Modeling spatial population scenarios

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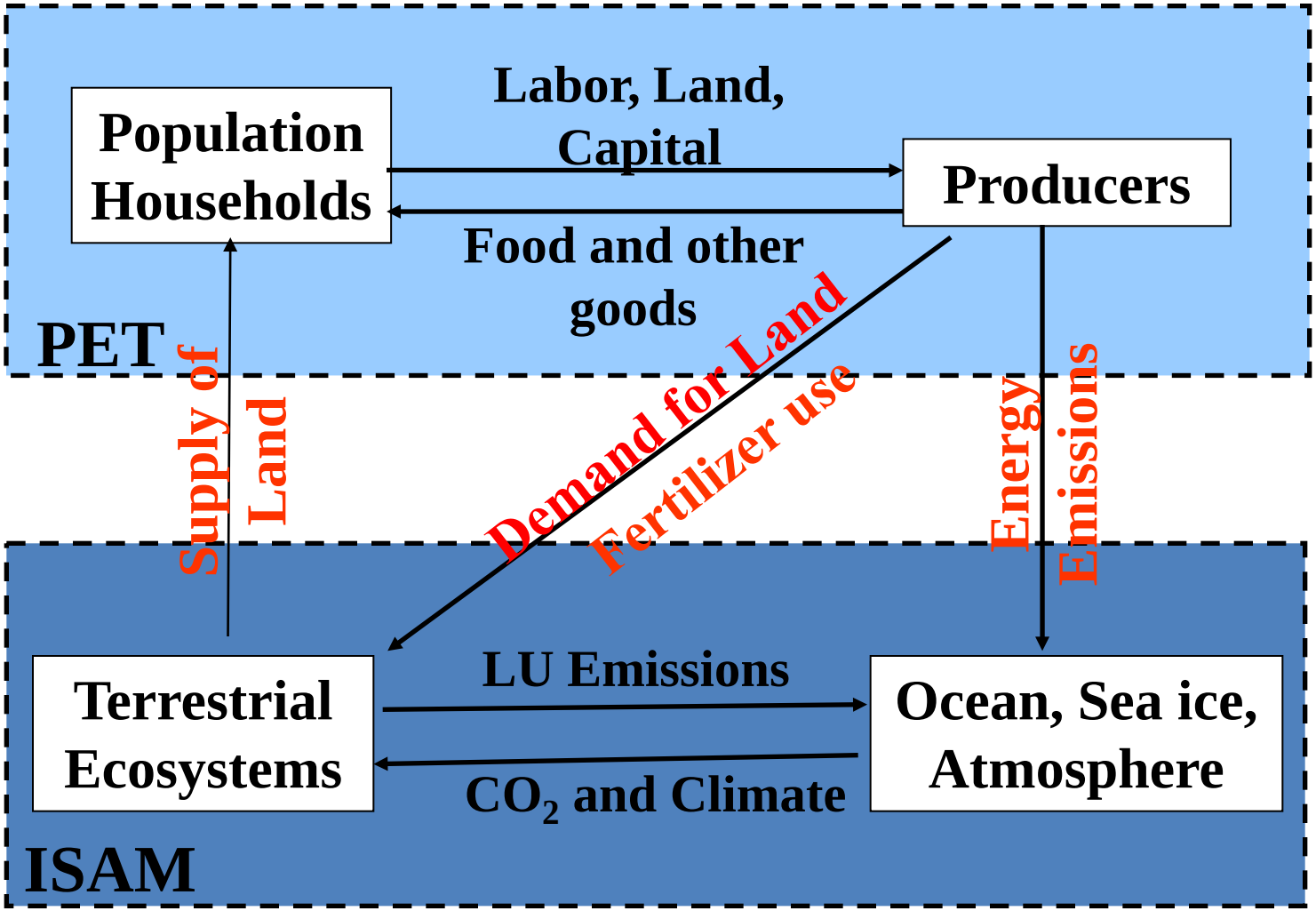
Introduction and Outline

- The iPETS integrated assessment model
  - Land use and spatial population
- Toward a spatial scenario generator
  - Understand a leading methodology (IIASA)
    - Apply to hypothetical, 1-D population distribution
  - Test against historical observations
  - Explore modifications
  - Goals for 2010

iPETS: Global, regionally disaggregated IA Model

(Integrated Population-Economy-Technology-Science Model)



