Package ‘rangr’

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Type Package

Title Mechanistic Simulation of Species Range Dynamics

Version 1.0.6

Description Integrates population dynamics and dispersal into a mechanistic virtual species simulator. The package can be used to study the effects of environmental change on population growth and range shifts. It allows for simple and straightforward definition of population dynamics (including positive density dependence), extensive possibilities for defining dispersal kernels, and the ability to generate virtual ecologist data. Learn more about the 'rangr' at <https://docs.ropensci.org/rangr/>.

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Contents

`disp` *Simulating Dispersal*

Description

This function simulates dispersal for each grid cell by calculating the number of individuals dispersing out of the cell and the number of individuals dispersing into the cell.

Usage

```
disp(
  N_t,
  id,
  id_matrix,
  data_table,
  kernel,
  dens_dep,
  dlist,
  id_within,
  within_mask,
  border,
  planar,
  dist_resolution,
  max_dist,
  dist_bin,
  ncells_in_circle,
  cl = NULL
)
```

Arguments

`N_t` integer matrix representing population numbers at a single time step; NA indicates cells outside the study area

`id` SpatRaster object (of the same size as `N_t`) with cell identifiers

`id_matrix` `id` in matrix format

`data_table` matrix that contains information about all cells in current time points

`kernel` function defining dispersal kernel

`dens_dep` character vector of length 1 specifying if the probability of settling in a target grid cell is (case-sensitive, default `"K2N"`):

- "none" - fully random,
- "K" - proportional to the carrying capacity of a target cell,
- "K2N" - density-dependent, i.e. proportional to the ratio of carrying capacity of a target cell to the number of individuals already present in a target cell

`dlist` list with identifiers of target cells at a specified distance from a focal cell

`id_within` integer vector with identifiers of cells inside the study area

`within_mask` logical matrix that specifies boundaries of the study area

`border` character vector of length 1 defining how to deal with borders (case-sensitive, default `"absorbing"`):

- "reprising" - cells outside the study area are not allowed as targets for dispersal
- "absorbing" - individuals that disperse outside the study area are removed from the population

planar
: logical vector of length 1; TRUE if input maps are planar rasters, FALSE if input maps are lon/lat rasters

dist_resolution
: integer vector of length 1; dimension of one side of one cell of id; in case of an irregular grid or lon/lat raster it is calculated during initialisation

max_dist
: distance (in the same units as used in the raster id) specifying the maximum range at which identifiers of target dispersal cells are determined in advance (see initialise)

dist_bin
: numeric vector of length 1 with value >= 0; in case of an irregular grid or lon/lat raster it is calculated during initialisation

ncells_in_circle
: numeric vector; number of cells on each distance

cl
: if simulation is done in parallel, the name of a cluster object created by makeCluster

Details

The function is used by sim internally and is not intended to be called by the user. The parameters for this function are passed from a sim_data object created by initialise.

Dispersal distance is expressed in original spatial units of the SpatRaster provided to the sim function (n1_map and K_map). However, it is internally converted to units of the simulation (i.e. the size of a single cell) by calculating round(distance/resolution). If the selected dispersal distance is smaller than resolution/2, the individual does not disperse effectively and remains in the same cell. The dispersal rate (proportion of dispersing individuals) can be estimated from the dispersal kernel probability function by calculating the probability that the dispersal distance is greater than resolution/2.

Value

The function returns a list that contains two matrices:

em - emigration matrix with the number of individuals that dispersed from each cell

im - immigration matrix with the number of individuals that dispersed to each cell

Examples

```
# data preparation
library(terra)

n1_small <- rast(system.file("input_maps/n1_small.tif", package = "rangr"))
K_small <- rast(system.file("input_maps/K_small.tif", package = "rangr"))

sim_data <- initialise(
  n1_map = n1_small,
  K_map = K_small,
  r = log(2),
  rate = 1 / 1e3
)

# disp
```

```
disp_output <- disp(
  N_t = sim_data$n1_map,
  id = unwrap(sim_data$id),
  id_matrix = as.matrix(unwrap(sim_data$id), wide = TRUE),
  data_table = sim_data$data_table,
  kernel = sim_data$kernel,
  dens_dep = sim_data$dens_dep,
  dlist = sim_data$dlist,
  id_within = sim_data$id_within,
  within_mask = sim_data$within_mask,
  border = sim_data$border,
  planar = sim_data$planar,
  dist_resolution = sim_data$dist_resolution,
  max_dist = sim_data$max_dist,
  dist_bin = sim_data$dist_bin,
  ncells_in_circle = sim_data$ncells_in_circle
)

# immigration and emigration matrices
names(disp_output)
```

`get_observations` *Observation Process*

Description

This function simulates an observation process. It accepts the `sim_results` object, which is generated by the `sim` function, and applies the virtual ecologist approach on the `N_map` component of the object. The function returns a `data.frame` with the 'observed' abundances.

