GMSE: an R package for generalised management strategy evaluation

Supporting Information 3

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An example of management conflict using GMSE

Agents in GMSE (managers and users) are goal-oriented, and their behaviour is therefore driven to maximise a particular utility of interest such as a target density of resources (managers), or a suitable resource or landscape harvest size (users). This model feature allows GMSE to evaluate the actions of agents in the context of their individual objectives, and to therefore quantify the degree to which those objectives are or are not achieved. When the actions of one party clashes with the objectives of another party, the objectives of one might be expressed at the expense of the other, causing conservation conflict (Redpath et al., 2013). Currently, there is no standard way to measure conservation conflict in a social-ecological system, and previous modelling approaches have not meaningfully separated agent objectives from agent actions. We suggest that a starting point to developing a useful metric of conservation conflict is to quantify the deviation of an individual's actions from their objectives, the former of which is restricted by the actions of other individuals. Here we show how GMSE can be used to evaluate the amount of conflict in a simulated social-ecological system under different management options.

To demonstrate how GMSE can be used to understand conflict in social-ecological systems, we build upon the example of resource management in the main text. We consider a protected population of waterfowl that exploits agricultural land and is therefore a source of conservation conflict (e.g., Fox and Madsen, 2017; Mason et al., 2017; Tulloch et al., 2017). As in the main text example, the objective of managers is to keep waterfowl at a target abundance, while the objective of farmers is to maximise agricultural production on their landscape. Here we consider a more complex simulation to reflect a scenario that is likely to occur in a real social-ecological system. We parameterise our model using demographic information from the Taiga Bean Geese (*Anser fabalis fabalis*), a managed population that is hunted for sport in Fennoscandinavia (Johnson et al., 2018). Taiga Bean Geese can also cause agricultural damage, which can potentially lead to conflict between farmers and management objectives (Johnson et al., 2018).

Using demographic parameters in simulations

Johnson et al. (2018) recently estimated key demographic parameters for the Taiga Bean Geese for the Central Management Unit that includes geese that breed in "Northern most Sweden, Northern Norway, Northern and Central Finland, and adjacent North-wester parts of Russia, wintering mostly in Southern Sweden and South-east Denmark" (AEWA, 2016). They estimated goose survival under ideal conditions to be ca 0.878; this can be interpreted in our model by setting mortality to `remove_pr = 1 - 0.878`. Similarly, Johnson et al. (2018) estimated intrinsic population growth rate and carrying capacity to be 0.15 and 93870, respectively, so we set `lambda = 0.183` (for convenience of demonstration, the upper 90% confidence interval of their estimate) and `res_death_K = 93870`. The global abundance of Taiga Bean Geese in 2009 was ca 63000 (Fox et al., 2010), and ca 35000 in the Central Management Unit (AEWA, 2016), which we can take as a starting abundance for our simulations (`RESOURCE_ini = 35000`). And the International Single Species Action Plan has a target population size of ca 70000 in the Central Management Unit (AEWA, 2016), which we can use as a management target (`manage_target = 70000`).

For simplicity, here we assess conflct using only the `gmse` function to show how parameter values can be set to provide useful results. Our goal is not to provide a detailed case study of the Taiga Bean Geese, but rather to demonstrate how such a case study would be possible using the `gmse` function. Additionally, all of the analysis that follows would also be possibe using the more detailed, but also more flexible, `gmse_apply` function. Where available, we use estimated demographic parameter values from Johnson et al. (2018) and AEWA (2016). Where GMSE parameter values are not available, we use reasonable values or GMSE defaults. To make model inferences for real case studies, we strongly recommend simulating across a range of parameter values when empirical estimates are unavailable, as social-ecological dynamics might be sensitive to these unknown values.