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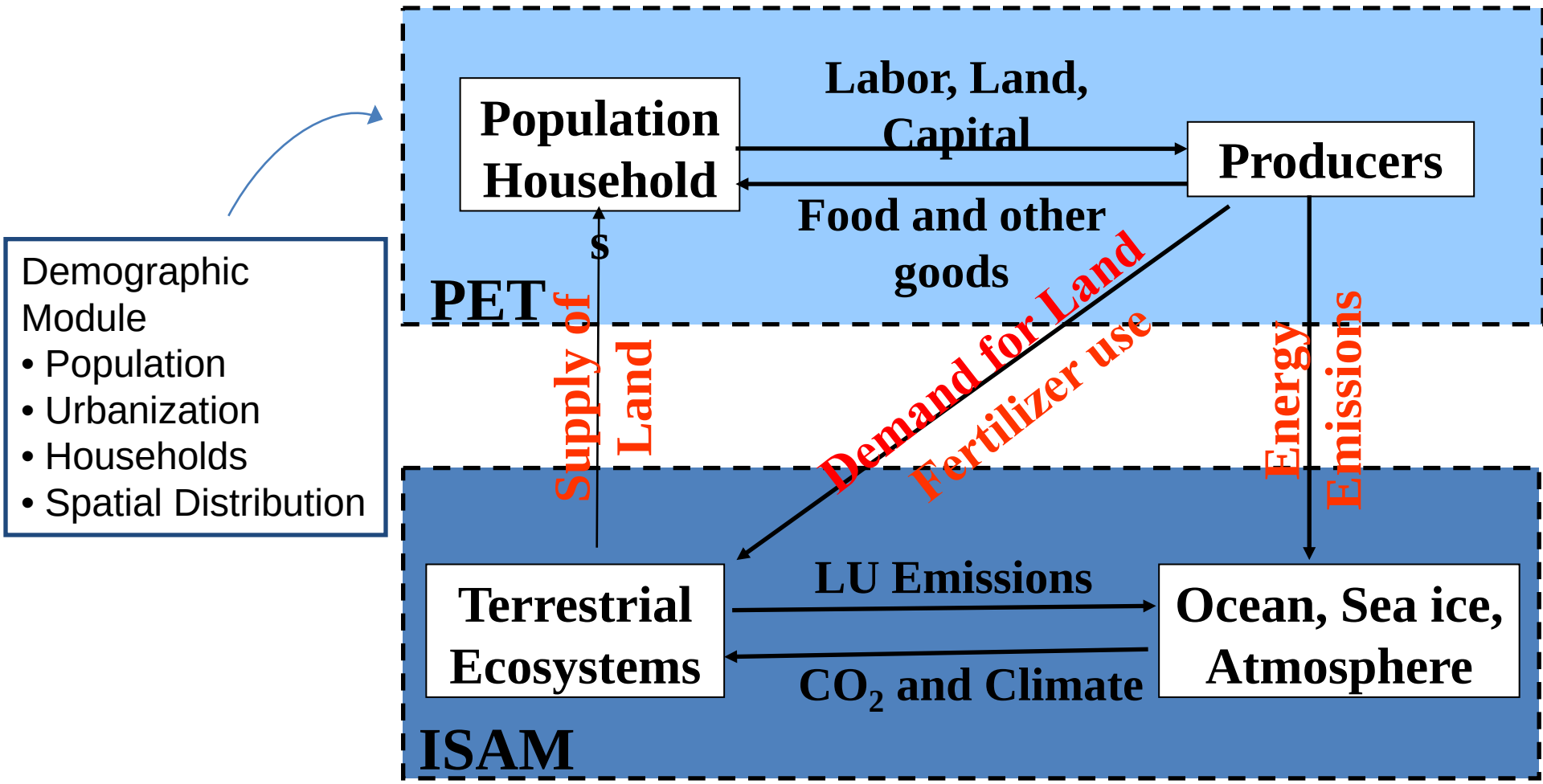


IIASA Methodology

1. Cells are classified as rural or urban.
2. Population change regime (*r*) is defined for rural and urban areas.
3. Potential is calculated for each cell according to:

$$v_i = \sum_{j=1}^{m} \frac{P_{j,u}}{D_{ij}^2} + \sum_{k=1}^{n} \frac{P_{k,r}}{D_{ik}^2}$$

4. For each time step, additional population is allocated proportional to cell potential such that:

$$P_i^{t+1} = P_i^t + (P_A^{t+1} - P_A^t) \frac{v_i^t}{\sum_{j=1}^{J_A} v_j^t}$$

- Calculation of potential for cell i does not include the population of cell i.
- Rural/urban population gain/loss is allocated separately.
- Cell potential used as a measure of attractiveness: geographic proximity to population is a proxy for all socio-economic characteristics that determine “attractiveness”.

Application to Hypothetical Population Distribution

Tested the model on a hypothetical 1-dimensional population distribution to explore general trends in population allocation and the implications of changes in certain parameters.

Findings

- When population growth is positive, the model tends to move towards a uniform spatial allocation.
- When population growth is negative, the model tends to move towards a concentrated spatial allocation.
- Population growth generally occurs in areas that are currently defined as urban, or are immediately adjacent to existing urban areas.
- The classification of a cell as urban/rural has a dramatic affect on the projected population in that cell, largely a result of exogenous urban/rural growth projections.

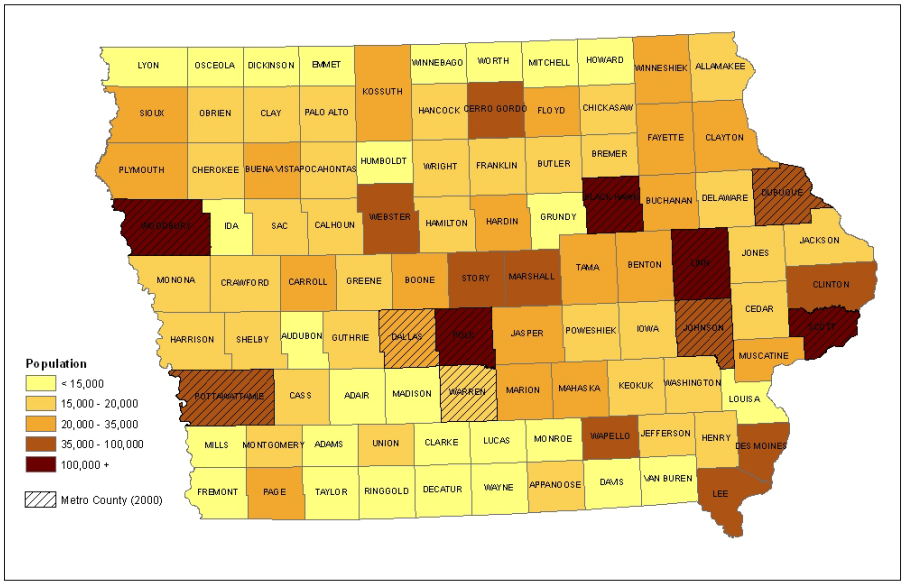
Test Against Historical Data

Using the state of Iowa as the study region, the IIASA methodology is applied in an attempt to replicate historical data.