Usage

```
get_observations(
  sim_data,
  sim_results,
 type = c("random_one_layer", "random_all_layers", "from_data", "monitoring_based"),
  obs_error = c("rlnorm", "rbinom"),
  obs_error_param = NULL,
  ...
)
```

Arguments

`sim_data`	`sim_data` object from `initialise` containing simulation parameters
`sim_results`	`sim_results` object; returned by `sim` function
`type`	character vector of length 1; describes the sampling type (case-sensitive):

- "random_one_layer" - random selection of cells for which abundances are sampled; the same set of selected cells is used across all time steps.
- "random_all_layers" - random selection of cells for which abundances are sampled; a new set of cells is selected for each time step.
- "from_data" - user-defined selection of cells for which abundances are sampled; the user is required to provide a `data.frame` containing three columns: "x", "y" and "time_step".
- "monitoring_based" - user-defined selection of cells for which abundances are sampled; the user is required to provide a matrix object with two columns: "x" and "y"; the abundance from given cell is sampled by different virtual observers in different time steps; a geometric distribution (`rgeom`) is employed to define whether a survey will be conducted by the same observer for several years or not conducted at all.

`obs_error` character vector of length 1; type of the distribution that defines the observation process: "`rlnorm`" (the log normal distribution) or "`rbinom`" (the binomial distribution)

`obs_error_param`
numeric vector of length 1; standard deviation (on a log scale) of the random noise in observation process generated from the log-normal distribution (`rlnorm`) or probability of detection (success) when the binomial distribution ("`rbinom`") is used.

`...` other necessary internal parameters:

- `prop`
numeric vector of length 1; proportion of cells to be sampled (default `prop = 0.1`); used when `type = "random_one_layer" or "random_all_layers"`,
- `points`
`data.frame` or `matrix` with 3 numeric columns named "x", "y", and "time_step" containing coordinates and time steps from which observations should be obtained; used when `type = "from_data"`,
- `cells_coords`
`data.frame` or `matrix` with 2 columns named "x" and "y"; survey plots coordinates; used when `type = "monitoring_based"`
- `prob`
numeric vector of length 1; a parameter defining the shape of `rgeom` distribution; defines whether an observation will be made by the same observer for several years, and whether it will not be made at all (default `prob = 0.3`); used when `type = "monitoring_based"`
- `progress_bar`
logical vector of length 1; determines if a progress bar for observation process should be displayed (default `progress_bar = FALSE`); used when `type = "monitoring_based"`

Value

`data.frame` object with geographic coordinates, time steps, estimated abundance, observation error (if `obs_error_param` is provided), and observer identifiers (if `type = "monitoring_based"`). If `type = "from_data"`, returned object is sorted in the same order as the input `points`.

Examples

```
library(terra)
n1_small <- rast(system.file("input_maps/n1_small.tif", package = "rangr"))
K_small <- rast(system.file("input_maps/K_small.tif", package = "rangr"))

# prepare data
sim_data <- initialise(
  n1_map = n1_small,
  K_map = K_small,
  r = log(2),
  rate = 1 / 1e3
)

sim_1 <- sim(obj = sim_data, time = 110, burn = 10)

# 1. random_one_layer
sample1 <- get_observations(
  sim_data,
  sim_1,
  type = "random_one_layer",
  prop = 0.1
)

# 2. random_all_layers
sample2 <- get_observations(
  sim_data,
  sim_1,
  type = "random_all_layers",
  prop = 0.15
)

# 3. from_data
sample3 <- get_observations(
  sim_data,
  sim_1,
  type = "from_data",
  points = observations_points
)

# 4. monitoring_based
# define observations sites
all_points <- xyFromCell(unwrap(sim_data$id), cells(unwrap(sim_data$K_map)))
sample_idx <- sample(1:nrow(all_points), size = 20)
sample_points <- all_points[sample_idx, ]

sample4 <- get_observations(
  sim_data,
  sim_1,
  type = "monitoring_based",
  cells_coords = sample_points,
  prob = 0.3,
```

```
  progress_bar = TRUE
)

# 5. noise "rlnorm"
sample5 <- get_observations(sim_data,
  sim_1,
  type = "random_one_layer",
  obs_error = "rlnorm",
  obs_error_param = log(1.2)
)

# 6. noise "rbinom"
sample6 <- get_observations(sim_data,
  sim_1,
  type = "random_one_layer",
  obs_error = "rbinom",
  obs_error_param = 0.8
)
```

---

growth *Population Growth Functions*

Description

Population growth functions are used during simulation conducted by the `sim` function. The user is required to specify the name of a growth function while initialising the `sim_data` object using `initialise`.

Usage

```
exponential(x, r, ...)

ricker(x, r, K, A = NA)

gompertz(x, r, K, A = NA)
```

Arguments

`x`	number of individuals
`r`	intrinsic population growth rate
`...`	not used, added for compatibility reasons
`K`	carrying capacity
`A`	coefficient of Allee effect (A <= 0: weak, A > 0: strong, NA: none)

Details

x can be a vector, matrix, SpatRaster or any other R object for which basic arithmetic operations produce valid results. These functions are intended to be used in the sim function, where x is a matrix of the same dimensions as the SpatRaster object specified in n1_map parameter.