The code below calls `gmse` using the empirically derived parameters for Taiga Bean Geese described above. We also set `manager_budget = 100000` and `user_budget = 100000`. Further, we consider the case in of a region in which farmland makes up 60% of all land, with 40% of land being 'public' (`public_land = 0.4`; which might be intpreted as any land in which stakeholders are not, or cannot be, invested in goose presence), and divide the farmland amongst 80 individual farmers (`stakeholders = 80`; `land_ownership = TRUE`). Landscape size is set to default 100 by 100 cells, so each farmer effectively owns 75 cells, which might be interpreted as hectares of land (for instructions on how to more precisely control landscape ownership, see the advanced GMSE options using `gmse_apply`). Because we need both density-dependent (`res_death_K = 93870`) and density-independent (`remove_pr = 0.122`) sources of mortality, we set `res_death_type = 3`. We assume that a single goose decreases agricultural production on a cell by 2% per time step (`res_consume = 0.02`). We further assume that the population is well-monitored, with observers counting goose numbers on each cell of the landscape in every timestep (`observe_type = 3`) with the ability to observe two landscape cells in every direction (`agent_view = 2`). All other parameter values are set to GMSE defaults.

Simulating goose management

Below, we first allow only the culling of geese by users and plot the dynamics of the social-ecological system from a single simulation. Next, we run the same simulation but allow users to scare geese from their landscape cells; we then use the model to make inferences regarding how scaring as a management option might affect goose population dynamics, agricultural production, and conservation conflict in the system. All simulations are run using the `gmse` function, but novice R users may prefer run all of the simulations below using the browser-based GMSE GUI by calling `gmse_gui()` from the R command line. Alternatively, experienced R users may prefer simulate by looping time steps through `gmse_apply`, which allows more flexibility for incorporating custom submodels and dynamically adjusting parameter values. We emphasise that the simulations below are intended only to demonstrate one use of GMSE on a species of conservation interest, not to make recommendations for management of Taiga Bean Geese.

```
sim_1 <- gmse(manager_budget = 10000, user_budget = 10000, res_death_K = 93870,
              manage_target = 70000, RESOURCE_ini = 35000, plotting = FALSE,
              stakeholders = 80, land_ownership = TRUE, public_land = 0.4,
              scaring = FALSE, lambda = 0.275, remove_pr = 0.122, time_max = 40,
              res_death_type = 3, res_consume = 0.02, res_birth_K = 200000,
              observe_type = 3, agent_view = 1, converge_crit = 0.1);
```

```
sim_1 <- gmse(time_max = 30, plotting = FALSE);
```

```
## [1] "Initialising simulations ... "
## [1] "Generation  22 of  30"
```

The results of the above simulation are plotted in Figure SI3-1 below.

```
plot_gmse_results(res = sim_1$resource, obs = sim_1$observation,
                  land = sim_1$land, agents = sim_1$agents, paras = sim_1$paras,
                  ACTION = sim_1$action, COST = sim_1$cost);
```