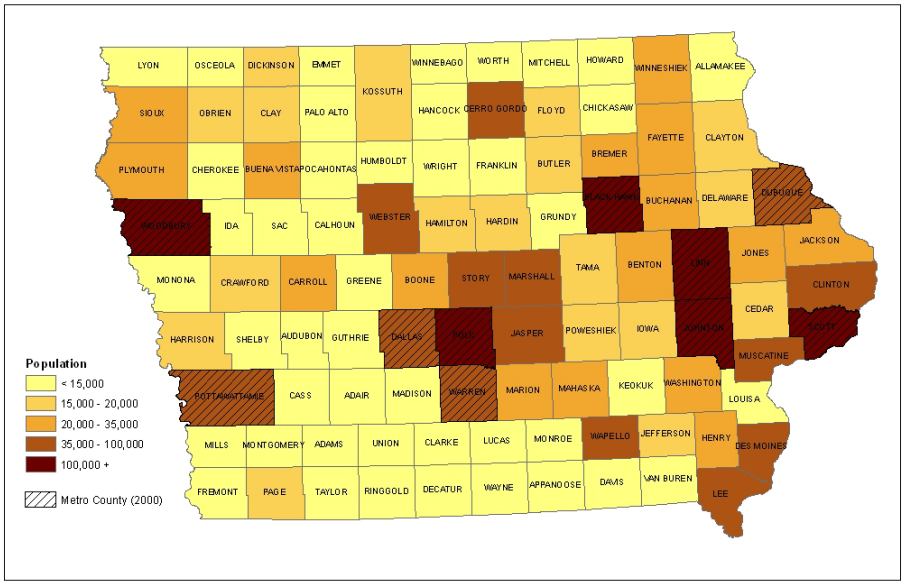
- Areal units are counties (in place of grid cells).
- Time period: 1950-2000
  - Observed county population in 1950 serves as the initial distribution.
- Observed decennial census data (1950-2000) are used to determine *r*.
  - Total urban/rural population change are therefore fixed at the observed levels.
- An attempt to replicate 2000 county-level population structure moving forward from 1950.
- The model was run seven times using various methods to re-classify counties as urban or rural over time.

The results in this presentation consider the population density threshold of 100 persons/mi² to classify/reclassify a county as urban or rural.

