Management frequency and extinction risk

GMSE: an R package for generalised management strategy evaluation (Supporting Information 5)

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The individual-based approach of default GMSE submodels

The default submodels of GMSE (`resource`, `observation`, `manager`, `user`) are individual-based (also called 'agent-based'), meaning that they model discrete individuals (resources or agents), which in GMSE are represented by individual table rows (`RESOURCES`, `AGENTS`, `OBSERVATION`) or layers of three-dimensional arrays (`COST`, `ACTION`). Individual-based models (IBMs) have been a useful approach in ecology for decades (Uchmański and Grimm, 1996; Grimm, 1999), providing both a pragmatic tool for the mechanistic modelling of complex populations and a powerful technique for theoretical investigation. A key advantage of the individual-based modelling approach is the discrete nature of individuals, which allows for detailed trait variation and complex interactions among individuals. In GMSE, some of the most important traits for resources include types, ages, demographic parameter values, locations, etc., and for agents (manager and users), traits include different types, utilities, budgets, etc. The traits that resources and managers have can potentially affect their interactions, and default GMSE submodels take advantage of this by simulating interactions explicitly on a landscape (see SI7 for an introduction to GMSE default data structures).

Replicate simulations as a tool for model inference

Modelling complex interactions among discrete individuals mechanistically typically causes some degree of stochasticity in IBMs (in the code, this is caused by the sampling of random values, which determine probabilistically whether or not events such as birth or death occur for individuals), reflecting the uncertainty that is inherent to complex systems. We can see a simple example of this by calling `gmse_apply` under the same default conditions twice.

```
rand_eg_1 <- gmse_apply();
print(rand_eg_1);
```

```
## $resource_results
## [1] 1124
##
## $observation_results
## [1] 1111.111
##
## $manager_results
##          resource_type scaring culling castration feeding help_offspring
## policy_1             1      NA      49         NA      NA             NA
##
## $user_results
##         resource_type scaring culling castration feeding help_offspring
## Manager             1      NA       0         NA      NA             NA
```

```
## user_1               1      NA      20          NA      NA              NA
## user_2               1      NA      20          NA      NA              NA
## user_3               1      NA      20          NA      NA              NA
## user_4               1      NA      20          NA      NA              NA
##         tend_crops kill_crops
## Manager         NA         NA
## user_1          NA         NA
## user_2          NA         NA
## user_3          NA         NA
## user_4          NA         NA
```

Although the second call to `gmse_apply` has identical initial conditions, because resource demographics (e.g., birth and death) and agent decision making (e.g., policy generation and user actions) is not deterministic, a slightly different result is obtained.

```r
rand_eg_2 <- gmse_apply();
print(rand_eg_2);
```

```
## $resource_results
## [1] 1123
##
## $observation_results
## [1] 1156.463
##
## $manager_results
##          resource_type scaring culling castration feeding help_offspring
## policy_1             1      NA      54         NA      NA             NA
##
## $user_results
##         resource_type scaring culling castration feeding help_offspring
## Manager             1      NA       0          NA      NA             NA
## user_1              1      NA      18          NA      NA             NA
## user_2              1      NA      18          NA      NA             NA
## user_3              1      NA      18          NA      NA             NA
## user_4              1      NA      18          NA      NA             NA
##         tend_crops kill_crops
## Manager         NA         NA
## user_1          NA         NA
## user_2          NA         NA
## user_3          NA         NA
## user_4          NA         NA
```

To make meaningful model inferences, it is often necessary to replicate simulations under the same initial conditions to understand the range of predicted outcomes for a particular set of parameter values. This can be computationally intense, but it can also lead to a more robust understanding of the range of dynamics that might be expected in a system.

References

Grimm, V. (1999). Ten years of individual-based modelling in ecology: what have we learned and what could we learn in the future? *Ecological Modelling*, 115(2-3):129–148.

Uchmański, J. and Grimm, V. (1996). Individual-based modelling in ecology: what makes the difference? *Trends in Ecology & Evolution*, 11(10):437–441.