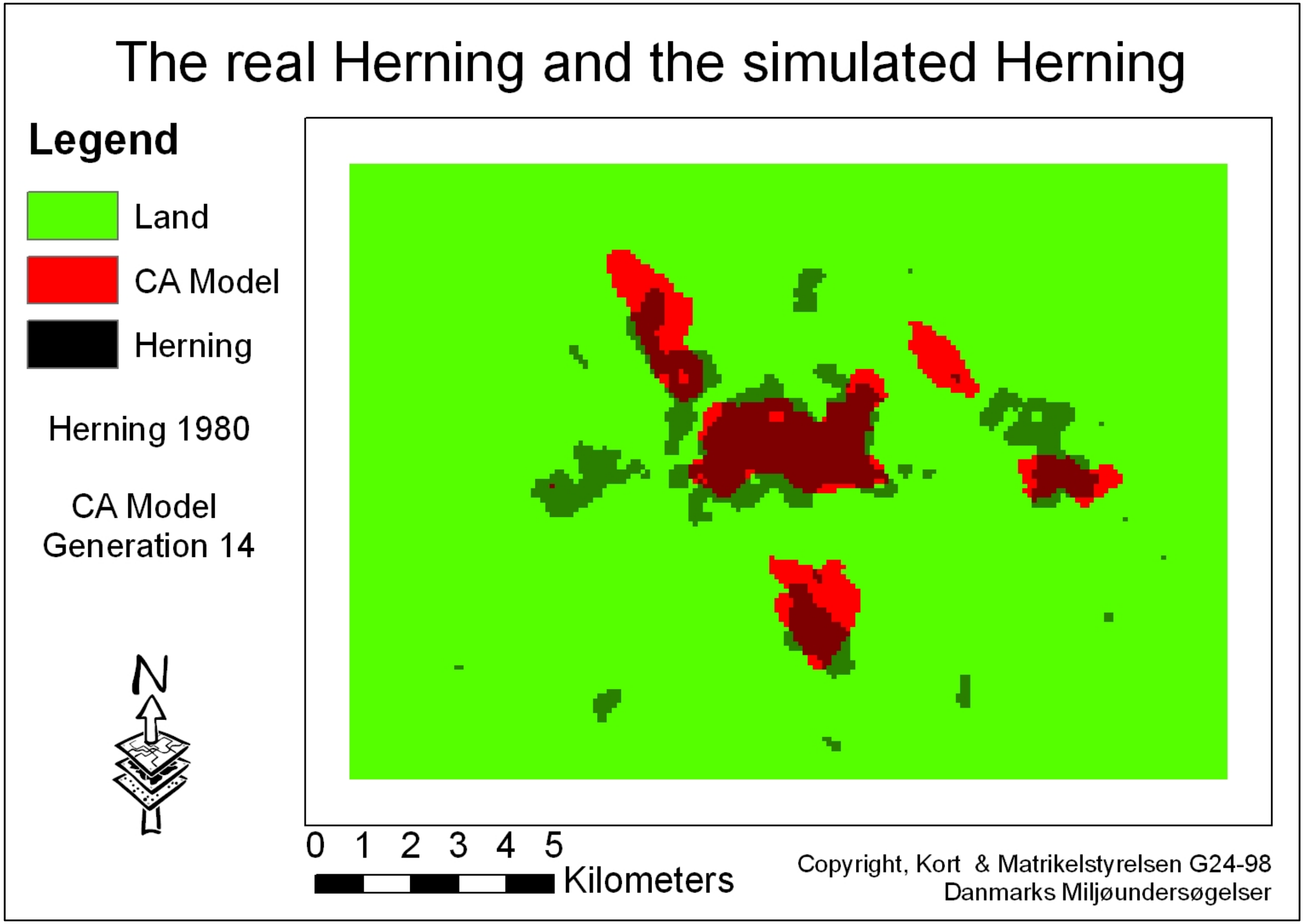

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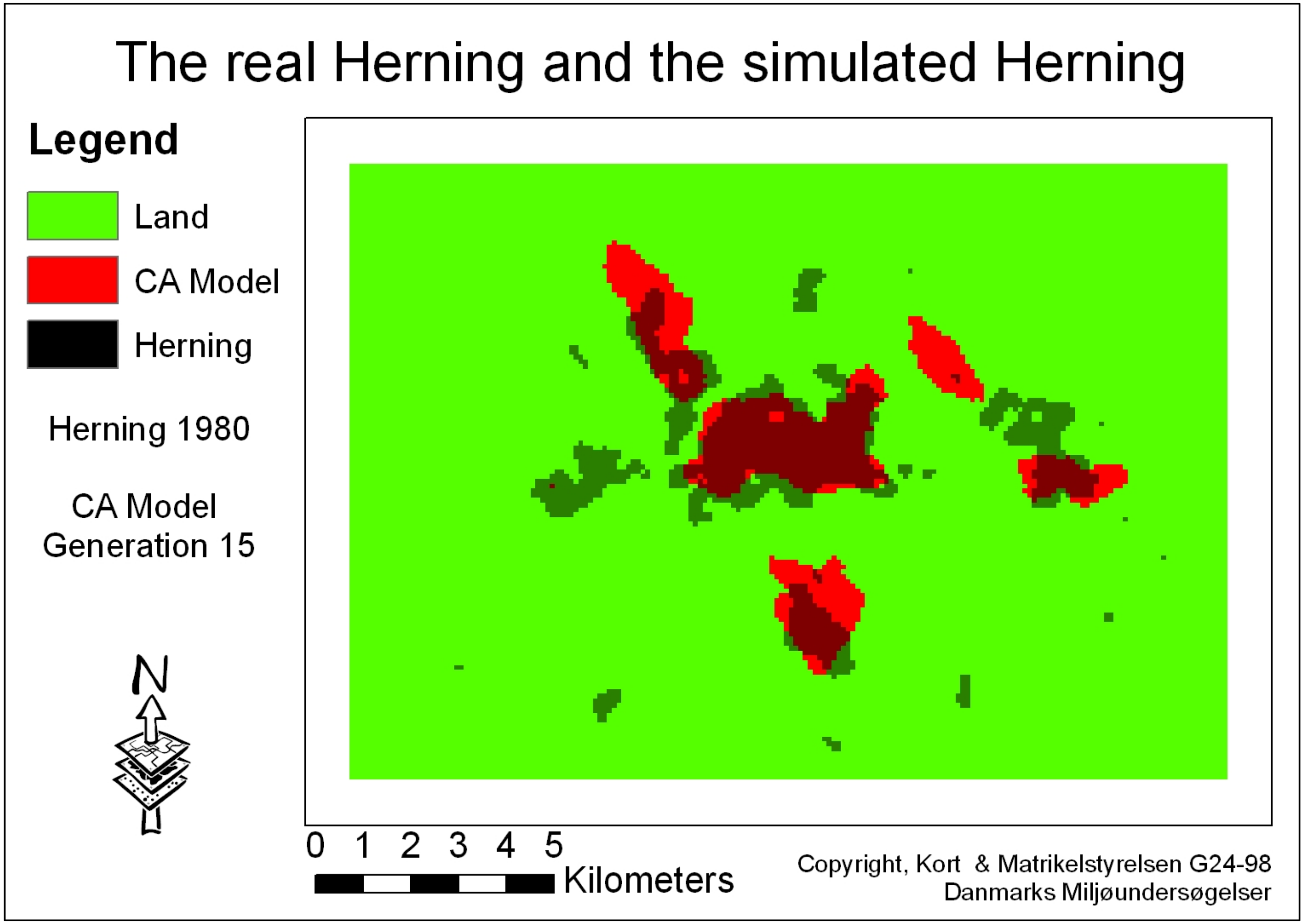

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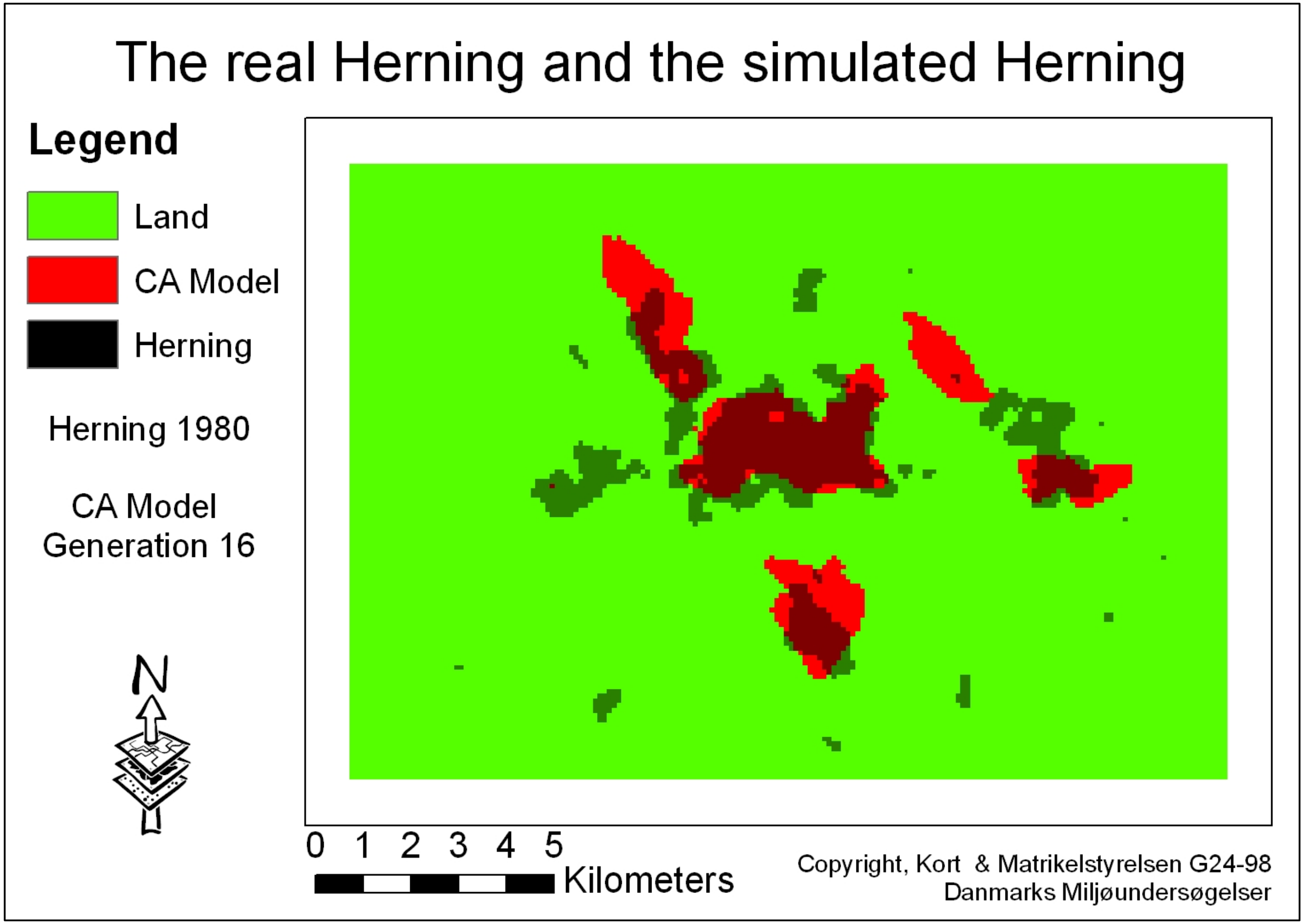

