Package ‘restoptr’

June 17, 2022

**Type** Package

**Title** Ecological Restoration Planning

**Version** 1.0.1

**Description** Flexible framework for ecological restoration planning. It aims to identify priority areas for restoration efforts using optimization algorithms (based on Justeau-Allaire et al. 2021 <doi:10.1111/1365-2664.13803>). Priority areas can be identified by maximizing landscape indices, such as the effective mesh size (Jaeger 2000 <doi:10.1023/A:1008129329289>), or the integral index of connectivity (Pascual-Hortal & Saura 2006 <doi:10.1007/s10980-006-0013-z>). Additionally, constraints can be used to ensure that priority areas exhibit particular characteristics (e.g., ensure that particular places are not selected for restoration, ensure that priority areas form a single contiguous network). Furthermore, multiple near-optimal solutions can be generated to explore multiple options in restoration planning. The package leverages the ‘Choco-solver’ software to perform optimization using constraint programming (CP) techniques (<https://choco-solver.org/>).

**License** GPL-3

**Encoding** UTF-8

**Language** en-US

**URL** https://dimitri-justeau.github.io/restoptr/

**BugReports** https://github.com/dimitri-justeau/restoptr/issues

**SystemRequirements** Java (>= 11.0.12)

**VignetteBuilder** knitr

**RoxygenNote** 7.2.0

**Imports** utils, assertthat (>= 0.2.1), magrittr, crayon (>= 1.4.1), methods

**Depends** R (>= 4.1.0), terra (>= 1.5-12), rJava (>= 1.0.5), units (>= 0.8-0)

**Suggests** testthat (>= 2.0.1), knitr (>= 1.2.0), roxygen2 (>= 6.1.1), rmarkdown (>= 1.10), landscapemetrics (>= 1.5.4), raster (>= 3.5), rgdal, vegan (>= 2.5.7), cluster (>= 2.1.2)
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'add_compactness_constraint.R' 'add_components_constraint.R'
'add_connected_constraint.R' 'add_locked_out_constraint.R'
'add_min_iic_constraint.R' 'add_min_mesh_constraint.R'
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'set_no_objective.R' 'solve.R' 'terra_io.R' 'terra_utils.R'
'utils.pipe.R' 'zzz.R'

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add_available_areas_constraint

Add available areas constraint

Description

Add constraint to a restoration problem (restopt_problem()) object to specify that only certain planning units can be selected for restoration activities.

Usage

add_available_areas_constraint(problem, data)

Arguments

problem
restopt_problem() Restoration problem object.

data
terra::rast() or terra::vect() Either a raster object containing binary values that indicate which planning units can be selected for restoration (i.e., only cells with a value equal one are available), or a vector object whose features correspond to the available areas.

Details

Available areas constraints can be used to incorporate a wide range of criteria into restoration planning problems. They can be used to account for existing land-use practices, feasibility of restoration activities, and stakeholder preferences. For example, available areas constraints can be used to ensure that urban areas are not selected for restoration. Additionally, if restoration activities can only be implemented depending on certain conditions – such as places where landscape slope is not too steep – then available areas constraints could be used to ensure restoration activities are not prioritized for places where they could not be implemented. Furthermore, if stakeholders require solutions that do not prioritize particular places for restoration, then available areas constraints
can also be used to achieve this. See `add_locked_out_constraint()`, which achieve the same as available areas constraint by defining areas that are NOT available for restoration. **Note:** The locked out constraint and the available are the same constraints, with a different input data. Thus, from a modelling perspective, `add_available_areas_constraint()` is just a pre processing layer in front of `add_locked_out_constraint()`. This is why if you print a restopt problem with an available areas constraint, you will see a locked out constraint.

**Value**

An updated restoration problem (`restopt_problem()`) object.