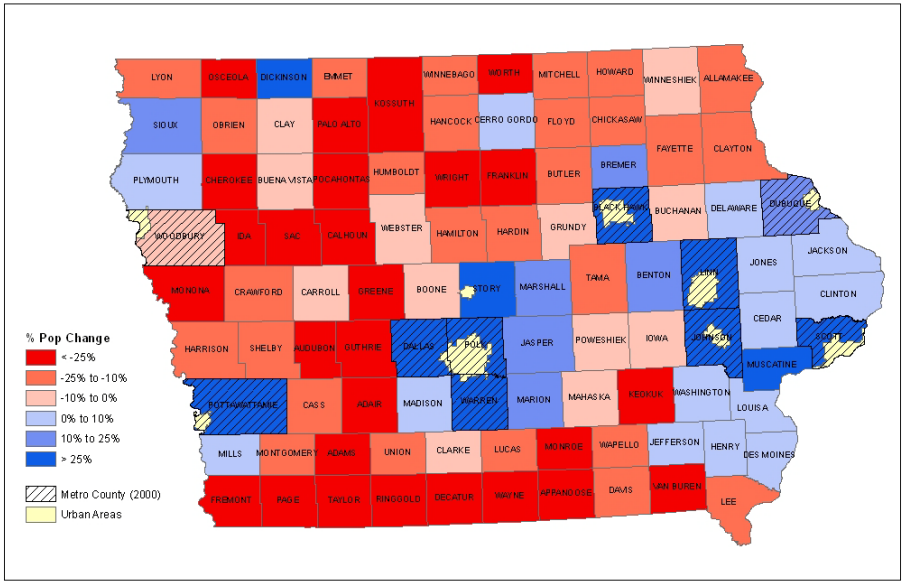
Observed Population: 1950



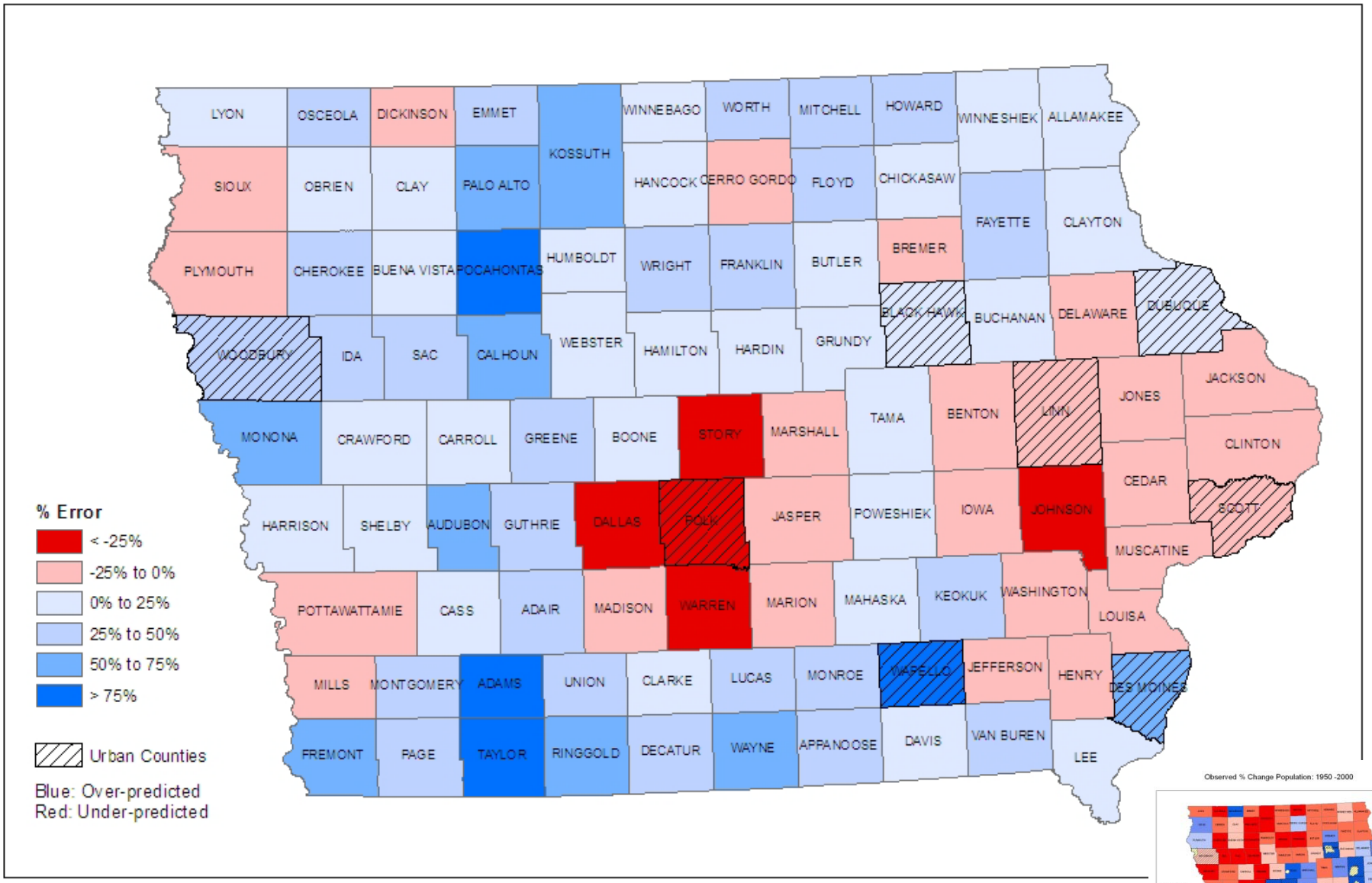
Observed Population: 2000



Observed % Change Population: 1950 -2000



Results: Prediction Error



Historical Test: Findings and Implications

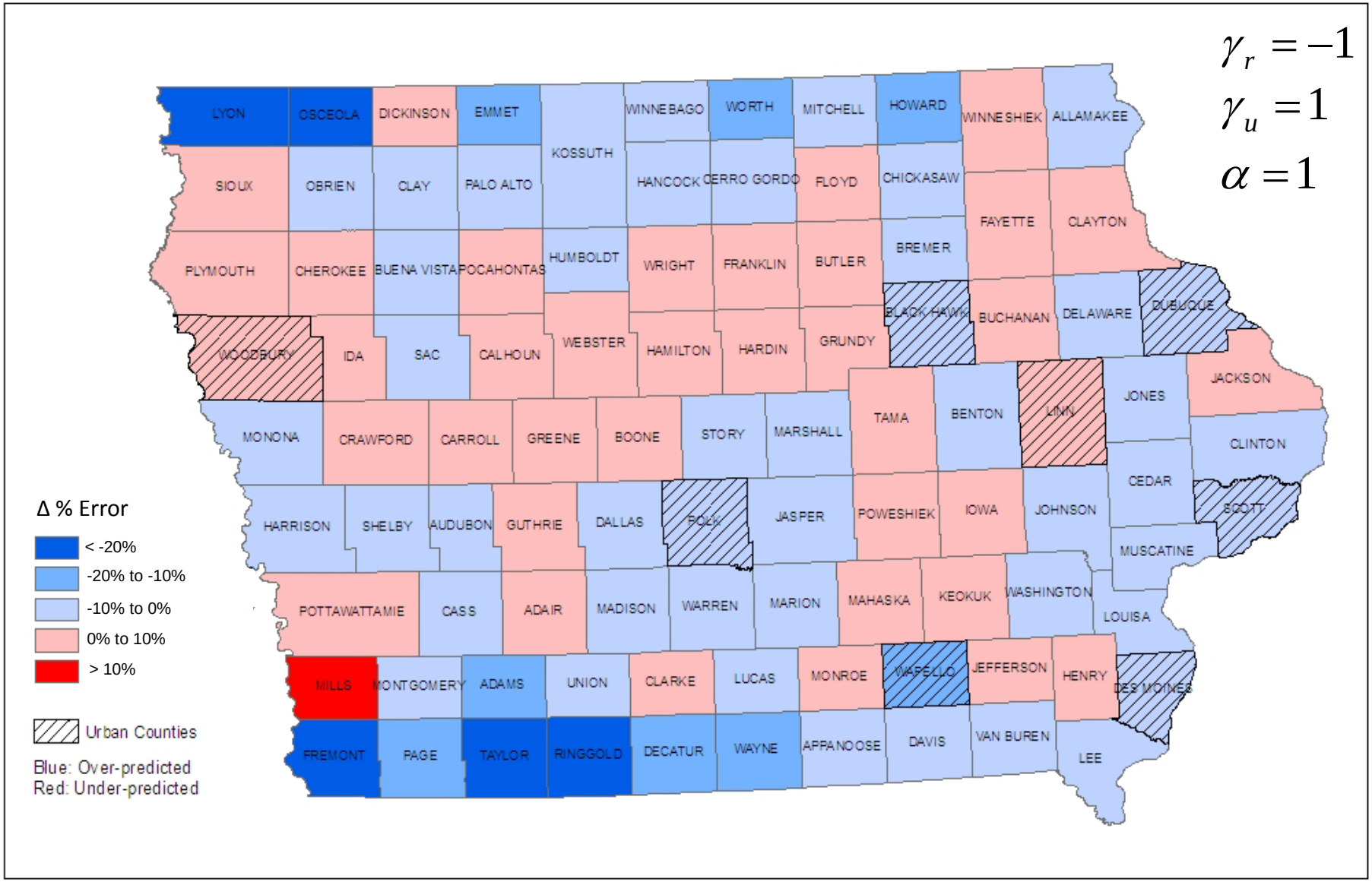
- Population change is allocated too uniformly within the urban and rural regions.
  - Population growth is under-estimated in some urban corridors.
  - Population loss is under-estimated in the most remote rural counties.
- Difficult for rural cells to reach the density threshold necessary to be reclassified.
  - Due to low rate of rural growth.
  - The model is likely to miss potential suburban growth that occurs in rural areas adjacent to urban centers.
- The model does not allow for population growth/decline to occur simultaneously across cells in the same category.
  - The model cannot account for population redistribution within rural areas, a common rural phenomena in which people congregate in larger regional centers.
- Cells located nearer to the regional borders are subject to lower potentials, relative to cells located in the center of the region.
  - Potential border or “coastal” effect in which growth occurring near regional borders (or on the coast) is under-predicted.