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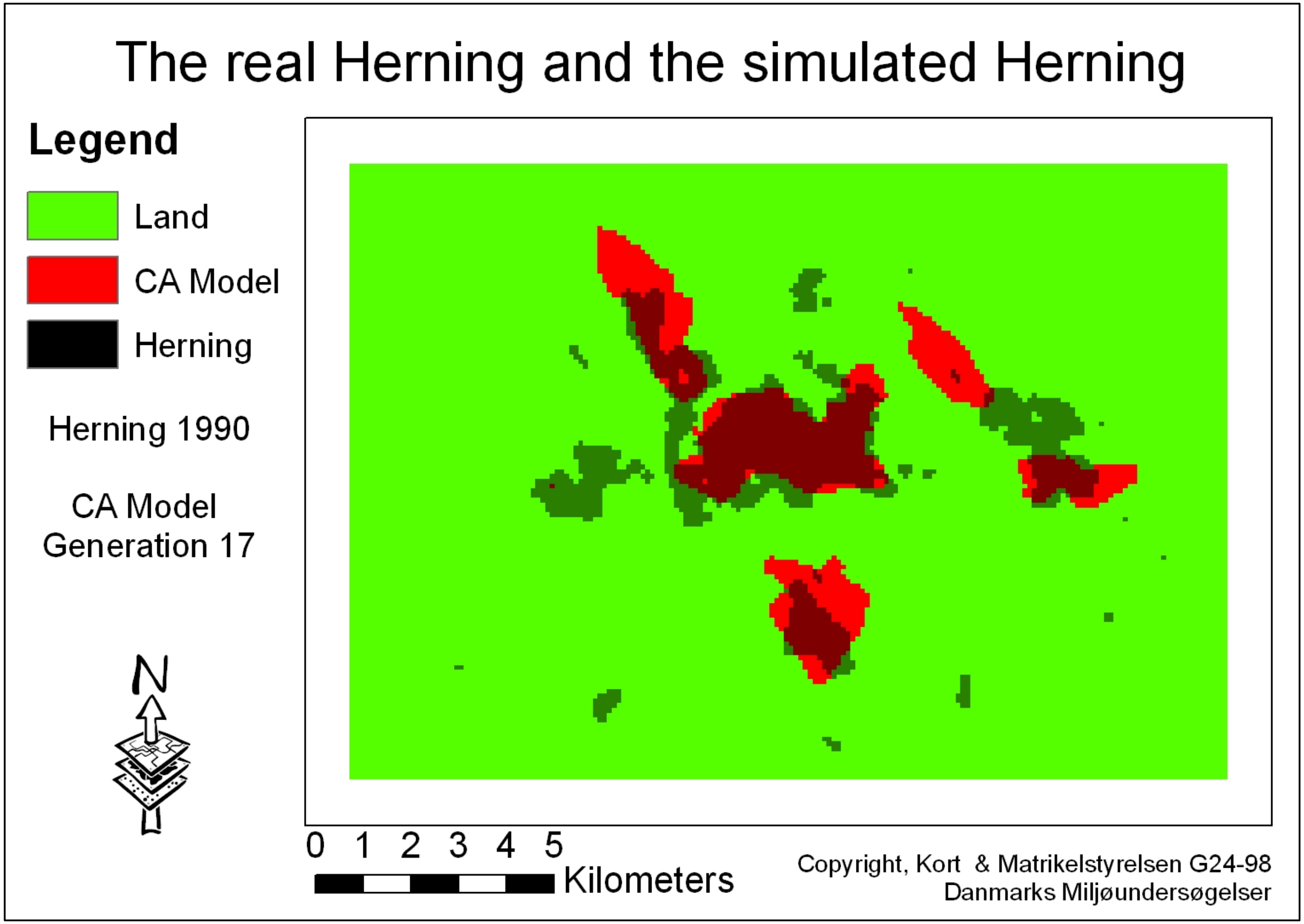

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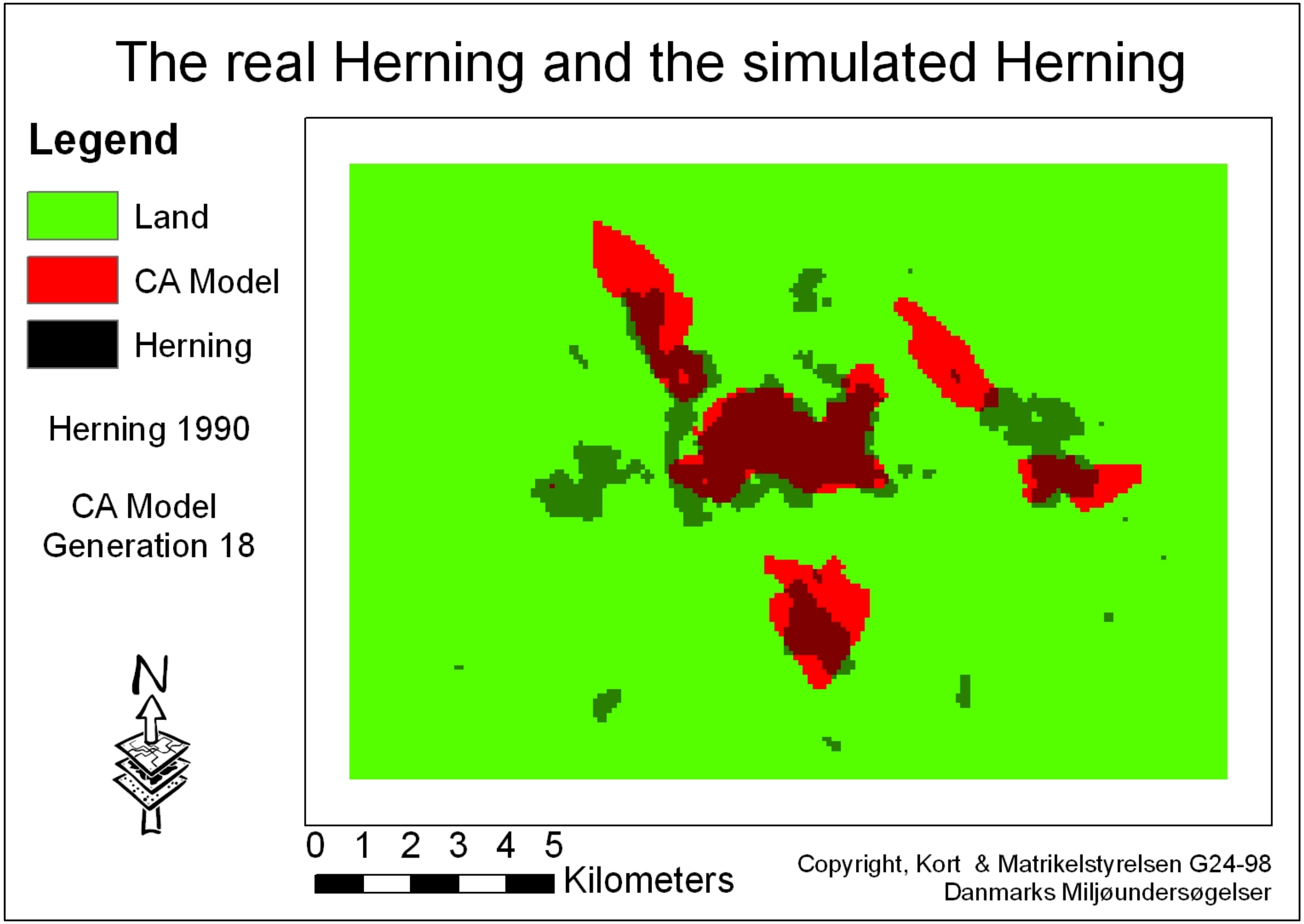

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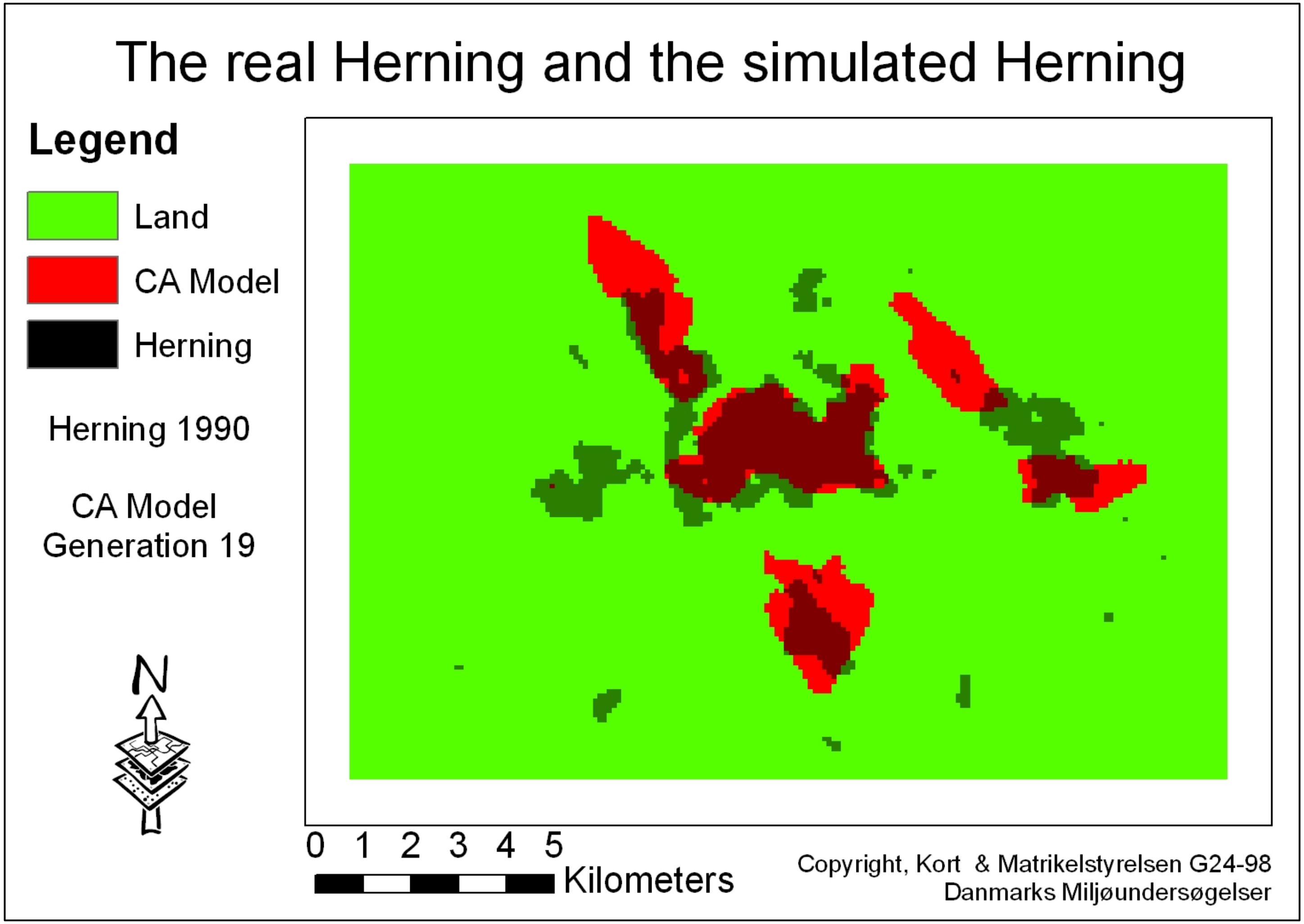