**See Also**

Other constraints: `add_compactness_constraint()`, `add_components_constraint()`, `add_connected_constraint()`, `add_locked_out_constraint()`, `add_min_iic_constraint()`, `add_min_mesh_constraint()`, `add_restorable_constraint()`

**Examples**

```r
# load data
habitat_data <- rast(
    system.file("extdata", "habitat_hi_res.tif", package = "restoptr")
)

available <- vect(
    system.file("extdata", "accessible_areas.gpkg", package = "restoptr")
)

# plot data
plot(habitat_data)
plot(available, add=TRUE)

# create problem with available areas constraints
p <- restopt_problem(
    existing_habitat = habitat_data,
    aggregation_factor = 16,
    habitat_threshold = 0.7
) %>%
set_max_iic_objective() %>%
add_restorable_constraint(
    min_restore = 5,
    max_restore = 5,
) %>%
add_available_areas_constraint(available) %>%
add_settings(time_limit = 1)

# print problem
print(p)

# solve problem
s <- solve(p)
```
add_compactness_constraint

# plot solution
plot(s)

---

**add_compactness_constraint**

*Add constraint to limit compactness*

**Description**

Add constraint to a restoration problem (*restopt_problem()* object to specify the compactness of a solution.

**Usage**

```
add_compactness_constraint(problem, max_diameter, unit = "m")
```

**Arguments**

- **problem**: *restopt_problem()* Restoration problem object.
- **max_diameter**: numeric Maximum diameter value.
- **unit**: unit object or a character that can be coerced to an area unit (see *unit* package), or "cells" for cell width of aggregated habitat raster. Corresponds to the unit of the maximum diameter. If the input habitat raster does not use a projected coordinate system, only "cells" is available.

**Details**

The compactness constraint is defined according to the diameter of the smallest enclosing circle which contains the center of selected planning units for restoration (see https://w.wiki/4vfg). The unit of the diameter corresponds either to a unit available in the unit package, or to planning unit width ("cells"). Note that, as the computation occurs on aggregated cells, if `max_diameter` is used with a different unit than "cells", it will be rounded to the closest corresponding number of cells. For example, a diameter of 4 cells means that no more than 4 cells can be found in line in the solution. In practice, this constraint is useful to ensure the feasibility of a restoration project, and to integrate economies of scale. Compact restoration areas are usually associated with lower costs and easier management, because it ensures that restoration sites are not too far away from each other (e.g. lower travel costs between sites, less areas to monitor, etc.).

**Value**

An updated restoration problem (*restopt_problem()* object.)
add_components_constraint

Add constraint to limit the number of connected components

Description

Add constraint to a restoration problem (restopt_problem()) object to specify the number of connected components that can be present within a solution.

Usage

add_components_constraint(problem, min_nb_components, max_nb_components)
Arguments

- **problem**: `restopt_problem()` Restoration problem object.
- **min_nb_components**: integer Minimum number of connected components.
- **max_nb_components**: integer Maximum number of connected components.

Details

A connected component is a spatially continuous set of planning units. This constraints applies on the set of planning units that are selected for restoration, and allows to specify a minimum and maximum number of connected components. In practice, this constraint is useful to ensure the feasibility of a restoration project, and to integrate economies of scale. Continuous restoration areas (i.e. less connected components) are usually associated with lower costs, because it ensures that restoration sites are not too far away from each other (e.g. lower travel costs between sites, less areas to monitor, etc.). On the other hand, it can be useful to enforce several disconnected restoration areas to ensure that hazards (e.g. fire) do not strike all planning units at the same time.

Value

An updated restoration problem (`restopt_problem()`) object.

See Also

Other constraints: `add_available_areas_constraint()`, `add_compactness_constraint()`, `add_connected_constraint()`, `add_locked_out_constraint()`, `add_min_iic_constraint()`, `add_min_mesh_constraint()`, `add_restorable_constraint()`

Examples

```r
# load data
habitat_data <- rast(
  system.file("extdata", "habitat_hi_res.tif", package = "restoptr")
)

# create problem
p <- restopt_problem(
  existing_habitat = habitat_data,
  aggregation_factor = 16,
  habitat_threshold = 0.7
) %>%
  add_restorable_constraint(
    min_restore = 10,
    max_restore = 100,
  ) %>%
  add_components_constraint(1, 1)

# plot preprocessed data
plot(rast(list(p$data$existing_habitat, p$data$restorable_habitat)), nc = 2)
```
# print problem
print(p)

# Solve problem
s <- solve(p)
# plot solution
plot(s)

--

add_connected_constraint

*Add constraint to ensure that the selected planning units for restoration are connected.*

Description

Add constraint to a restoration problem (`restopt_problem()`) object to specify the selected planning units are connected.

