**S5 Supporting Information**

*Sensitivity testing for parameters res\_consume and tend\_crop\_yield*

The two parameters *res\_consume* and *tend\_crop\_yield* are important because they influence the decision making of the users. *Res\_consume* governs the quantity of crops each resource consumes on a given landscape cell at a given time step, thus reducing the users yield on that cell by a certain amount. *Tend\_crop\_yield* governs the amount a user can increase their yield on a given cell by tending their crops, as opposed to taking another action such as felling.

Chart, scatter chart

Description automatically generated

**Figure S5.1. Parameter values for *res\_consume* and *tend\_crop\_yield* that were tested prior to the final simulations.**

Chart

Description automatically generated

**Figure S5.2. The number of trees remaining at each time step for each of the simulations from plot S5.1. above.**

N1a results in the fewest trees being lost, which was expected as N1a has no incentive to fell trees (equal parameter values). N1 and N1b:f are all similar in their loss of trees. Interestingly, the simulation with the highest *res\_consume* (N1c) does not end up with the fewest trees, and that is because *tend\_crop\_yield* is higher than some of the others and so users will be more likely to choose to tend crops when costs of felling are very high. The simulation with the most trees lost is N1d, where *tend\_crop\_yield* is very low (0.01) and *res\_consume* is quite high (0.08). This is closely followed by N1f which although has a lower *res\_consume* value than N1b and N1c, it also has a lower *tend\_crop\_yield* value. This quite nicely shows the interaction between the two parameters. This further demonstrates that small incremental changes in *tend\_crop\_yield* are more influential than similar increases in *res\_consume*.

Chart, line chart

Description automatically generated

**Figure S5.3. The total yield for each user at each time step, as a percentage of the total available yield, for each of the simulations from plot S5.1.**

Yield is lowest in N1c, as this simulation has the highest value for *res\_consume* (0.1), followed by N1b and N1d (0.08). N1f is on its own in the middle (0.06). The highest yields are for N1, N1a, and N1e, where *res\_consume* is 0.05 for all. For this last group, we see that N1e is increasing slightly faster, as *tend\_crop\_yld* is set lower than N1 and N1a, and so users are more likely to fell trees as tending crops has less value.

Chart, bar chart

Description automatically generated

**Figure S5.4. The total number of culling (felling) actions taken by users at each time step for each of the simulations from plot S5.1.**

The simulations appear to be broadly split between N1 and N1a, and the rest. N1 and N1a show much more variation in the number of felling actions, with the number of felling actions regularly dropping to 0. For simulation N1a, which has the two parameters set equally at 0.05, we see regular spells of 0 felling actions, where the users are choosing to tend crops (as that produces the same benefits in terms of yield). This happens less frequently with simulation N1, and in simulation N1 there are no occasions when number of cull actions remain at 0 for more than a single time step. This is because *tend\_crop\_yield* is lower than *res\_consume*, and so it is more beneficial to fell trees. For all of the other simulations though, there appears to be a minimum number of culls below which they never drop (just over 100). Even simulation N1e, which is very similar to N1 in terms of parameters, never drops below a certain value of cull actions.

*Null scenarios*

**N1**

The null scenario N1 had the manager and user budgets (community resources) as stable and equal. Both budgets were set to 500.

Chart

Description automatically generated

**Figure S5.5. Summary results from null scenario N1. The cost of a felling action at each time step (top left), number of felling actions at each time step (top right), the number of trees remaining on the landscape at each time step (bottom left), and the total yield from all users at each time step (bottom right).**

The results of scenario N1 were as expected – the manager uses all of their budget to reduce felling by time step 2, which coincides with the number of felling actions dropping between time step 1 and time step 2. The stable budgets for both the manager and user results in a stabilisation of felling costs and number of felling actions, as neither user nor manager loses or gains power over the other. The manager is unable to entirely stop felling taking place, and therefore there is a steady decrease in the number of trees remaining. This results in a steady increase in the yield that the users get from the landscape over time.

**N2**

The null scenario N2 tested the situations when either the manager or user had a decreasing budget, whilst the other was stable. The scenario was therefore split into two sub-scenarios. N2a had the manager budget stable, and the user budget (community resources) decreasing linearly. N2b had the user budget (community resources) stable, and the manager budget decreasing linearly.