Cell Potential Parameters

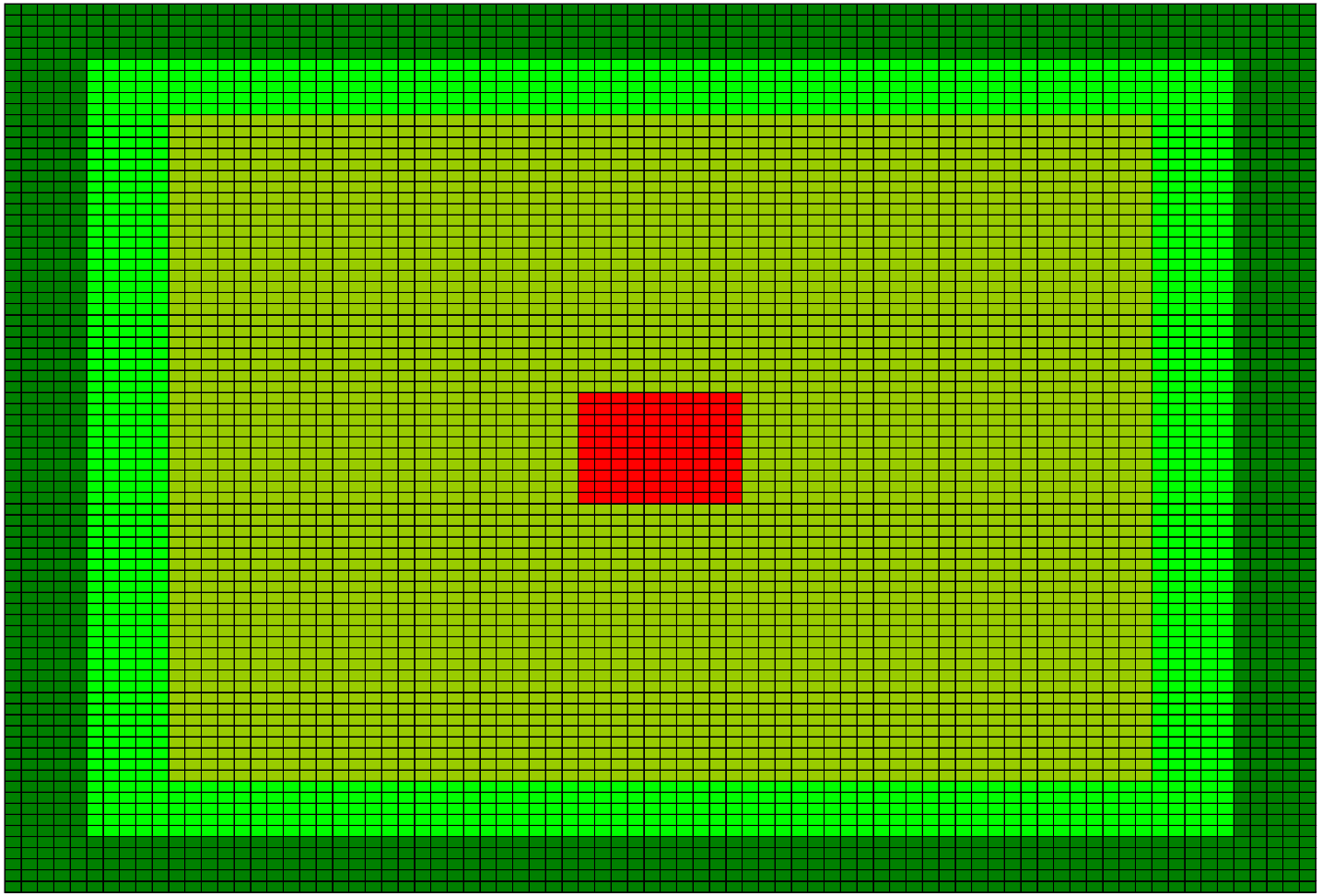
$$v_i = \left(\sum_{j=1}^{m} \frac{P_i^{\alpha} P_{j,u}^{\lambda}}{D_{ij}^{\beta}} + \sum_{k=1}^{n} \frac{P_i^{\alpha} P_{k,r}^{\lambda}}{D_{ik}^{\beta}} \right)^{\gamma}$$

