CS361 Artificial Life and Digital Evolution

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For our final project, we attempted to replicate select results from the paper "The Effect of Habitat Destruction Pattern on Species Persistence: A Cellular Model" by Calvin Dytham which was published in 1995. Paper Link: https://doi.org/10.2307/3545665

Paper Methodology

The experiment used a cellular automaton model to explore how different patterns of habitat destruction influence the survival of two competing species. The experiment is done in a 50x50 world, with 2500 grids. Each cell can be one of the four states: destroyed, empty, occupied by a species c, occupied by species d, empty or permanently destroyed. Both species have an extinction rate of 0.1. If an organism in a cell goes extinct, then the cell returns to empty and available for colonization. Species c (the superior competitor) has stronger competitive ability but weaker dispersal, while species d (the superior disperser) has better dispersal ability but always loses in direct competition. This is implemented as the rate of colonization: 0.2 for species c and 0.5 for species d. And the colonization rule that species d may only invade empty (not destroyed) cells, while species c may invade both empty patches and those currently occupied by d. At the start of the simulation, of the available not destroyed cells, species c is randomly populated to take up 25% of them, and species d takes up another 25% of them.

The main variable manipulated in the simulations is the pattern of habitat destruction. Dytham tests four patterns: random destruction (as in traditional Levins-type models), destruction along a gradient (with more loss on one side of the grid), destruction in random blocks (simulating agricultural clearing), and destruction along roads (which expand into surrounding cells, simulating deforestation by infrastructure development). In each simulation, between 25% and 75% of the grid is destroyed before the simulation starts. The remaining habitat is filled with the two species in equal proportion (each occupying 25% of the available patches), and the system is run for 1000 updates. Each condition is repeated 10 times to ensure consistency.

	Species c	Species d
Extinction rate	0.1	0.1
Colonization rate	0.2	0.5
Competitiveness	High, can invade species d and empty cells	Low, can only invade empty cells

Paper Results

The results show that the pattern of habitat destruction has a significant impact on species persistence. Within the paper, all of the results are collected after the simulation has been run for 1000 updates. When habitat is removed at random, species c (the superior competitor) goes extinct once only 60% of the habitat remains. However, in the gradient pattern, it survives until just 40% of the habitat is left. In the block and road destruction patterns, species c performs even better, often surviving down to 25% habitat availability. Species d (the superior disperser), by contrast, performs best under random destruction, peaking in abundance when 70% of the habitat remains and going extinct at 25%. In the gradient case, its peak abundance is lower and occurs later, while its performance under block and line destruction is generally poor except at high levels of habitat loss. The study also reports on the number of empty but habitable cells. In the random pattern, empty cells increase in number as habitat is lost. Under gradient, block, and line removal, the number of empty cells either remains constant or decreases. Coexistence of both species is possible down to 35% remaining habitat in the random case, extended to 55% in the gradient case, and maintained throughout all levels of habitat loss in the block and line pattern.

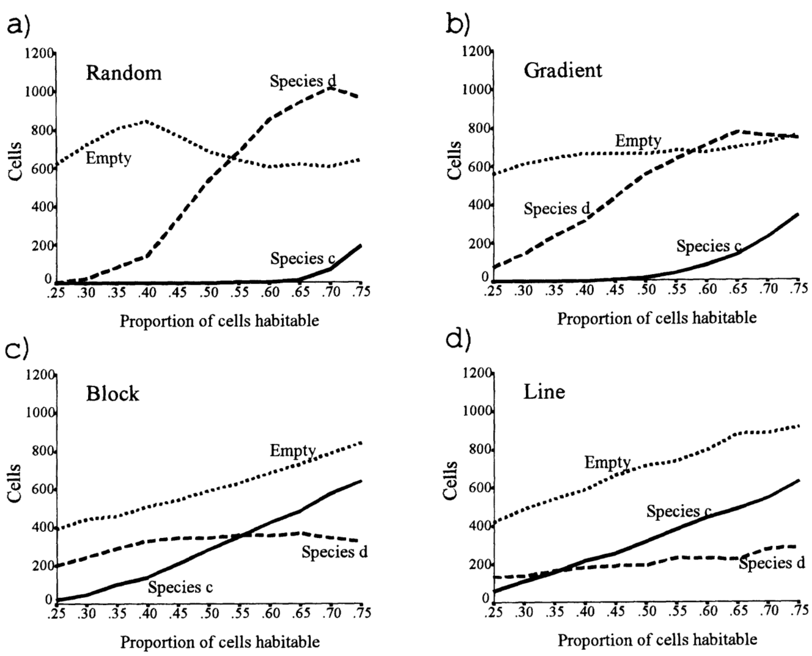

Fig. 2. Mean number of cells occupied, after 1000 iterations, by species c, the superior competitor (solid lines); species d, the inferior competitor (dashed lines); or empty, but still available for colonisation (dotted lines) when 25% to 75% of habitat patches are available. In a) habitat patches are destroyed at random, in b) they are removed on a gradient, in c) they are removed in blocks and in d) along lines (roads).