Value

Object of the same dimensions as x that contains expected number of individuals in the next time step.

References

Boukal, D. S., & Berec, L. (2002). Single-species models of the Allee effect: extinction boundaries, sex ratios and mate encounters. Journal of Theoretical Biology, 218(3), 375-394. doi:10.1006/jtbi.2002.3084

Gompertz, B. (1825) On the Nature of the Function Expressive of the Law of Human Mortality, and on a New Mode of Determining the Value of Life Contigencies. Philosophical Transactions of the Royal Society of London, 115, 513-583. doi:10.1098/rstl.1825.0026

Ricker, W.E. (1954) Stock and Recruitment. Journal of the Fisheries Research Board of Canada, 11, 559-623. doi:10.1139/f54039

Hostetler, J.A. and Chandler, R.B. (2015), Improved state-space models for inference about spatial and temporal variation in abundance from count data. Ecology, 96: 1713-1723. doi:10.1890/14-1487.1

Courchamp, F., L. Berec and J. Gascoigne. 2008. Allee Effects in Ecology and Conservation. Oxford University Press, New York. 256 pp. ISBN 978-0-19-857030-1

Examples

```
x <- 1:10
exponential(x, r = 0.4)

ricker(x, r = 2, K = 5)
ricker(x, r = 2, K = 5, A = -5)

gompertz(x, r = 1.2, K = 5)
gompertz(x, r = 1.2, K = 5, A = 5)
```

---

initialise *Prepare Data Required To Perform A Simulation*

Description

This function generates a sim_data object containing all the necessary information required to run a simulation by the sim function. The input maps (n1_map and K_map) can be in the Cartesian or longitude/latitude coordinate system.

Usage

```
initialise(
  n1_map,
  K_map,
  K_sd = 0,
  r,
  r_sd = 0,
  growth = "gompertz",
  A = NA,
  dens_dep = c("K2N", "K", "none"),
  border = c("reprising", "absorbing"),
  kernel_fun = "rexp",
  ...,
  max_dist = NA,
  calculate_dist = TRUE,
  dlist = NULL,
  progress_bar = TRUE,
  quiet = FALSE
)
```

Arguments

`n1_map`	`SpatRaster` object with one layer; population numbers in every grid cell at the first time step
`K_map`	`SpatRaster` object with one layer; carrying capacity map (if K is constant across time) or maps (if K is time-varying)
`K_sd`	numeric vector of length 1 with value `>= 0` (default 0); this parameter can be used if additional environmental stochasticity is required; if `K_sd` > `0`, random numbers are generated from a log-normal distribution with the mean `K_map` and standard deviation `K_sd`
`r`	numeric vector of length 1; intrinsic population growth rate
`r_sd`	numeric vector of length 1 with value `>= 0` (default `0`); if additional demographic stochasticity is required, `r_sd` > `0` is the standard deviation for a normal distribution around `r` (defined for each time step)
`growth`	character vector of length 1; the name of a population growth function, either defined in `growth` or provided by the user (case-sensitive, default `"gompertz"`)
`A`	numeric vector of length 1; strength of the Allee effect (see the `growth` function)
`dens_dep`	character vector of length 1 specifying if the probability of settling in a target grid cell is (case-sensitive, default `"K2N"`): • "none" - fully random, • "K" - proportional to the carrying capacity of a target cell, • "K2N" - density-dependent, i.e. proportional to the ratio of carrying capacity of a target cell to the number of individuals already present in a target cell
`border`	character vector of length 1 defining how to deal with borders (case-sensitive, default `"absorbing"`):

- "reprising" - cells outside the study area are not allowed as targets for dispersal
- "absorbing" - individuals that disperse outside the study area are removed from the population

`kernel_fun`	character vector of length 1; name of a random number generation function defining a dispersal kernel (case-sensitive, default `"rexp"`)
`...`	any parameters required by `kernel_fun`
`max_dist`	numeric vector of length 1; maximum distance of dispersal to pre-calculate target cells
`calculate_dist`	logical vector of length 1; determines if target cells will be precalculated
`dlist`	list; target cells at a specified distance calculated for every cell within the study area
`progress_bar`	logical vector of length 1; determines if progress bar for calculating distances should be displayed
`quiet`	logical vector of length 1; determines if messages should be displayed

Details

The most time-consuming part of computations performed by the `sim` function is the simulation of dispersal. To speed it up, a list containing indexes of target cells at a specified distance from a focal cell is calculated in advance and stored in a `dlist` slot. The `max_dist` parameter sets the maximum distance at which this pre-calculation is performed. If `max_dist` is `NULL`, it is set to 0.99 quantile from the `kernel_fun`. All distance calculations are always based on metres if the input maps are latitude/longitude. For planar input maps, distances are calculated in map units, which are typically metres, but check the `crs()` if in doubt.