Parameter	Description	IIASA Value	Test Range
α	Weight of cell *i*'s population, higher values lead to more concentrated change.	0	0-2
λ	Weight of cell *j*'s population, higher values lead to more dispersed growth.	1	0-2
β	Distance weight, higher values lead to more concentrated change.	2	1-3
γ	Either 1 (population gain), or -1 (population loss). Allocates gain or loss with theoretical appropriateness.	1	1,-1

Results: Change in Prediction Error



Hypothetical Study Area



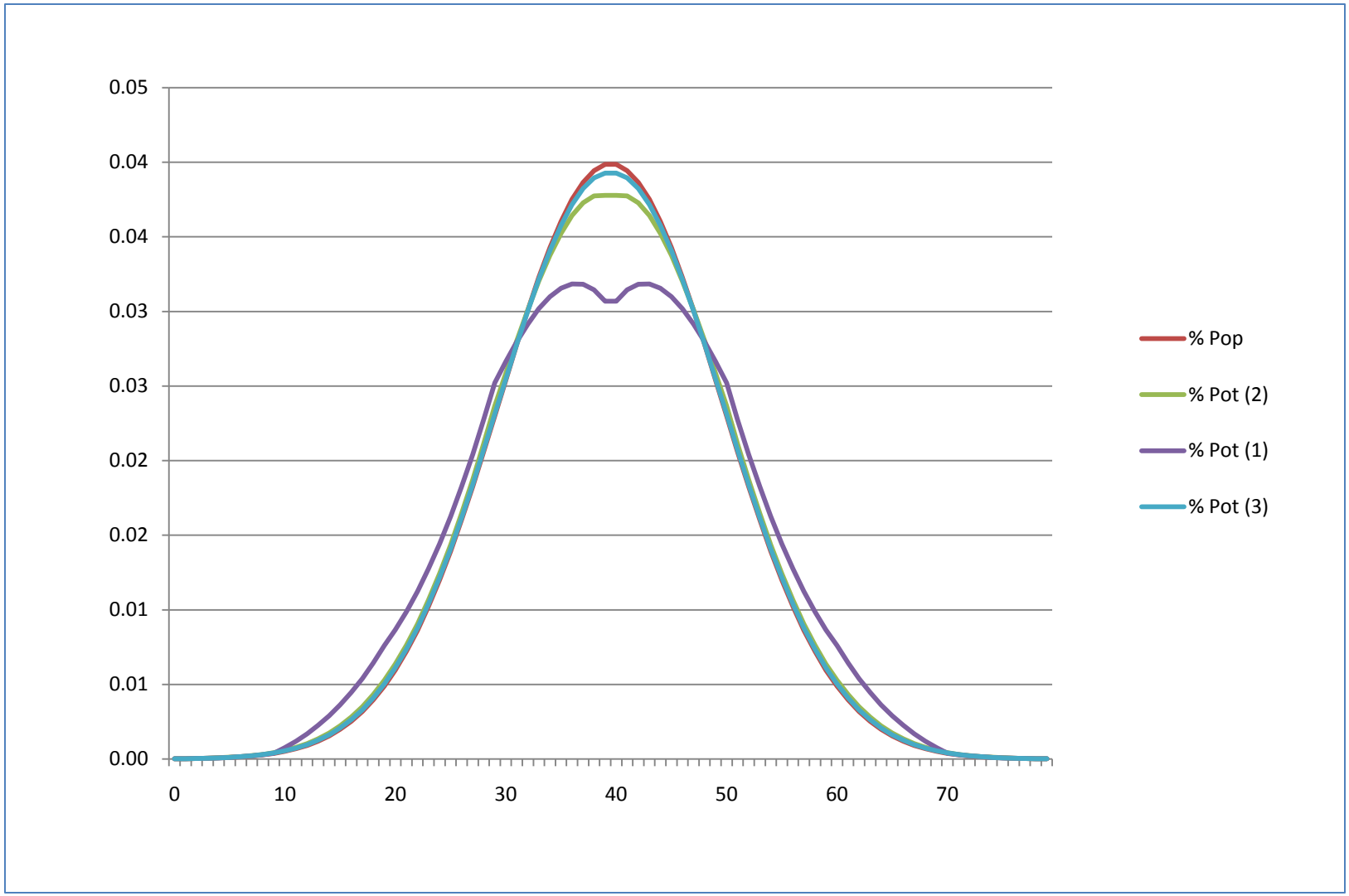
Rural with border effects

Rural, no border effects and no urban influence

Rural with urban influence

Urban

Distribution of Population and Potential when varying the *β* parameter.



Next Steps

- Parameterization of factors affecting potential calculation and allocation rule using hypothetical study area (allow tuning/calibrating model to data).
- Alternative methods for re-classifying cells as urban/rural.
- Allow aggregate growth rate (r) to vary within the urban/rural region as a function of density or distance.
- Add a third broad population category; “suburban”.

Future Plans

- Developing a model that can produce plausible alternative spatial population scenarios given assumptions concerning future aggregate demographic change.
- Explore the link between spatial population scenarios and urban land cover.