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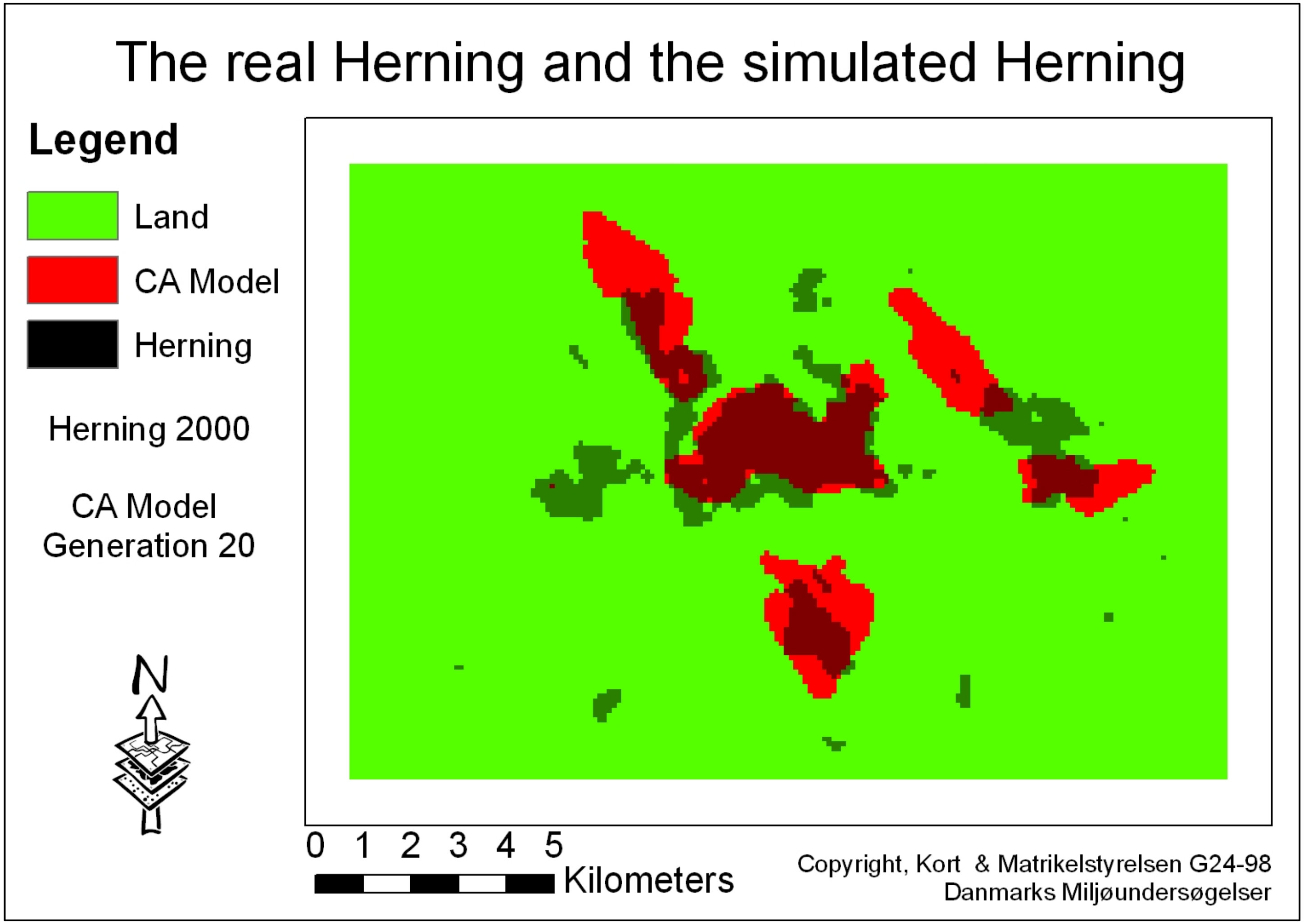

Conclusion

- The CA model were able to simulate the development of Herning in the period 1900-1960 relatively precisely.
  - Industrial city?
- After 1960 there is a larger difference between the model and the real city
  - Post-industrial city?
  - Public Planning since the 1970's, Gullestrup in the case area is one of few totally planned cities in Denmark.
- The three simple dynamics were able to model the development of the city surprisingly well!
  - Buildings are build near existing buildings.
  - Buildings are build near infrastructure.
  - Some barriers have slowed development in some areas.
- CA based urban models can simulate relatively small cities!
- It is worth while to examine wheter it is possible to incorporate planning and new urban dynamics into CA based urban models!

Further Work

- Development of better models
  - Models which simulates more dynamics
  - Models which builds on better data
- Theory of science
  - What is the scientific foundation of simulating future phenomena's in a societal context?
  - Is it possible scientifically to predict phenomenons in a social context?
- Comment are welcome!
  - reinau@plan.aau.dk
  - Download project in Danish 140 pages from www.plan.aau.dk/~reinau

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