If the input maps are in the Cartesian coordinate system and the grid cells are squares, then the distances between cells are calculated using the `distance` function from the `terra` package. These distances are later divided by the resolution of the input maps.

For input maps with grid cells in shapes other than squares (e.g. with rectangular cells or longitude/latitude coordinate system), the distance resolution is calculated by finding the shortest distance between each "queen" type neighbor. All distances calculated by the `distance` function are further divided by this distance resolution. To avoid discontinuities in the distances at which the target cells are located, an additional parameter `dist_bin` is calculated as half of the maximum distance between each "queen" type neighbour. It is used to expand the distances at which target cells are located from a single number to a range.

NA in the input maps represents cells outside the study area.

The `K_get_interpolation` function can be used to prepare `K_map` that changes over time. This may be useful, when simulating environmental change or exploring the effects of ecological disturbances.

Value

Object of class `sim_data` which inherits from `list`. This object contains all necessary information to perform a simulation using `sim` function.

References

Hijmans R (2024). terra: Spatial Data Analysis. R package version 1.7-81, https://rspatial.github.io/terra/, https://rspatial.org/

Solymos P, Zawadzki Z (2023). pbapply: Adding Progress Bar to '*apply' Functions. R package version 1.7-2, https://CRAN.R-project.org/package=pbapply.

See Also

update

Examples

```
# input maps
library(terra)

n1_small <- rast(system.file("input_maps/n1_small.tif", package = "rangr"))
K_small <- rast(system.file("input_maps/K_small.tif", package = "rangr"))
K_small_changing <- rast(system.file("input_maps/K_small_changing.tif",
                         package = "rangr"))
n1_small_lon_lat <- rast(system.file("input_maps/n1_small_lon_lat.tif", package = "rangr"))
K_small_lon_lat <- rast(system.file("input_maps/K_small_lon_lat.tif", package = "rangr"))

# basic example
sim_data_1 <- initialise(
  n1_map = n1_small,
  K_map = K_small,
  r = log(2),
  rate = 1 / 1e3
)

# example with changing environment
K_interpolated <- K_get_interpolation(
  K_small_changing,
  K_time_points = c(1, 25, 50)
)

sim_data_2 <- initialise(
  n1_map = n1_small,
  K_map = K_interpolated,
  r = log(2),
  rate = 1 / 1e3
)

# example with lon/lat rasters
sim_data_3 <- initialise(
  n1_map = n1_small_lon_lat,
  K_map = K_small_lon_lat,
  r = log(2),
  rate = 1 / 1e3
)
```

```
# example without progress bar and messages
sim_data_4 <- initialise(
  n1_map = n1_small, K_map = K_small, K_sd = 0.1, r = log(5),
  r_sd = 4, growth = "ricker", rate = 1 / 200,
  max_dist = 5000, dens_dep = "K2N", progress_bar = FALSE, quiet = TRUE
)
```

`K_big.tif` *Example Of Carrying Capacity Map (Big)*

Description

SpatRaster object that can be used as a carrying capacity map to initialise data necessary to perform a simulation with the sim function. This map is compatible with n1_big.tif.

Format

SpatRaster object with 100 rows and 100 columns containing integer values 0-25 and NA's indicating unsuitable areas.

Source

Data generated in-house to serve as an example (using spatial autocorrelation).

Examples

```
system.file("input_maps/K_big.tif", package = "rangr")
```

`K_big_lon_lat.tif` *Example Of Carrying Capacity Map (Big)*

Description

SpatRaster object representing a carrying capacity map projected to WGS 84 (CRS84) from the original raster `K_big`. This map can be used as a carrying capacity map to initialise data necessary to perform a simulation with the sim function. It is compatible with the `n1_big_lon_lat.tif` raster.

Format

SpatRaster object with 74 rows and 125 columns containing integer values 0-25 and NA's indicating unsuitable areas.

Source

Data generated in-house to serve as an example (using spatial autocorrelation).

Examples

```
system.file("input_maps/K_big_lon_lat.tif", package = "rangr")
```

K_get_interpolation *Prepare Time-Varying Carrying Capacity Maps*

Description

This function linearly interpolates values in a series of carrying capacity maps.

Usage

```
K_get_interpolation(K_map, K_time_points = NULL, time = NULL)
```

Arguments

K_map	SpatRaster object with carrying capacity maps for each K_time_points
K_time_points	integer vector; time for each layer in K_map, should contain unique values
time	integer vector of length 1; number of total time steps required (this is defined when evoking the function sim).

Details

To simulate dynamic environmental scenarios (e.g. climate change, land use change, ecological disturbance, etc.) one needs to provide time-varying carrying capacity maps.

Either K_time_points or the time parameter is needed to perform interpolation. If the interpolation should be calculated between two carrying capacity maps, there is no need to pass the time points, because 1 will be set as the starting time point and time will be used as the ending point. On the other hand, in the absence of the time argument, the maximum element of K_time_points is considered to be the ending point for the interpolation.