Modifying the IIASA Methodology

Two changes were applied to the IIASA methodology:

1. Including the population of each cell i in the calculation of its own potential.
2. Allocating population loss using the *inverse* of cell potential.

Potentially:

- Increasing the concentration of population growth by increasing the relative potential of already highly populated cells.
    - Improving ability to capture rapid urban growth.
- Increasing the concentration of rural growth in areas adjacent to urban areas.
- Increasing the concentration of population loss in those cells with the lowest potential (usually the most remote cells).
- Allowing for simultaneous growth/decline to take place within rural regions by concentrating growth in cells with the highest potential, and decline in those with the lowest.
- Decreasing the impact of the border effect, particularly in areas of concentrated coastal development.

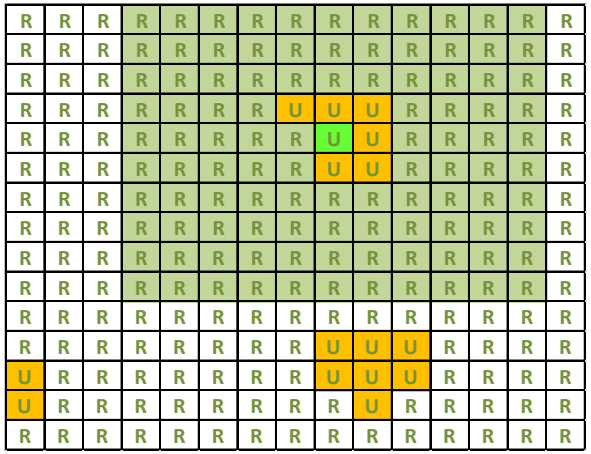
Methodological Changes: Findings and Implications

- The adjustments did produce improvements in the right direction, however not at the level necessary to eliminate the issues that have been identified.
- Urban population allocation is more concentrated.
- Rural population growth is more concentrated in areas adjacent to urban centers, while population loss is more concentrated in remote areas.
- The model projected both growth and decline within the rural region over the entire period.
- However, population growth in rural cells was still too small to allow any of them to reach the density threshold necessary for reclassification.
- The initial urban/rural classification (and rule for re-classification over time) appears to remain the largest factor affecting population change.

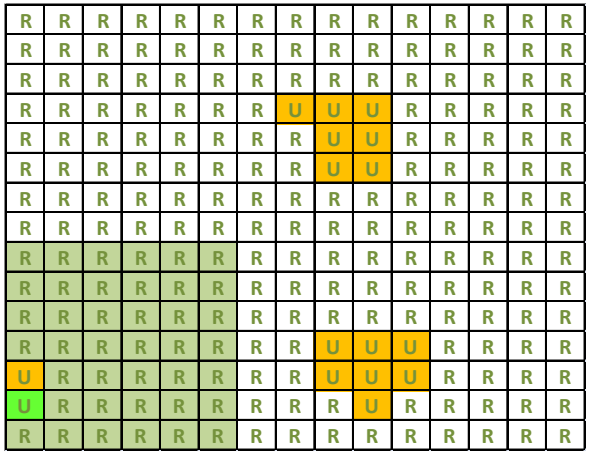
Cell Potential: Examples

A

B



B



R Rural Cell
U Urban Cell

Cell i
Rural cell k
Urban cell j
Not included

Spatial/Theoretical Implications

- The classification of a cell as rural/urban has a large impact on the calculation of potential for all cells within the urban window.
  - Inclusion in window
  - Size of population
- The classification of a cell as rural/urban has a no impact on the calculation of potential for cell i.
- Possible border/coastal effects.
  - The interior urban area (B) has a larger rural window than the border urban area (C).
- **Proximity** to population as an indicator of future growth/decline.
- Suggests that future urban development will take place almost exclusively in areas that are either currently urban, or are adjacent to existing urban areas.

Results: Assuming constant r = 5%

Cell	Pop(0)	Pop(50)	Δ Pop	% Δ Pop	Δ %Pop
A	13	10,287	10,274	79032%	0.88%
B	53	15,762	15,709	29640%	1.32%
C	187	22,018	21,831	11674%	1.73%
D	564	30,395	29,831	5289%	2.09%
E	1,455	41,839	40,384	2776%	2.19%
F	3,205	56,805	53,600	1672%	1.75%
G	6,027	74,711	68,684	1140%	0.49%
H	9,680	93,433	83,753	865%	-1.53%
I	13,273	109,410	96,137	724%	-3.73%
J	15,543	118,709	103,166	664%	-5.19%
K	15,543	118,709	103,166	664%	-5.19%
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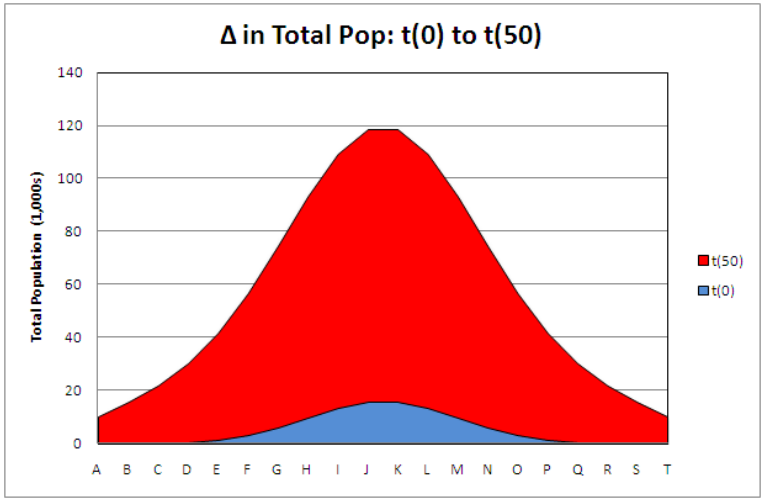
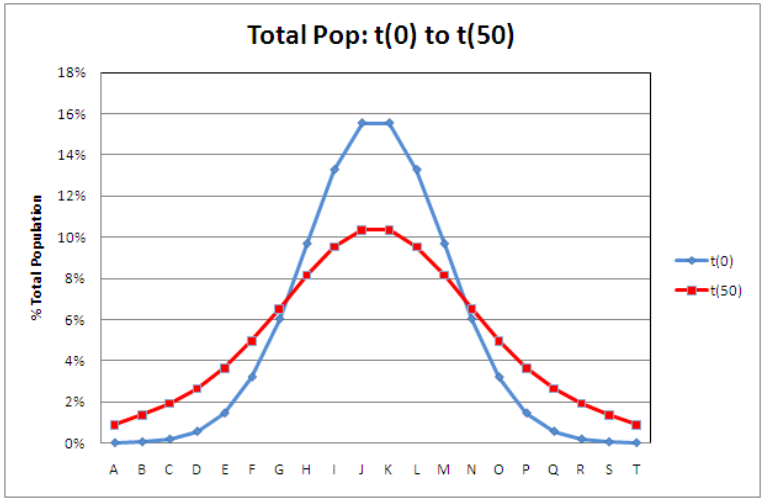