The above Figure SI3-1 shows the dynamics of goose abundance and agricultural yield, along with how
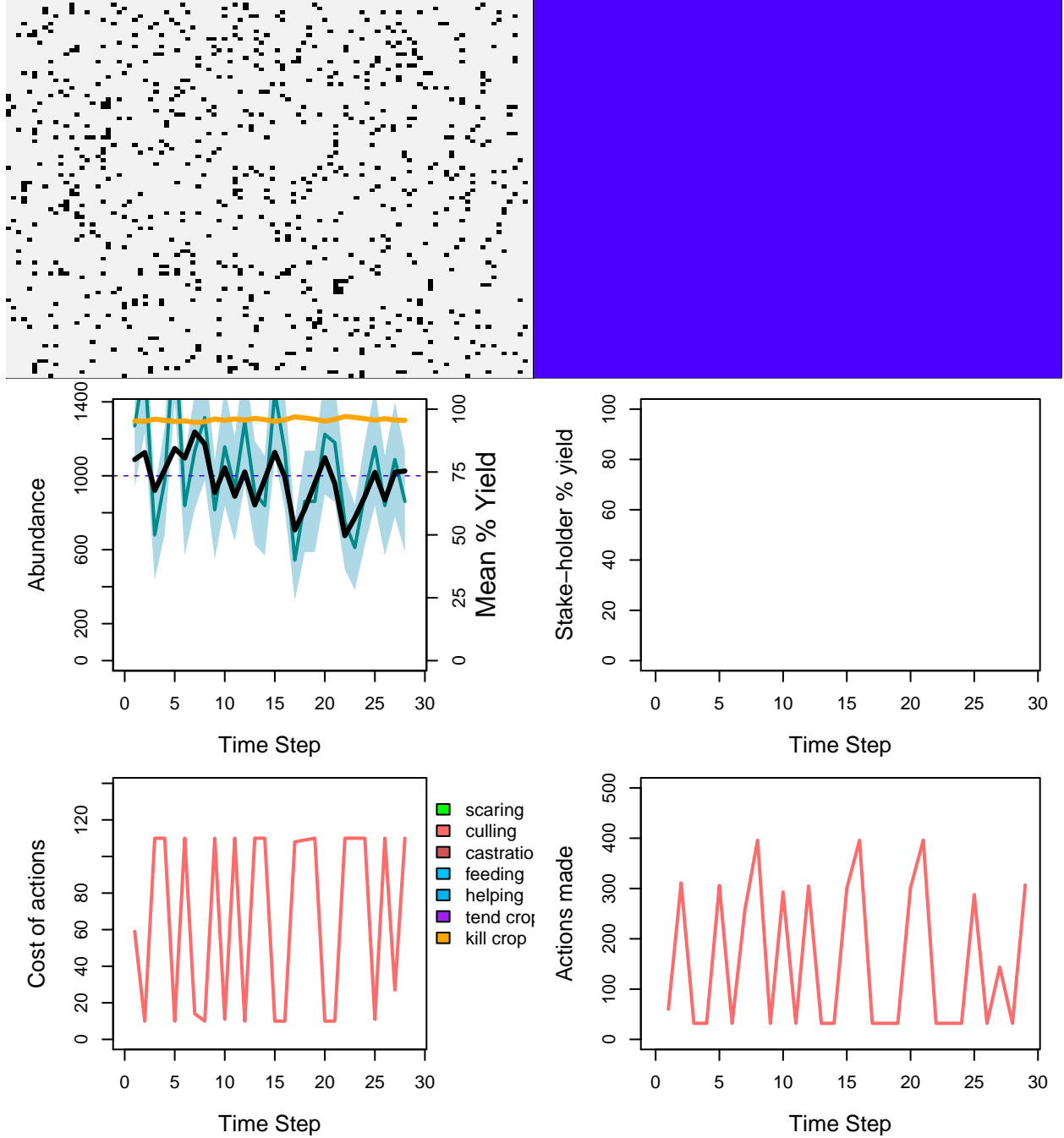
Figure 1: Results of a GMSE simulation using parameters estimated for Taiga Been Geese Central Management Unit. This example includes 80 farmers whose objective is to maximise their agricultural output, and one manager whose objective is to keep geese at a target abundance, over 20 simulated time steps. Goose locations at the end of the simulation are shown in the upper left panel, while the upper right panel shows the same landscape broken down among the 80 farmers (upper 60% of the landscape in multiple colours), along with non-agricultural land (lower 40% of the landscape in blue). Actual goose abundance is shown in the middle left panel (black solid line), along with its estimate by the manager (blue solid line). Horizontal red and blue dotted lines show landscape-level goose carrying capacity enacted on adult mortality and the manager's target for goose abundance, respectively. The organge line shows the total percent of landscape cells (including non-farmed cells) yield, as decreased by geese. The middle right panel shows this yield for each farmer, and for the public land (lower line in blue). The lower left panel shows the cost of culling for farmers, as set by the manager, and the lower right panel shows the total number of culls attempted by farmers over time.

managers react to change in abundance and farmers react to manager policy. In the case of the simulation above, goose population begins to decline, causing managers to set policy to increase the cost of culling. This higher cost of culling restricts farmers from culling on their land, leading to fewer total culling actions. In this case, the abundance of geese continues downward, while agricultural yield increases over time. We can investigate the conflict between management policy and farmers using the `plot_gmse_effort` function in GMSE.

```
plot_gmse_effort(sim_1$agents, sim_1$paras, ACTION = sim_1$action,
                 COST = sim_1$cost);
```