Value

SpatRaster object with number of layers equal to time.

Examples

```
# data preparation
library(terra)

n1_small <- rast(system.file("input_maps/n1_small.tif", package = "rangr"))
K_small_changing <- rast(system.file("input_maps/K_small_changing.tif",
package = "rangr"))

K_interpolated_01 <- K_get_interpolation(
  K_small_changing,
  K_time_points = c(1, 10, 15)
)

K_two_layers <- subset(
  K_small_changing,
  c(1, 2)
)
K_interpolated_02 <- K_get_interpolation(
  K_two_layers,
  time = 15
)
```

K_small.tif — *Example Of Carrying Capacity Map (Small)*

Description

SpatRaster object that can be used a carrying capacity map to initialise data necessary to perform a simulation with the sim function. This map is compatible with n1_small.tif.

Format

SpatRaster object with 15 rows and 10 columns containing integer values 0-100 and NA's indicating unsuitable areas.

Source

Data generated in-house to serve as an example (using spatial autocorrelation).

Examples

```
system.file("input_maps/K_small.tif", package = "rangr")
```

K_small_changing.tif *Example Of Changing Carrying Capacity Maps (Small)*

Description

SpatRaster object that can be used as carrying capacity maps to initialise data necessary to perform a simulation with the sim function. To utilise these maps in initialise the user first must use K_get_interpolation to generate a map for every time step of the simulation. These maps are compatible with n1_small.tif. Each subsequent map contains a virtual environment with greater carrying capacity than the previous one.

Format

SpatRaster object with 3 layers, each has 15 rows and 10 columns containing integer values 0-170 and NA's that indicates unsuitable areas.

Source

Data generated in-house to serve as an example (using spatial autocorrelation).

Examples

```
system.file("input_maps/K_small_changing.tif", package = "rangr")
```

K_small_changing_lon_lat.tif *Example Of Changing Carrying Capacity Maps (Small)*

Description

SpatRaster object representing changing carrying capacity maps projected to WGS 84 (CRS84) from the original raster K_small_changing. These maps can be used as carrying capacity maps to initialise data necessary to perform a simulation with the sim function. To utilise these maps in initialise the user must first use K_get_interpolation to generate a map for every time step of the simulation. These maps are compatible with the n1_small_lon_lat.tif raster.

Format

SpatRaster object with 3 layers, each having 12 rows and 14 columns containing integer values 0-170 and NA's indicating unsuitable areas.

Source

Data generated in-house to serve as an example (using spatial autocorrelation).

Examples

```
system.file("input_maps/K_small_changing_lon_lat.tif", package = "rangr")
```

`K_small_lon_lat.tif` *Example Of Carrying Capacity Map (Small)*

Description

`SpatRaster` object that represents a carrying capacity map projected to WGS 84 (CRS84) from the original raster `K_small`. This map can be used as a carrying capacity map to `initialise` data necessary to perform a simulation with the `sim` function. It is compatible with the `n1_small_lon_lat.tif` raster.

Format

`SpatRaster` object with 12 rows and 14 columns containing integer values 0-100 and NA's indicating unsuitable areas.

Source

Data generated in-house to serve as an example (using spatial autocorrelation).

Examples

```
system.file("input_maps/K_small_lon_lat.tif", package = "rangr")
```

`n1_big.tif` *Example Of Abundance Map At First Time Step Of The Simulation (Big)*

Description

`SpatRaster` object that can be used a as simulation starting point to `initialise` data necessary to perform a simulation with the `sim` function. This map is compatible with `K_big.tif` map.

Format

`SpatRaster` object with 100 rows and 100 columns containing integer values 0-50 and NA's that indicates unsuitable areas.

Source

Data generated in-house to serve as an example.

Examples

```
system.file("input_maps/n1_big.tif", package = "rangr")
```

---

n1_big_lon_lat.tif — *Example Of Abundance Map At First Time Step Of The Simulation (Big)*

Description

SpatRaster object representing an abundance map at the first time step of the simulation projected to WGS 84 (CRS84) from the original raster n1_big. This map can be used as a simulation starting point to initialise data necessary to perform a simulation with the sim function. It is compatible with the K_big_lon_lat.tif map.

Format

SpatRaster object with 74 rows and 125 columns containing integer values 0-50 and NA's indicating unsuitable areas.

Source

Data generated in-house to serve as an example.

Examples

```
system.file("input_maps/n1_big_lon_lat.tif", package = "rangr")
```

---

n1_small.tif — *Example Of Abundance Map At First Time Step Of The Simulation (Small)*

Description

SpatRaster object that can be used a as simulation starting point to initialise data necessary to perform a simulation with the sim function. This map is compatible with K_small.tif and K_small_changing.tif maps.

Format

SpatRaster object with 15 rows and 10 columns containing integer values 0-10 and NA's indicating unsuitable areas.

Source

Data generated in-house to serve as an example.