Chart, line chart

Description automatically generated

**Figure S5.6. summary results from null scenario N2a and N2b. a – budgets at each time step for N2a, b – budgets at each time step for N2b, c – the number of felling actions at each time step for both scenarios, d – the cost of felling actions at each time step for both scenarios, e – the number of trees remaining at each time step for both scenarios.**

The results from null scenarios N2a and N2b were as expected. When the manager budget was stable and the user budget (community resources) were decreasing, the cost of felling remained stable over time, but due to the decreasing community resources the number of felling actions decreased over time. The rate of forest loss in N2a was decreasing over time as the community lost power to take actions (i.e., fell trees). When the community resources were stable, but the manager budget decreased over time, the cost of felling trees decreased over time as the manager had less budget at each time step with which to set the cost of felling actions. This resulted in an increasing number of felling actions over time, and a rate of forest loss that was increasing.

**N3**

The final null scenario, N3, had the manager budget increasing linearly and the user budget (community resources) stable.

Chart, line chart

Description automatically generated

**Figure S5.7. Summary results from null scenario N3. The budget at each time step for both the manager and the users (top left), the cost of a felling action at each time step (top right), the total number of felling actions at each time step (bottom left), and the number of trees remaining on the landscape at each time step (bottom right).**

The results from N3 were as expected; the power of the manager to affect the system increased as the manager budget increased and the community resources remained stable. This led to a steady increase in the cost of felling actions for the community, and therefore a steady decrease in the number of felling actions. The relative differences between the manager budget and community resources were never large enough to completely eliminate felling actions, and therefore forest loss was still occurring.

*Parameter values*

The below parameter values were used in all null and final scenarios. See the GMSE package documentation for further details on *gmse()* and *gmse\_apply()* parameter values. All genetic algorithm parameters were kept at their default value.

**Table S5.1. GMSE parameter values used in all final simulations.**

|  |  |
| --- | --- |
| **Parameter** | **Value** |
| time\_max | 50 |
| land\_dim\_1 | 100 |
| land\_dim\_2 | 100 |
| res\_movement | 0 |
| agent\_view | 150 |
| agent\_move | 50 |
| res\_move\_type | 0 |
| res\_death\_type | 0 |
| lambda | 0 |
| observe\_type | 2 |
| times\_observe | 1 |
| obs\_move\_type | 1 |
| res\_min\_age | 0 |
| res\_move\_obs | FALSE |
| res\_consume | 0.08 |
| move\_agents | TRUE |
| minimum\_cost | 10 |
| usr\_budget\_range | User budget / 10 |
| manage\_target | 100000 |
| RESOURCE\_ini | 100000 |
| culling | TRUE |
| tend\_crops | TRUE |
| tend\_crop\_yield | 0.01 |
| stakeholders | 30 |
| land\_ownership | TRUE |
| public\_land | 0 |
| manage\_freq | 1 |
| group\_think | FALSE |

*Manager budgets*

Scenarios 4 and 5 used a Fourier series approach to produce random complex waves that mimicked unpredictable manager budgets over time. Three sine waves were produced for each simulation replicate, and were summed to produce a single complex wave. Sine waves for both scenarios were created using,

Where is the trajectory at time for wave , *T* is the total number of time steps (, is the strength of wave , is the frequency of wave , and is the delay of wave .

The frequency values for each sine wave were sampled from a uniform distribution, for scenario 4 using,

And scenario 5 using,

Delay values for each sine wave were sampled from a uniform distribution, for scenario 4 and 5 using,

Wave strength for each sine wave were sampled from a uniform distribution, for scenario 4 using,

And scenario 5 using,

Figure 4sa below shows an example, where the budget *B* (black line) is determined by the sum of the three coloured lines.

Chart, line chart, histogram

Description automatically generated

**Figure S5.8. An unpredictable manager budget *B* (black line), produced by the sum of three sine waves (, coloured lines).**

Diagram

Description automatically generated with medium confidence

**Figure S5.9. Manager budgets for each of the 100 replicate simulations for scenario 4. Each budget was produced using three randomly produced sine waves and an Inverse Fourier Transform.**

Text

Description automatically generated

**Figure S5.10.** **Manager budgets for each of the 100 replicate simulations for scenario 5. Each budget was produced using three randomly produced sine waves and an Inverse Fourier Transform.**

*Results*

Chart, line chart

Description automatically generated

**Figure S5.11. Remaining trees at each time step for all five scenarios. Thick lines and confidence ribbons are the 50, 2.5, and 97.5 percentiles taken from the 100 replicates for each scenario.**