Black lines indicate how permissive a manager is toward a particular action on a scale of 0 to 100, while coloured lines indicate how much effort farmers expend on a given action. When black lines are far below coloured lines, we can (cautiously) interpret this as a conflict between management of the goose population and farmer's interest in agricultural production. These time periods represent instances in which managers are not at very permissive of a particular action (in this case culling), but farmers continue to expend effort to do the action anyway.

```
sim_2 <- gmse(time_max = 30, scaring = TRUE, plotting = FALSE);
```

```
## [1] "Initialising simulations ... "
## [1] "Generation  23 of  30"
```

```
sim_2 <- gmse(manager_budget = 10000, user_budget = 10000, res_death_K = 93870,
              manage_target = 70000, RESOURCE_ini = 35000, plotting = FALSE,
              stakeholders = 80, land_ownership = TRUE, public_land = 0.4,
              scaring = TRUE, lambda = 0.275, remove_pr = 0.122, time_max = 40,
              res_death_type = 3, res_consume = 0.02, res_birth_K = 200000,
              observe_type = 3, agent_view = 1, converge_crit = 0.1);
```

The results are plotted below.

```
plot_gmse_results(res = sim_2$resource, obs = sim_2$observation,
                  land = sim_2$land, agents = sim_2$agents, paras = sim_2$paras,
                  ACTION = sim_2$action, COST = sim_2$cost);
```
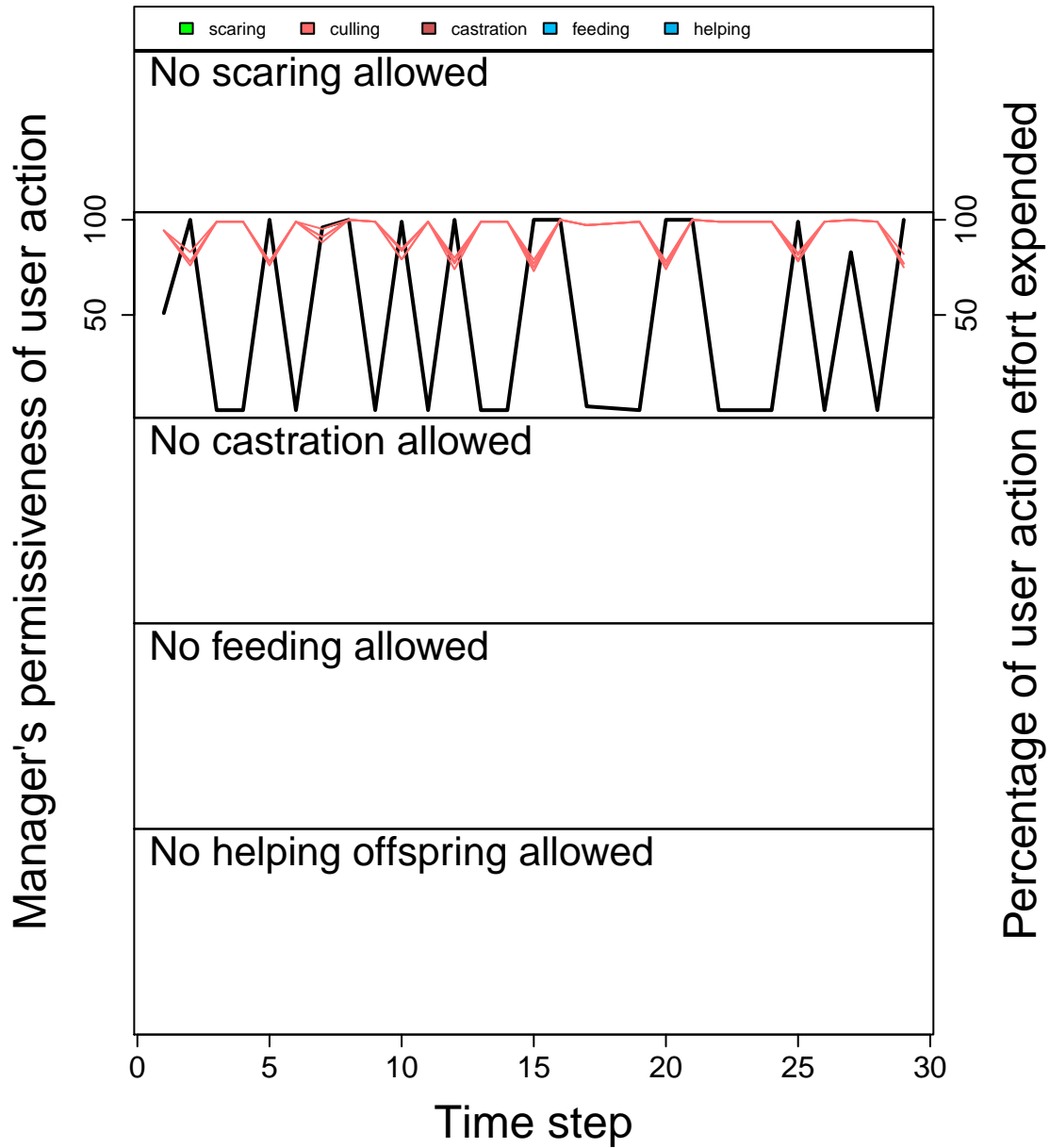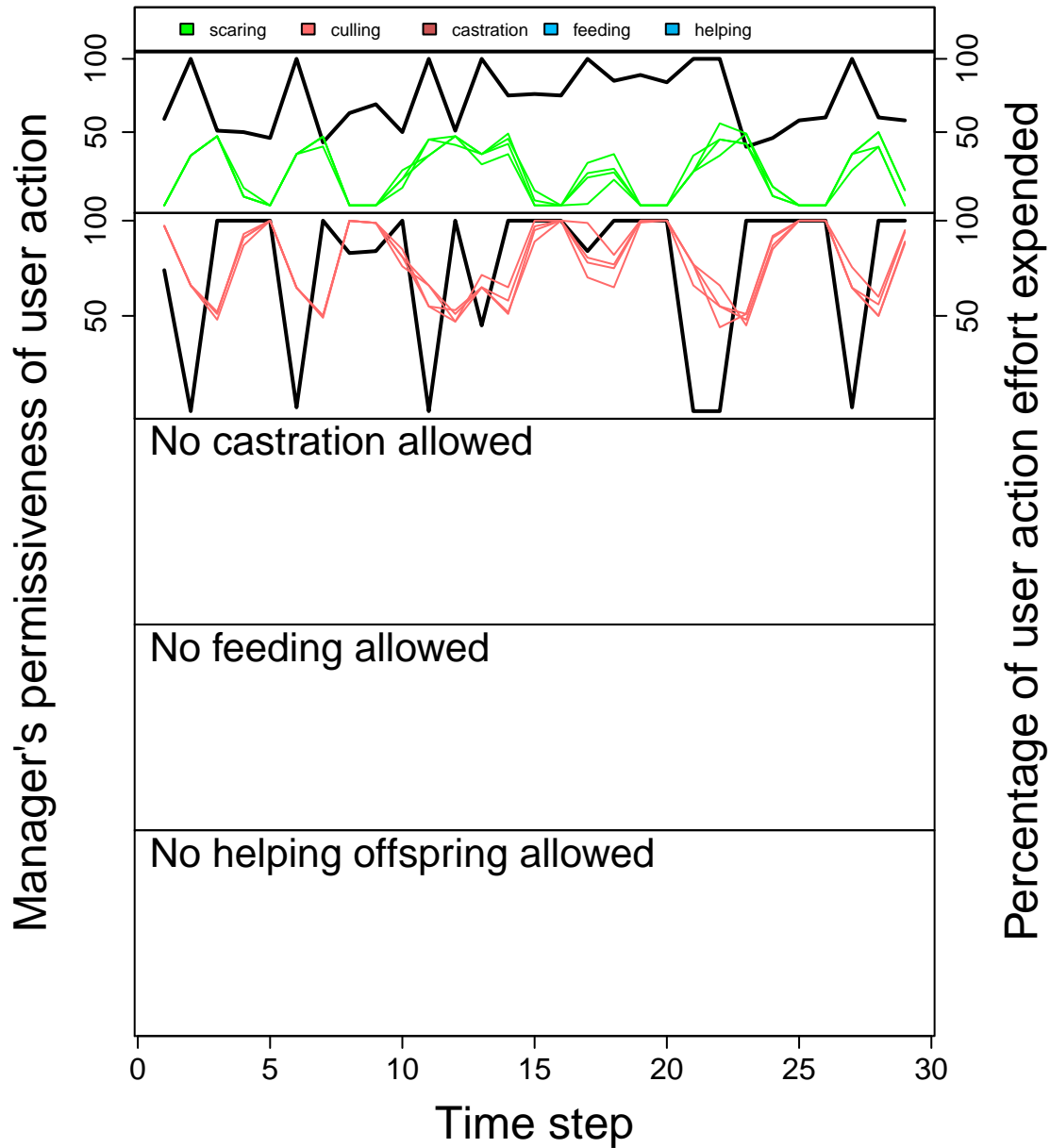