Examples

```
system.file("input_maps/n1_small.tif", package = "rangr")
```

---

n1_small_lon_lat.tif *Example Of Abundance Map At First Time Step Of The Simulation (Small)*

Description

SpatRaster object representing an abundance map at the first time step of the simulation projected to WGS 84 (CRS84) from the original raster n1_small. This map can be used as a simulation starting point to initialise data necessary to perform a simulation with the sim function. It is compatible with the K_small_lon_lat.tif and K_small_changing_lon_lat.tif maps.

Format

SpatRaster object with 12 rows and 14 columns containing integer values 0-10 and NA's indicating unsuitable areas.

Source

Data generated in-house to serve as an example.

Examples

```
system.file("input_maps/n1_small_lon_lat.tif", package = "rangr")
```

---

observations_points *Example Of Observation Points List*

Description

A data.frame containing a sample input data to the function get_observations when type argument is set to "from_file". This data is compatible with n1_small.tif, K_small.tif and K_small_changing.tif maps.

Usage

```
observations_points
```

Format

A data frame with 1500 rows and 3 variables:

x x coordinate

y y coordinate

time_step time_step at which the abundances should be observed

Source

Data generated in-house to serve as an example

`plot.sim_results` *Plot* `sim_results` *Object*

Description

Plots abundances obtained during simulation.

Usage

```
## S3 method for class 'sim_results'
plot(x, template = NULL, time_points = NULL, range, type, ...)
```

Arguments

`x`	`sim_results` object; returned by `sim`
`template`	`SpatRaster` object; can be used as a template to create returned object
`time_points`	numeric vector; specifies points in time from which plots will be generated
`range`	numeric vector of length 2; range of values to be used for the legend (if `type = "continuous"`), which by default is calculated from the N_map slot of `sim_result` object
`type`	character vector of length 1; type of map: "continuous" (default), "classes" or "interval" (case-sensitive)
`...`	further arguments passed to `terra::plot`

Value

`SpatRaster` object with as many layers as the length of `time_points` parameter

Examples

```
library(terra)

n1_small <- rast(system.file("input_maps/n1_small.tif", package = "rangr"))
K_small <- rast(system.file("input_maps/K_small.tif", package = "rangr"))

sim_data <- initialise(
  n1_map = n1_small,
  K_map = K_small,
  r = log(2),
  rate = 1 / 1e3
)
sim_res <- sim(sim_data, time = 10)
plot(sim_res)
plot(sim_res, template = n1_small, time_points = c(1, 10))

# plot specific area
plot(sim_res, xlim = c(4, 10), ylim = c(0, 10))
plot(sim_res, ext = c(4, 10, 0, 10))
plot(sim_res, template = n1_small, ext = c(274000, 280000, 610000, 620000))
```

---

print.sim_data *Print* sim_data *Object*

Description

Print sim_data Object

Usage

```
## S3 method for class 'sim_data'
print(x, ...)
```

Arguments

x	sim_data object; returned by the initialise function
...	further arguments passed to or from other methods; currently none specified

Value

sim_data object is invisibly returned (the x param)

Examples

```
library(terra)

n1_small <- rast(system.file("input_maps/n1_small.tif", package = "rangr"))
K_small <- rast(system.file("input_maps/K_small.tif", package = "rangr"))

sim_data <- initialise(
  n1_map = n1_small,
  K_map = K_small,
  r = log(2),
  rate = 1 / 1e3
)
print(sim_data)
```

---

print.sim_results   *Print* sim_results *Object*

Description

Print sim_results Object

Usage

```
## S3 method for class 'sim_results'
print(x, ...)
```

Arguments

x	sim_results object; returned by the sim function
...	further arguments passed to or from other methods; none specified

Value

sim_results object is invisibly returned (the x param)

Examples

```
library(terra)

n1_small <- rast(system.file("input_maps/n1_small.tif", package = "rangr"))
K_small <- rast(system.file("input_maps/K_small.tif", package = "rangr"))

sim_data <- initialise(
  n1_map = n1_small,
  K_map = K_small,
  r = log(2),
  rate = 1 / 1e3
)
```

```
sim_res <- sim(obj = sim_data, time = 20, burn = 5)
print(sim_res)
```

print.summary.sim_data

Print summary.sim_data *Object*

Description

Print summary.sim_data Object

Usage

```
## S3 method for class 'summary.sim_data'
print(x, ...)
```

Arguments

x	summary.sim_data object; returned by summary.sim_data function
...	further arguments passed to or from other methods; currently none specified

Value

None

Examples

```
# data preparation
library(terra)

n1_small <- rast(system.file("input_maps/n1_small.tif", package = "rangr"))
K_small <- rast(system.file("input_maps/K_small.tif", package = "rangr"))

sim_data <- initialise(
  n1_map = n1_small,
  K_map = K_small,
  r = log(2),
  rate = 1 / 1e3
)
summary_sim_data <- summary(sim_data)
print(summary_sim_data)
```

print.summary.sim_results
Print summary.sim_results *Object*

Description

Print summary.sim_results Object

Usage

```
## S3 method for class 'summary.sim_results'
print(x, ...)
```

Arguments

x	summary.sim_results object; returned by summary.sim_results function
...	further arguments passed to or from other methods; currently none specified