Reimplementation

In our reimplementation, we followed the world setting in the paper, and started by only including species d for a random habitat destruction, then to gradient habitat destruction, finally both species c and species d for both destruction patterns. In simulation, species run the extinction/colonization dynamics from the paper. We use R to graph our experiment data, scripts are included.

Absolute baseline experiment (species d)

Independent variable: habitat destruction rate (from 25% to 75%, with steps of 1%)
Dependent variable: number of cells occupied by species d and empty cells after 1000 updates
Control variable: species d, random habitat destruction pattern

In the absolute baseline experiment, habitats are destroyed randomly with a reset destruction rate. Only species d is placed randomly in the remaining cells. We run each trial 10 times (with seed 1 through 10), and use the mean value of all trials as the final result.

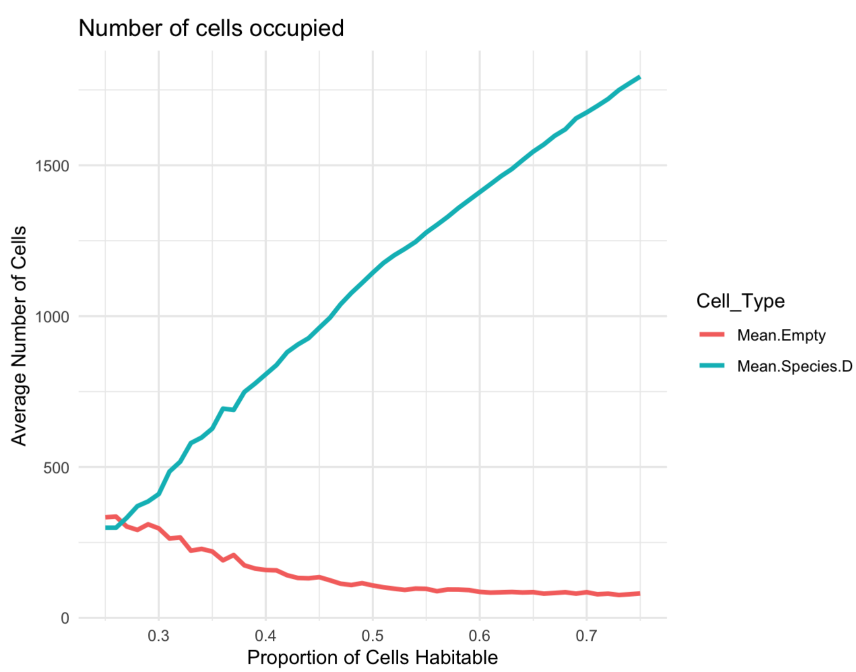

Figure 1: Absolute baseline experiment

As the paper relies on competition between two species, it doesn't list an expected result for a single species simulation. According to our result, with habitable cells, the number of empty cells increases. This meets our expectation, because in this experiment, habitat is destroyed randomly. With more destroyed cells separating available spaces, it becomes harder for species d to colonize on the separated spaces.

Basic controlled experiment (species d)

Independent variable: habitat destruction rate Dependent variable: number of cells occupied by species d and empty cells after 1000 updates Control variable: species d, gradient habitat destruction pattern

In the basic controlled experiments, we built from our absolute baseline experiment and added habitat destruction patterns of gradient. Still, only species d is placed randomly in remaining cells. We run each trial 10 times (with seeds 1 through 10), and use the mean value of all trials as the final result.