Usage

```r
add_connected_constraint(problem)
```

Arguments

- `problem` `restopt_problem()` Restoration problem object.

Details

A connected area is such that there is a path between any to planning units within the area. This constraint applies on the set of planning units that are selected for restoration. In practice, this constraint is useful to ensure the feasibility of a restoration project, and to integrate economies of scale. Connected restoration areas are usually associated with lower costs, because it ensures that restoration sites are not too far away from each other (e.g. lower travel costs between sites, less areas to monitor, etc.). **Note** This constraint relies on the `add_components_constraint()`, with parameters set to enforce exactly one connected component. Also see `add_components_constraint` and `add_compactness_constraint`.

Value

An updated restoration problem (`restopt_problem()`) object.

See Also

Other constraints: `add_available_areas_constraint()`, `add_compactness_constraint()`, `add_components_constraint()`, `add_locked_out_constraint()`, `add_min_iic_constraint()`, `add_min_mesh_constraint()`, `add_restorable_constraint()`
add_locked_out_constraint

Examples

```r
# load data
habitat_data <- rast(
  system.file("extdata", "habitat_hi_res.tif", package = "restoptr")
)

# create problem
p <- restopt_problem(
  existing_habitat = habitat_data,
  aggregation_factor = 16,
  habitat_threshold = 0.7
) %>%
  add_restorable_constraint(
    min_restore = 10,
    max_restore = 100,
  ) %>%
  add_connected_constraint()

# plot preprocessed data
plot(rast(list(p$data$existing_habitat, p$data$restorable_habitat)), nc = 2)

# print problem
print(p)

# Solve problem
s <- solve(p)
# plot solution
plot(s)
```

add_locked_out_constraint

*Add locked out constraint*

**Description**

Add constraint to a restoration problem (`restopt_problem()`) object to specify that certain planning units cannot be selected for restoration activities.

**Usage**

```r
add_locked_out_constraint(problem, data)
```

**Arguments**

`problem` `restopt_problem()` Restoration problem object.
Either a raster object containing binary values that indicate which planning units cannot be selected for any restoration (i.e., cells with a value equal one are locked out from the solution), or a vector object whose features correspond to the locked out areas. See the function `add_available_areas_constraint()` to get a locked out constraint from allowed restoration areas.

Details

Locked out constraints can be used to incorporate a wide range of criteria into restoration planning problems. They can be used to account for existing land-use practices, feasibility of restoration activities, and stakeholder preferences. For example, locked out constraints can be used to ensure that urban areas are not selected for restoration. Additionally, if restoration activities can only be implemented depending on certain conditions – such as places where landscape slope is not too steep – then locked out constraints could be used to ensure restoration activities are not prioritized for places where they could not be implemented. Furthermore, if stakeholders require solutions that do not prioritize particular places for restoration, then locked out constraints can also be used to achieve this. See `add_available_areas_constraint()`, which achieve the same as the locked out constraint by defining areas that ARE available for restoration.

Value

An updated restoration problem (`restopt_problem()`) object.

See Also

Other constraints: `add_available_areas_constraint()`, `add_compactness_constraint()`, `add_components_constraint()`, `add_connected_constraint()`, `add_min_iic_constraint()`, `add_min_mesh_constraint()`, `add_restorable_constraint()`.

Examples

```r
# load data
habitat_data <- rast(
  system.file("extdata", "habitat_hi_res.tif", package = "restoptr")
)

locked_out_data <- rast(
  system.file("extdata", "locked_out.tif", package = "restoptr")
)

# plot data
plot(rast(list(habitat_data, locked_out_data)), nc = 2)

# create problem with locked out constraints
p <- restopt_problem(
  existing_habitat = habitat_data,
  aggregation_factor = 16,
  habitat_threshold = 0.7
) %>%
set_max_iic_objective() %>%
```
add_min_iic_constraint

```r
add_restorable_constraint(
  min_restore = 5,
  max_restore = 5,
) %>%
add_locked_out_constraint(data = locked_out_data) %>%
add_settings(time_limit = 1)

# print problem
print(p)

# solve problem
s <- solve(p)

# plot solution
plot(s)
```

---

**add_min_iic_constraint**

*Add constraint to enforce a minimum integral index of connectivity (IIC) value*

### Description

Add constraint to a restoration problem (`restopt_problem()`) object to specify the minimum integral index of connectivity of a solution.