Figure 2: Permissiveness that each manager exhibits for each farmer action (black lines) and the effort that each individual farmer puts into each action over time (coloured lines). Each panel row reports a different action (in decreasing order: scaring, culling, castration, feeding, and helping). The left axis shows the permissiveness that a manager has for the focal action (black line), which is calculated as 100 minus the percent of the manager's budget that is put into increasing the cost of the focal action. For example, if the manager puts all of their effort (total budget) into increasing the cost of culling, then permissiveness of culling is 0; if the manager puts no effort into increasing culling cost, then permissiveness of culling is 100. The right axis shows effort that farmers put into an action (coloured lines), which defined as the percentage of a farmer's budget put into a particular action (note, values might not add up to 100 because farmers are not forced to use their entire budget).
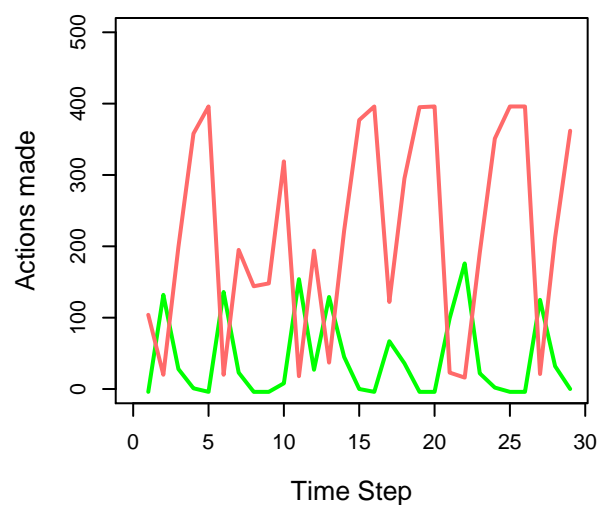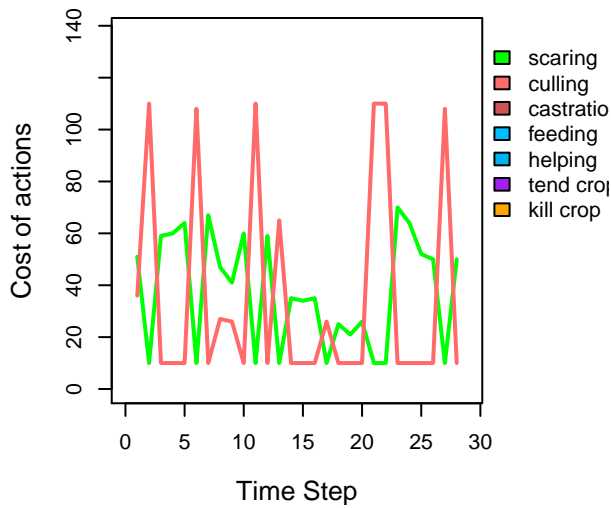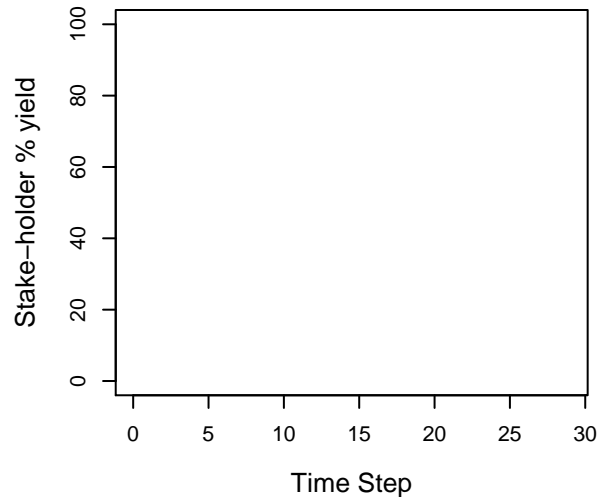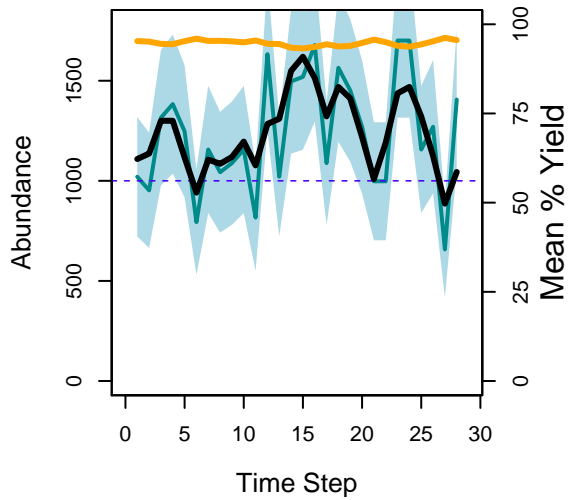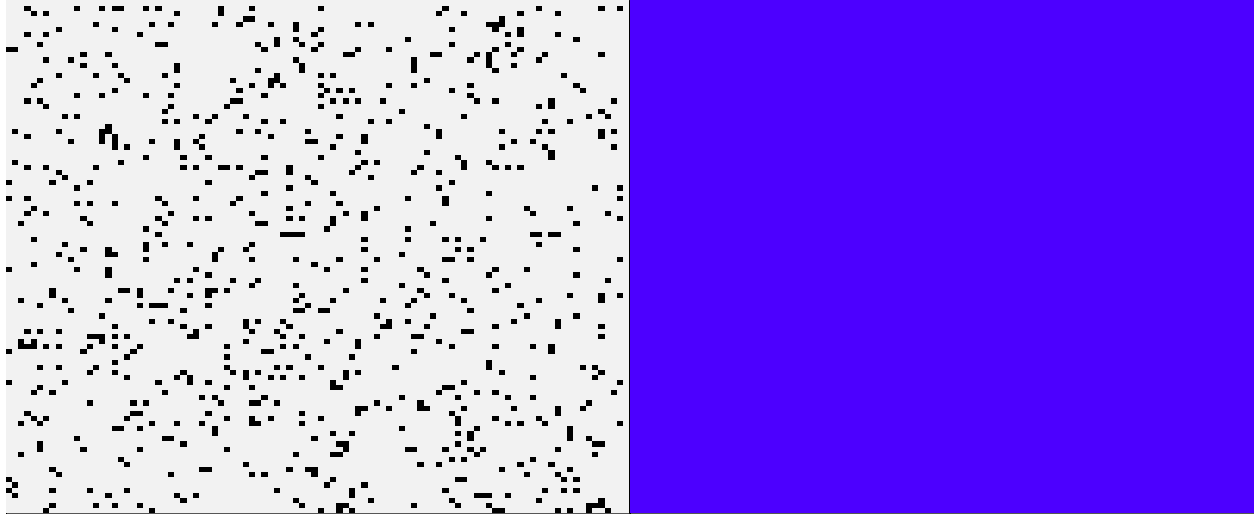
Look at the conflict

```r
plot_gmse_effort(sim_2$agents, sim_2$paras, ACTION = sim_2$action,
                 COST = sim_2$cost);
```

No castration allowed

No feeding allowed

No helping offspring allowed

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