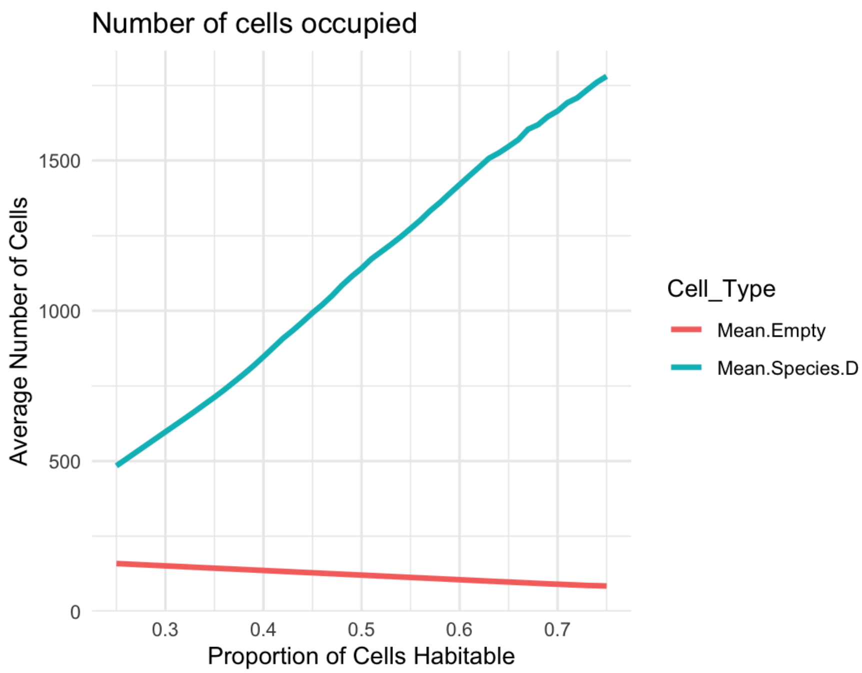

Figure 2: basic control experiment

Again, the paper does not provide direct results for a single-species simulation. While the difference may not be immediately obvious from the graphs alone, species d is able to maintain colonies more effectively under the gradient destruction pattern compared to random destruction. It sustains higher population levels for a longer time, and there are fewer empty cells at equivalent destruction rates. We argue that this is because the gradient pattern preserves larger clusters of connected habitable cells, making colonization and survival easier for species d.

Ideal result experiment (Two species)

Independent variable: habitat destruction pattern (random vs gradient) Dependent variable: number of cells occupied by species d and empty cells after 1000 updates Control variable: two species

In the ideal result experiment, we added species c to the simulation, and ran for both random and gradient destruction patterns. Similarly, each condition is run 10 times (with seeds 1 through 10).