### Usage

```r
add_min_iic_constraint(
  problem,
  min_iic,
  distance_threshold = -1,
  unit = "m",
  precision = 4
)
```

### Arguments

<table>
<thead>
<tr>
<th>argument</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>problem</td>
<td><code>restopt_problem()</code> Restoration problem object.</td>
</tr>
<tr>
<td>min_iic</td>
<td>numeric Minimum IIC value (between 0 and 1).</td>
</tr>
<tr>
<td>distance_threshold</td>
<td>numeric greater than 0. Minimum distance (in unit) between two patches to consider them connected in the computation of the IIC. The default value -1 causes the function to use 1 aggregated cell as the distance threshold.</td>
</tr>
</tbody>
</table>
add_min_iic_constraint

unit object or a character that can be coerced to a distance unit (see unit package), or "cells" for cell width of aggregated habitat raster. Units of the distance_threshold parameter. If the input habitat raster does not use a projected coordinate system, only "cells" is available. Meters by default, expected if distance_threshold is set to its default value (-1), which causes the function to use 1 cell by default.

precision integer Precision for calculations. Defaults to 4.

Details

The integral index of connectivity (IIC) is a graph-based inter-patch connectivity index based on a binary connection model (Pascual-Hortal & Saura, 2006). Its maximization in the context of restoration favours restoring the structural connectivity between large patches. IIC is unitless and comprised between 0 (no connectivity) and 1 (all the landscape is habitat, thus fully connected).

The distance_threshold parameter indicates to the solver how to construct the habitat graph, i.e. what is the minimum distance between two patches to consider them as connected. Note that, as the computation occurs on aggregated cells, if distance_threshold is used with a different unit than "cells", it will be rounded to the closest corresponding number of cells.

The effective mesh size (MESH) is a measure of landscape fragmentation based on the probability that two randomly chosen points are located in the same patch (Jaeger, 2000). Maximizing it in the context of restoration favours fewer and larger patches.

Value

An updated restoration problem (restopt_problem()) object.

References


See Also

set_max_iic_objective

Other constraints: add_available_areas_constraint(), add_compactness_constraint(), add_components_constraint(), add_connected_constraint(), add_locked_out_constraint(), add_min_mesh_constraint(), add_restorable_constraint()

Examples

# load data
habitat_data <- rast(
  system.file("extdata", "habitat_hi_res.tif", package = "restoptr")
)

locked_out_data <- rast(
  system.file("extdata", "locked_out.tif", package = "restoptr")
)
# create problem with locked out constraints
p <- restopt_problem(
  existing_habitat = habitat_data,
  aggregation_factor = 16,
  habitat_threshold = 0.7
) %>%
  add_min_iic_constraint(0.2) %>%
  add_restorable_constraint(
    min_restore = 200,
    max_restore = 300,
  ) %>%
  add_locked_out_constraint(data = locked_out_data) %>%
  add_compactness_constraint(2500, unit = "m") %>%
  add_settings(time_limit = 1)

# print problem
print(p)

# solve problem
s <- solve(p)

# plot solution
plot(s)

---

**add_min_mesh_constraint**

Add constraint to enforce a minimum effective mesh size (MESH) value

---

**Description**

Add constraint to a restoration problem (`restopt_problem()`) object to specify the minimum effective mesh size of a solution.

**Usage**

```
add_min_mesh_constraint(problem, min_mesh, precision = 4, unit = "ha")
```

**Arguments**

- `min_mesh` : numeric Minimum MESH value.
- `unit` : unit object or a character that can be coerced to an area unit (see `unit` package), or "cells" for cell width of aggregated habitat raster. Corresponds to the unit of the minimum mesh value If the input habitat raster does not use a projected coordinate system, only "cells" is available. Defaults to "ha".
add_min_mesh_constraint

Details
The effective mesh size (MESH) is a measure of landscape fragmentation based on the probability that two randomly chosen points are located in the same patch (Jaeger, 2000). Maximizing it in the context of restoration favours fewer and larger patches.