Value

None

Examples

```
# data preparation
library(terra)

n1_small <- rast(system.file("input_maps/n1_small.tif", package = "rangr"))
K_small <- rast(system.file("input_maps/K_small.tif", package = "rangr"))

sim_data <- initialise(
  n1_map = n1_small,
  K_map = K_small,
  r = log(2),
  rate = 1 / 1e3
)
sim_results <- sim(sim_data, time = 10)
summary_sim_results <- summary(sim_results)
print(summary_sim_results)
```

sim *Mechanistic Metapopulation Simulator*

Description

This function simulates population growth and dispersal providing a given environmental scenario. All parameters for the simulation must be set in advance using `initialise`.

Usage

```
sim(
  obj,
  time,
  burn = 0,
  return_mu = FALSE,
  cl = NULL,
  progress_bar = TRUE,
  quiet = FALSE
)
```

Arguments

`obj`	`sim_data` object created by `initialise` containing all simulation parameters and necessary data
`time`	positive integer vector of length 1; number of time steps simulated
`burn`	positive integer vector of length 1; the number of burn-in time steps that are discarded from the output
`return_mu`	logical vector of length 1; if `TRUE` demographic process return expected values; if `FALSE` the `rpois` function should be used
`cl`	an optional cluster object created by `makeCluster` needed for parallel calculations
`progress_bar`	logical vector of length 1 determines if progress bar for simulation should be displayed
`quiet`	logical vector of length 1; determines if warnings should be displayed

Details

This is the main simulation module. It takes the `sim_data` object prepared by `initialise` and runs simulation for a given number of time steps. The initial (specified by the `burn` parameter) time steps are skipped and discarded from the output. Computations can be done in parallel if the name of a cluster created by `makeCluster` is provided.

Generally, at each time step, simulation consists of two phases: local dynamics and dispersal.

Local dynamics (which connects habitat patches in time) is defined by the function `growth`. This parameter is specified while creating the `obj` using `initialise`, but can be later modified by using the `update` function. Population growth can be either exponential or density-dependent, and the regulation is implemented by the use of Gompertz or Ricker models (with a possibility of providing any other, user defined function). For every cell, the expected population density during the next time step is calculated from the corresponding number of individuals currently present in this cell, and the actual number of individuals is set by drawing a random number from the Poisson distribution using this expected value. This procedure introduces a realistic randomness, however additional levels of random variability can be incorporated by providing parameters of both demographic and environmental stochasticity while specifying the `sim_data` object using the `initialise` function (parameters `r_sd` and `K_sd`, respectively).

To simulate dispersal (which connects habitat patches in space), for each individual in a given cell, a dispersal distance is randomly drawn from the dispersal kernel density function. Then, each individual is translocated to a randomly chosen cell at this distance apart from the current location. For more details, see the `disp` function.

Value

This function returns an object of class `sim_results` which is a list containing the following components:

- `extinction` - `TRUE` if population is extinct or `FALSE` otherwise
- `simulated_time` - number of simulated time steps without the burn-in ones
- `N_map` - 3-dimensional array representing spatio-temporal variability in population numbers. The first two dimensions correspond to the spatial aspect of the output and the third dimension represents time.

In case of a total extinction, a simulation is stopped before reaching the specified number of time steps. If the population died out before reaching the `burn` threshold, then nothing can be returned and an error occurs.

References

Solymos P, Zawadzki Z (2023). pbapply: Adding Progress Bar to '*apply' Functions. R package version 1.7-2, https://CRAN.R-project.org/package=pbapply.

See Also

get_observations

Examples

```
# data preparation
library(terra)

n1_small <- rast(system.file("input_maps/n1_small.tif", package = "rangr"))
K_small <- rast(system.file("input_maps/K_small.tif", package = "rangr"))

sim_data <- initialise(
  n1_map = n1_small,
  K_map = K_small,
  r = log(2),
```

```
  rate = 1 / 1e3
)

# simulation
sim_1 <- sim(obj = sim_data, time = 20)

# simulation with burned time steps
sim_2 <- sim(obj = sim_data, time = 20, burn = 10)

# example with parallelization
library(parallel)
cl <- makeCluster(2)

# parallelized simulation
sim_3 <- sim(obj = sim_data, time = 20, cl = cl)
stopCluster(cl)


# visualisation
plot(
  sim_1,
  time_points = 20,
  template = sim_data$K_map
)

plot(
  sim_1,
  time_points = c(1, 5, 10, 20),
  template = sim_data$K_map
)

plot(
  sim_1,
  template = sim_data$K_map
)
```

---

subset.sim_results *Subset of Given Time Points from* `sim_results` *Object*

Description

This function creates a subset of given time points from the `sim_results` object.