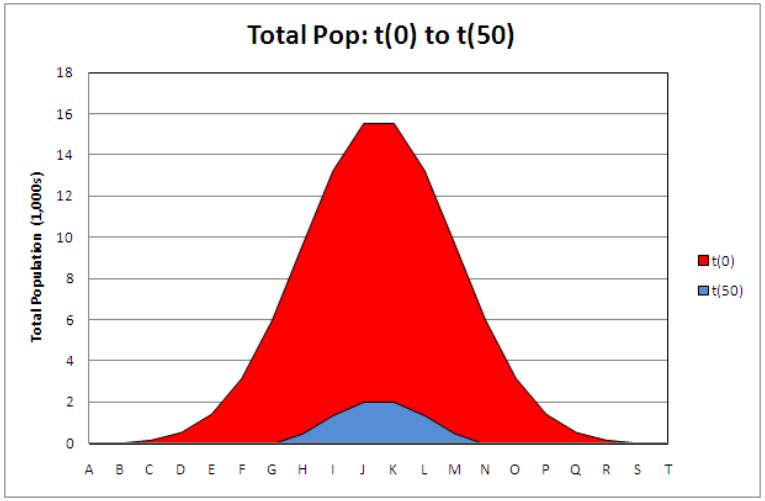


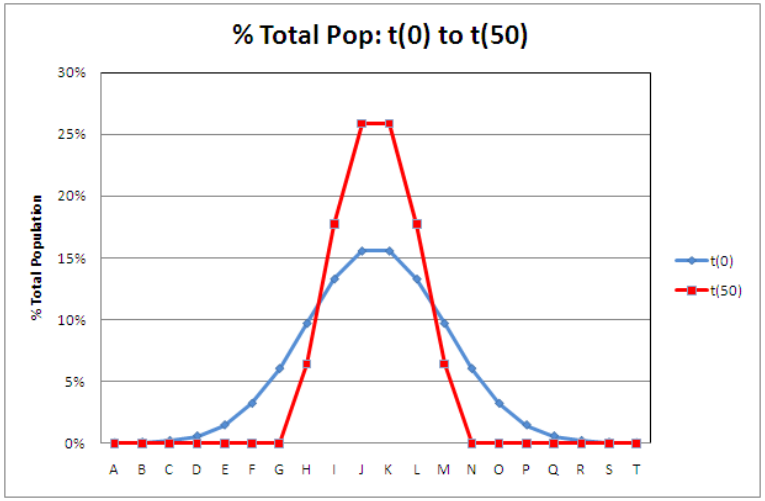
Notes

- The trends are the same as those we saw previously, just exaggerated due to the larger rate of growth.

Results: Assuming constant r = -5%

Cell	Pop(0)	Pop(50)	Δ Pop	% Δ Pop	Δ %Pop
A	13	0	-13	-100%	-0.01%
B	53	0	-53	-100%	-0.05%
C	187	0	-187	-100%	-0.19%
D	564	0	-564	-100%	-0.56%
E	1,455	0	-1,455	-100%	-1.46%
F	3,205	0	-3,205	-100%	-3.21%
G	6,027	0	-6,027	-100%	-6.03%
H	9,680	494	-9,186	-95%	-3.26%
I	13,273	1,363	-11,910	-90%	4.44%
J	15,543	1,990	-13,553	-87%	10.32%
K	15,543	1,990	-13,553	-87%	10.32%
L	13,273	1,363	-11,910	-90%	4.44%
M	9,680	494	-9,186	-95%	-3.26%
N	6,027	0	-6,027	-100%	-6.03%
O	3,205	0	-3,205	-100%	-3.21%
P	1,455	0	-1,455	-100%	-1.46%
Q	564	0	-564	-100%	-0.56%
R	187	0	-187	-100%	-0.19%
S	53	0	-53	-100%	-0.05%
T	13	0	-13	-100%	-0.01%





Notes

- The lightly populated exterior cells quickly empty out.
- Population becomes concentrated in the interior cells.
- Potential remains greater in the interior cells, so these cells suffer more absolute population loss at each time step.