Value
An updated restoration problem (`restopt_problem()`) object.

References

See Also
- `set_max_mesh_objective`
- Other constraints: `add_available_areas_constraint()`, `add_compactness_constraint()`, `add_components_constraint()`, `add_connected_constraint()`, `add_locked_out_constraint()`, `add_min_iic_constraint()`, `add_restorable_constraint()`

Examples

```r
# load data
habitat_data <- rast(
  system.file("extdata", "habitat_hi_res.tif", package = "restoptr")
)

# create problem
p <- restopt_problem(
  existing_habitat = habitat_data,
  aggregation_factor = 16,
  habitat_threshold = 0.7
) %>%
  add_restorable_constraint(
    min_restore = 200,
    max_restore = 300,
  ) %>%
  add_min_mesh_constraint(min_mesh = 2500, unit = "ha")

# plot preprocessed data
plot(rast(list(p$data$existing_habitat, p$data$restorable_habitat)), nc = 2)

# print problem
print(p)

# Solve problem
s <- solve(p)
# plot solution
plot(s)
```
add_restorable_constraint

Add constraint to specify the available amount of surface for restoration

Description

Add constraint to a restoration problem (restopt_problem()) object to specify the available amount of surface for restoration.

Usage

add_restorable_constraint(
  problem,
  min_restore,
  max_restore,
  min_proportion = 1,
  unit = "ha"
)

Arguments

- **problem**: restopt_problem() Restoration problem object.
- **min_restore**: integer Minimum allowed area to restore in the solution.
- **max_restore**: integer Maximum allowed area to restore in the solution.
- **min_proportion**: float Minimum habitat proportion to consider a cell as restored.
- **unit**: unit object or a character that can be coerced to an area unit (see unit package), or "cells" for number of cells from the original habitat raster. If the input habitat raster does not use a projected coordinate system, only "cells" is available.

Details

Given the restorable_habitat input raster in restopt_problem, this constraint ensures that the total amount of restorable habitat in selected planning units is at least min_restore and at most max_restore. The unit of min_restore and max_restore can be either in a surface unit handled by the unit package, or in number of cells from the original habitat input raster ("cells"). The min_proportion parameter is a numeric between 0 and 1, and correspond to the minimum proportion of habitat area that needs to be restored in the planning unit to consider the planning unit as restored. This proportion is relative to the area of a planning unit, which is computed automatically from the input habitat raster. Note that planning unit area is considered uniform, and the distortion is not corrected. It could be using the cellSize function of the terra package, but this function is currently pretty slow for large rasters. If your problem is at regional scale, the distortion should be negligible. However, at larger scales, the best is to use an equal-area projected coordinate system.
Note that when a solution is found, the "maximum restorable habitat" is displayed, this value does not correspond to the max_restore parameter, but to the total area that can be restored in the selected planning units. The max_restore parameter is actually an upper bound of the minimum habitat that needs to be restored to reach the min_proportion of habitat in every selected planning units.

Value

An updated restoration problem (`restopt_problem()`) object.

See Also

Other constraints: `add_available_areas_constraint()`, `add_compactness_constraint()`, `add_components_constraint()`, `add_connected_constraint()`, `add_locked_out_constraint()`, `add_min_iic_constraint()`, `add_min_mesh_constraint()`

Examples

```r
# load data
habitat_data <- rast(
  system.file("extdata", "habitat_hi_res.tif", package = "restoptr")
)

# create problem
p <- restopt_problem(
  existing_habitat = habitat_data,
  aggregation_factor = 16,
  habitat_threshold = 0.7
) %>%
  add_restorable_constraint(
    min_restore = 200,
    max_restore = 300,
    min_proportion = 0.7
  ) %>%
  add_compactness_constraint(5, unit = "cells")

# print problem
print(p)

# plot preprocessed data
plot(rast(list(get_existing_habitat(p),
              get_restorable_habitat(p),
              get_locked_out_areas(p))), nc = 3)

# Solve problem
s <- solve(p)
# plot solution
plot(s)
```
Description

Add settings to a restoration problem (\texttt{restopt\_problem()}) object to customize the optimization procedure.