Usage

```
## S3 method for class 'sim_results'
subset(x, from = NULL, time_points = NULL, ...)
```

Arguments

x	sim_results object; returned by the sim function
from	numeric vector of length 1; indicates the starting time point from which all time point should be kept
time_points	numeric vector; indicates all time points to keep
...	further arguments to be passed to or from other methods

Details

Either from or time_points argument has to be specified. Time point passed by the from argument will be set as a cutoff point and all abundances for previous time points will be discarded.

Value

sim_results object with only selected time_points present in the N_map slot

Examples

```
# data preparation
library(terra)

n1_small <- rast(system.file("input_maps/n1_small.tif", package = "rangr"))
K_small <- rast(system.file("input_maps/K_small.tif", package = "rangr"))

sim_data <- initialise(
  n = n1_small,
  r = log(2),
  K_map = K_small,
  max_dist = 1000,
  rate = 1 / 1e3
)

sim_results <- sim(sim_data, time = 10)
summary(sim_results)

sim_results_cropped <- subset(sim_results, time_points = c(1:2))
summary(sim_results_cropped)
```

---

summary.sim_data *Summary Of* sim_data *Object*

Description

Summary Of sim_data Object

Usage

```
## S3 method for class 'sim_data'
summary(object, ...)
```

Arguments

`object`	`sim_data` object; returned by `initialise` function
`...`	further arguments passed to or from other methods; currently none specified

Value

`summary.sim_data` object

Examples

```
# data preparation
library(terra)

n1_small <- rast(system.file("input_maps/n1_small.tif", package = "rangr"))
K_small <- rast(system.file("input_maps/K_small.tif", package = "rangr"))

sim_data <- initialise(
  n1_map = n1_small,
  K_map = K_small,
  r = log(2),
  rate = 1 / 1e3
)
summary(sim_data)
```

`summary.sim_results` *Summary Of* `sim_results` *Object*

Description

Summary Of `sim_results` Object

Usage

```
## S3 method for class 'sim_results'
summary(object, ...)
```

Arguments

`object`	`sim_results` object; returned by `sim` function
`...`	further arguments passed to or from other methods; none specified

Value

summary.sim_results object

Examples

```
# data preparation
library(terra)

n1_small <- rast(system.file("input_maps/n1_small.tif", package = "rangr"))
K_small <- rast(system.file("input_maps/K_small.tif", package = "rangr"))

sim_data <- initialise(
  n1_map = n1_small,
  K_map = K_small,
  r = log(2),
  rate = 1 / 1e3
)

# simulation
sim_results <- sim(sim_data, time = 10)
summary(sim_results)
```

---

to_rast — *Transformation* sim_results *To Raster*

Description

This function transforms selected subset of abundance matrices from sim_results into SpatRaster object. Layers are specified by time_points, which can be one or multiple points in time.

Usage

```
to_rast(sim_results, time_points = sim_results$simulated_time, template = NULL)
```

Arguments

sim_results	sim_results object created by sim
time_points	numeric vector of length 1 or more; specifies points in time from which SpatRaster will be created - as default the last year of simulation; if length(time_points) > 0 SpatRaster will be returned with layers for each element of time_points
template	SpatRaster object; can be used as a template to create returned object

Value

SpatRaster based on sim_results object with layers corresponding to time_points.

References

Hijmans R (2024). terra: Spatial Data Analysis. R package version 1.7-81, https://rspatial.github.io/terra/, https://rspatial.org/

Examples

```
# data preparation
library(terra)

n1_small <- rast(system.file("input_maps/n1_small.tif", package = "rangr"))
K_small <- rast(system.file("input_maps/K_small.tif", package = "rangr"))

sim_data <- initialise(
  n1_map = n1_small,
  K_map = K_small,
  r = log(2),
  rate = 1 / 1e3
)

# simulation
sim_1 <- sim(obj = sim_data, time = 100)

# raster construction
my_rast <- to_rast(
  sim_1,
  time_points = c(1, 10, 20, 100),
  template = sim_data$K_map
)

# visualization
plot(my_rast, range = range(sim_1$N_map, na.rm = TRUE))
```

---

update.sim_data *Update* `sim_data` *Object*

Description

This function updates a `sim_data` object.

Usage

```
## S3 method for class 'sim_data'
update(object, ..., evaluate = TRUE)
```

Arguments

object	sim_data object; returned by initialise function
...	further arguments passed to or from other methods; currently none specified
evaluate	logical vector of length 1; if TRUE evaluates the new call, otherwise returns the call

Value

If evaluate = TRUE then the updated sim_data object, otherwise the updated call.

Examples

```
# data preparation
library(terra)
n1_small <- rast(system.file("input_maps/n1_small.tif", package = "rangr"))
K_small <- rast(system.file("input_maps/K_small.tif", package = "rangr"))

sim_data_1 <- initialise(
  n1_map = n1_small,
  K_map = K_small,
  r = log(2),
  rate = 1 / 1e3
)
summary(sim_data_1)

sim_data_2 <- update(sim_data_1, max_dist = 3000)
summary(sim_data_2)
```

Index