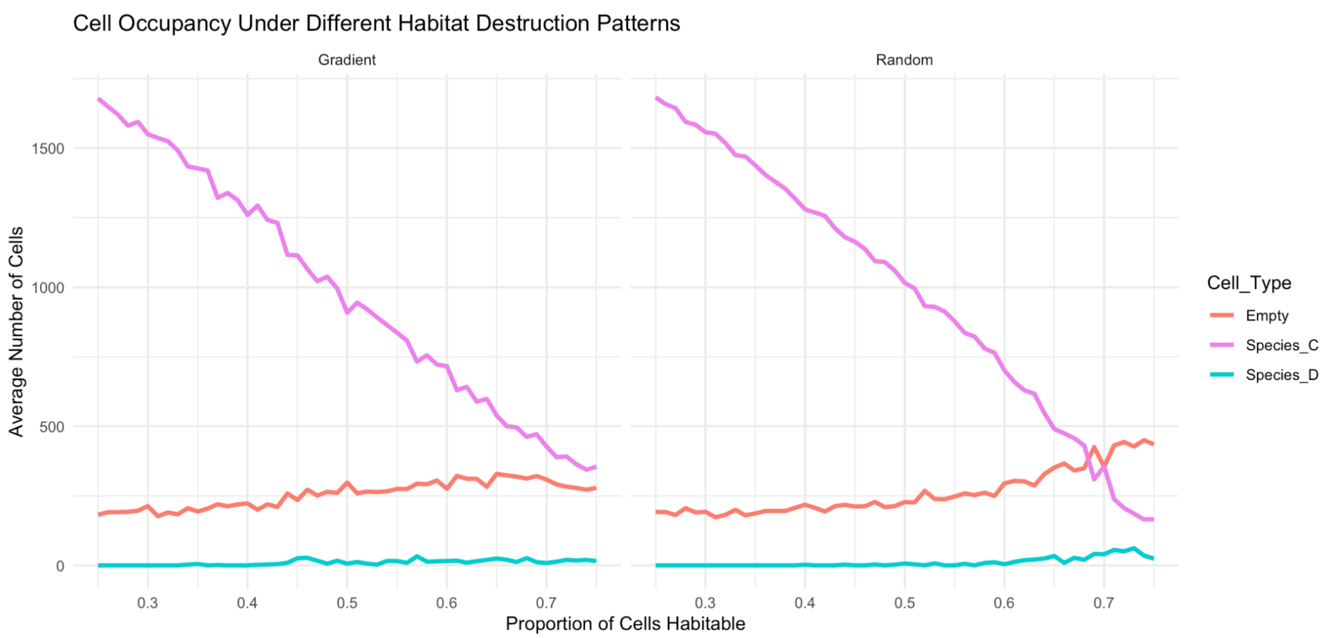

Figure 3: Ideal result experiment

In our ideal experiment result , across both patterns, species c consistently dominates, but the gradient pattern appears to favor its persistence even more strongly. Under gradient destruction, species c reaches its highest population—over 1670 occupied cells—at low destruction levels and maintains a dominant presence even as destruction increases. In contrast, under random destruction, species c also remains dominant but its growth is slightly less steep, and it plateaus earlier. Species d struggles under both conditions, but its decline is sharper and begins earlier in the gradient pattern. For example, species d reaches zero presence by the time 60% of habitat remains under gradient conditions, whereas it survives slightly longer under random conditions. Additionally, while both patterns result in relatively few empty but habitable cells, the gradient pattern shows more rapid reduction in empty space, indicating more efficient colonization by species c. This comparison suggests that the spatial clustering of available cells in the gradient pattern may accelerate species c's spread and further hinder species d's dispersal.

Analysis for inconsistency between our replication and the paper

Our results above are contrary to some expectations from the original Dytham study. We are confident in our results and that we implemented the methodology outlined in the paper correctly, however we are more so unsure of how the paper reached their results. From what was outlined in the paper, given that the simulation is run for 1,000 iterations utilizing the given species colonization rates of 0.2 and 0.5 respectively, with an extinction rate of only 0.1, then it makes sense for seeing our results having so few empty spaces and species c domination. In theory, the colony should continue to rapidly increase, as for both species the colonization rate is higher than the extinction rate, so this should continue to increase and from testing clearly plateaus a long time before 1,000 rounds of the simulation. The paper results puzzle us as to how there remain such high proportions of empty cells available for colonization over all of the different destruction proportions, and we are unsure as to how the paper came to these conclusions, as the species should in theory happily colonize those free sections.

We feel that to be able to replicate the results as described in the paper, more detailed and outlined methods needed to be included in the paper, as for proper replication, there were certain details which were left out and left up to the assumption as to how to implement these. Despite vagueness in methods at times, we still are unsure as to how the paper found the results that they did, as with the current colonization model it does not appear clear to us how such large amounts of cells remain free for population after 1,000 iterations when the colonization rates of both species greatly exceed the extinction rates of them.

Our results demonstrate that species c's competitive advantage compounds over time through superior competitiveness ability. Initially, species d spread out because of its dispersal advantage. However, this phrase lasts only a few steps. As species c colonizes, it begins to outcompete species d. Because species d lacks the ability to invade species c patches, it is trapped and restricted from further colonization by the surrounding destroyed habitat and species c habitat. This shows that rapid dispersers may achieve numerical dominance immediately following disturbance events, but competitively superior species will reclaim territory as the system stabilizes. This shifts the analytical focus from short-term numerical advantage to long-term ecological resilience.

Expansion

In the paper, Dytham assumes static habitat destruction, where destruction happens before the first step. For expansion, we implement stepwise habitat destruction, specifically, linearly fills out predetermined space over a set number of rounds(the round number can be changed through the config panel, from 0 to 100). With this expansion, we can now gain insight into time as a factor for habitat destruction influences.

Independent variable: number of rounds over which habitat is destroyed Dependent variable: number of cells occupied by species d and empty cells after 1000 updates Control variable: random habitat destruction pattern, 50% total percent destroyed

We set the experiment with a random habitat destruction pattern, keeping the total portion of habitat destroyed at 50% and each round is run 10 times (with seeds 1 through 10).

Figure 4: Expansion result

In our stepwise destruction model, we found that increasing the destruction over 100 rounds did not significantly affect species persistence dynamics. The superior competitor (Species C) consistently dominated, while the superior disperser (Species D) failed to establish. This suggests that under current colonization-extinction parameters, the rate of habitat loss is too slow to disrupt Species C's early and sustained expansion. Time as a factor only matters when it is fast enough to interfere with colonization before competitive dominance is established.

References:
Dytham, C. (1995). The Effect of Habitat Destruction Pattern on Species Persistence: A Cellular Model. Oikos, 74(2), 340–344. https://doi.org/10.2307/3545665