Usage

\begin{verbatim}
add_settings(
  problem,
  precision = 4,
  time_limit = 0,
  nb_solutions = 1,
  optimality_gap = 0
)
\end{verbatim}

Arguments

- \texttt{problem} \texttt{restopt\_problem()} Restoration problem object.
- \texttt{precision} integer Precision for calculations. Defaults to 4.
- \texttt{time_limit} integer Maximum permitted run time for optimization (seconds). Defaults to 0.
- \texttt{nb_solutions} integer Number of desired solutions. Defaults to 1.
- \texttt{optimality_gap} numeric Optimality gap (between 0 and 1). For example, an argument of 0.1 means that solutions should be within 10\% of optimality. Defaults to 0, such that optimal solutions are returned.

Value

An updated restoration problem (\texttt{restopt\_problem()}) object.

Examples

```r
# load data
habitat_data <- rast(
  system.file("extdata", "habitat_hi_res.tif", package = "restoptr")
)

# create problem
p <- restopt_problem(
  existing_habitat = habitat_data,
  aggregation_factor = 16,
  habitat_threshold = 0.7
) %>%
```
get_aggregation_factor

Retrieve the aggregation factor of a restopt problem.

Description
Retrieve the aggregation factor of a restopt problem.

Usage
get_aggregation_factor(problem)

Arguments

problem restopt_problem() Restoration problem object.

Value
numeric The aggregation factor of the restopt problem.

Examples

```r
#' # load data
habitat_data <- rast(
  system.file("extdata", "habitat_hi_res.tif", package = "restoptr")
)

# create problem
problem <- restopt_problem(
  existing_habitat = habitat_data,
  aggregation_factor = 4,
  habitat_threshold = 0.7
)

get_aggregation_factor(problem)
```
get_cell_area

Retrieve the aggregated cell area of a restopt problem.

Description
Retrieve the aggregated cell area of a restopt problem.

Usage
get_cell_area(problem)

Arguments
problem restopt_problem() Restoration problem object.

Value
terra::rast() The aggregated cell area of the restopt problem.

Examples
#
# load data
habitat_data <- rast(
    system.file("extdata", "habitat_hi_res.tif", package = "restoptr")
)

# create problem
problem <- restopt_problem(
    existing_habitat = habitat_data,
    aggregation_factor = 4,
    habitat_threshold = 0.7
)

get_cell_area(problem)

get_constraints

Retrieve the constraints of a restopt problem.

Description
Retrieve the constraints of a restopt problem.

Usage
get_constraints(problem)
get_existing_habitat

Arguments

problem restopt_problem() Restoration problem object.

Value

list The constraints of the restopt problem.

Examples

```r
# load data
habitat_data <- rast(
  system.file("extdata", "habitat_hi_res.tif", package = "restoptr")
)

# create problem
problem <- restopt_problem(
  existing_habitat = habitat_data,
  aggregation_factor = 4,
  habitat_threshold = 0.7
)

dput(constraints(problem))
```

---

get_existing_habitat Retrieve the existing (i.e. aggregated) habitat data.

Description

Retrieve the existing (i.e. aggregated) habitat data.

Usage

get_existing_habitat(problem)

Arguments

problem restopt_problem() Restoration problem object.

Value

terra::rast() The existing (aggregated) habitat data.
get_habitat_threshold

Examples

```r
#' # load data
habitat_data <- rast(
  system.file("extdata", "habitat_hi_res.tif", package = "restoptr")
)

# create problem
problem <- restopt_problem(
  existing_habitat = habitat_data,
  aggregation_factor = 4,
  habitat_threshold = 0.7
)

plot(get_existing_habitat(problem))
```

---

get_habitat_threshold  Retrieve the habitat threshold parameter of a restopt problem.

Description

Retrieve the habitat threshold parameter of a restopt problem.

Usage

```r
get_habitat_threshold(problem)
```

Arguments

- `problem`  
  - `restopt_problem()` Restoration problem object.

Value

- numeric  
  - The habitat threshold parameter of the restopt problem.

Examples

```r
#' # load data
habitat_data <- rast(
  system.file("extdata", "habitat_hi_res.tif", package = "restoptr")
)

# create problem
problem <- restopt_problem(
  existing_habitat = habitat_data,
  aggregation_factor = 4,
```
get_locked_out_areas

	habitat_threshold = 0.7

get_habitat_threshold(problem)

get_locked_out_areas  Retrieve the locked out areas of a restopt problem.

Description
Retrieve the locked out areas of a restopt problem.

Usage
get_locked_out_areas(problem)

Arguments

problem             restopt_problem() Restoration problem object.

Value
	erra::rast() The locked out areas of the restopt problem.

Examples

#' # load data
habitat_data <- rast(
  system.file("extdata", "habitat_hi_res.tif", package = "restoptr")
)

# create problem
problem <- restopt_problem(
  existing_habitat = habitat_data,
  aggregation_factor = 4,
  habitat_threshold = 0.7
)

get_locked_out_areas(problem)
**get_metadata**

*Restopt solution metadata*

**Description**

Return the metadata associated with a restopt solution, which contains the characteristics of the solution. The unit for area characteristics can be chosen among "ha" (hectares), "m" (square meters), "km" (square kilometers), and "cells" (cells from the original input habitat raster). Note that the solving time is expressed in seconds.

**Usage**

```r
get_metadata(restopt_solution, area_unit = "ha", distance_unit = "m")
```

**Arguments**

- `restopt_solution`
  - `restopt_solution()` Restopt solution to this solution.
- `area_unit`
  - unit object or a character that can be coerced to an area unit (see `unit` package), or "cells" for number of cells from the original habitat raster). Unit for areas. If the input habitat raster does not use a projected coordinate system, only "cells" is available. Default is "ha"
- `distance_unit`
  - unit object or a character that can be coerced to an area unit (see `unit` package), or "cells" for number of cell width from the original habitat raster). Unit for distances. If the input habitat raster does not use a projected coordinate system, only "cells" is available. Default is "m"

**Value**

A list containing the characteristics of the restopt solution.

**get_objective**

*Retrieve the optimization objective of a restopt problem.*

**Description**

Retrieve the optimization objective of a restopt problem.

**Usage**

```r
get_objective(problem)
```

**Arguments**

- `problem`
  - `restopt_problem()` Restoration problem object.
get_original_habitat

Value

RestoptObjective The optimization objective of the restopt problem.

Examples

```r
# load data
habitat_data <- rast(  
  system.file("extdata", "habitat_hi_res.tif", package = "restoptr")
)

# create problem
problem <- restopt_problem(  
  existing_habitat = habitat_data,
  aggregation_factor = 4,
  habitat_threshold = 0.7
)

get_objective(problem)
```

get_original_habitat Retrieve the original (i.e. not aggregated) habitat data.

Description

Retrieve the original (i.e. not aggregated) habitat data.

Usage

get_original_habitat(problem)

Arguments

problem restopt_problem() Restoration problem object.

Value

terra::rast() The original (i.e. not aggregated) habitat data.

Examples

```r
# load data
habitat_data <- rast(  
  system.file("extdata", "habitat_hi_res.tif", package = "restoptr")
)
```
get_restorable_habitat

Retrieve the restorable habitat (aggregated) data.

Description
Retrieve the restorable habitat (aggregated) data.

Usage
get_restorable_habitat(problem)

Arguments
problem restopt_problem() Restoration problem object.

Value
terra::rast() The restorable habitat (aggregated) data.

Examples

```r
# load data
habitat_data <- rast(
  system.file("extdata", "habitat_hi_res.tif", package = "restoptr")
)

# create problem
problem <- restopt_problem(
  existing_habitat = habitat_data,
  aggregation_factor = 4,
  habitat_threshold = 0.7
)

plot(get_restorable_habitat(problem))
```
get_settings

Retrieve the settings of a restopt problem.

Description
Retrieve the settings of a restopt problem.

Usage
get_settings(problem)

Arguments
problem restopt_problem() Restoration problem object.

Value
list The settings associated with the restopt problem.

Examples
```r
# load data
habitat_data <- rast(
  system.file("extdata", "habitat_hi_res.tif", package = "restoptr")
)

# create problem
problem <- restopt_problem(
  existing_habitat = habitat_data,
  aggregation_factor = 4,
  habitat_threshold = 0.7
)

get_settings(problem)
```

invert_vector

Invert a vector layer according to the extent of a restopt problem.

Description
Invert a vector layer according to the extent of a restopt problem.

Usage
invert_vector(vector_layer, extent = NULL, filter = NULL)
is_java_available

Arguments

vector_layer terra::vect() Vector layer.
extent SpatExtent Optional: you can specify another extent as the input vector layer extent for the inversion.
filter Optional: filter to apply to x. Leave NULL for no filtering.

Details

Invert a vector layer according to its extent, or a user-specified extent. This function is useful to derive locked out areas from accessible areas, e.g. buffer around tracks.

Value

A terra::vect() Vector object.

Examples

habitat_data <- rast(
  system.file("extdata", "habitat_hi_res.tif", package = "restoptr")
)
available <- vect(
  system.file("extdata", "accessible_areas.gpkg", package = "restoptr")
)
locked_out <- invert_vector(
  vector_layer = available,
  extent = ext(habitat_data),
  filter = available$ID==2
)

is_java_available

Is Java is available?

Description

The restoptr package uses Java to perform optimization procedures. As such, it is important that Java is installed correctly when using this package. This function verifies if Java is available on the system.

Usage

is_java_available()

Value

A logical (TRUE or FALSE) value indicating if Java is available for usage.
print.RestoptProblem  

Print a restoration optimization problem

Description

Display information about a restoration optimization problem.

Usage

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

Arguments

x  
restopt_problem() Restoration problem object.

...  
Arguments not used.

Examples

```
#' # load data
habitat_data <- rast(
  system.file("extdata", "habitat_hi_res.tif", package = "restoptr")
)

# create problem
p <- restopt_problem(
  existing_habitat = habitat_data,
  aggregation_factor = 4,
  habitat_threshold = 0.7
)

# print problem
print(p)
```

restoptr  

restoptr: Ecological Restoration Planning
**Description**

The `restoptr` package relies on Constraint Programming (CP) to build and solve ecological restoration planning problems. A `restoptr` problem starts from an existing habitat (raster), where the aim is to identify optimal areas that are suitable for restoration. Several constraints are available to define what is expected for a suitable area for (e.g. it must be connected, compact, must respect a budget, etc). Several optimization objective are also available to define what is a good restoration area (e.g. it must reduce fragmentation, increase ecological connectivity, minimize costs, etc.). `restoptr` relies on advanced landscape indices such as the effective mesh size (Jaeger, 2000), or the integral index of connectivity (Pascual-Hortal & Saura, 2006) to address complex restoration planning problems.

**Details**

`restoptr` relies on Choco-solver (https://choco-solver.org/), an open-source Java CP solver (Prud’homme et al., 2017). The computationally intensive solving part is thus delegated to Java (see restopt, https://github.com/dimitri-justeau/restopt), and the communication between R and Java is handled with the rJava package. Therefore, a Java Runtime Environment (>= 8) is necessary to use restopt.

Note that the methodology used in `restoptr` was first described in Justeau-Allaire et al. (2021), but `restoptr` provides much more flexibility, new features (e.g. reliable and consistent data pre-processing), new constraints, new optimization objectives, and an improved computational efficiency. Also note that the API was inspired by the prioritizr package.

This package contains several vignettes to detail its usage and showcase its features. You can explore these vignettes using browseVignettes("restoptr")

**References**


restopt_problem

**Description**

Create a new restoration optimization problem (RestoptProblem) using data that describe the spatial distribution of existing habitat (potentially at high resolution), and parameters to derive a downsampled existing habitat raster, suitable for a tractable optimization, and a restorable habitat raster. Constraints can be added to a restopt problem using add_****_constraint() functions, and an optimization objective can be set using set_****_objective() functions.

**Usage**

```
restopt_problem(
  existing_habitat,
  habitat_threshold = 1,
  aggregation_factor = 1
)
```

**Arguments**

- **existing_habitat**
  `terra::rast()` Raster object containing binary values that indicate if each planning unit contains habitat or not. Cells with the value 1 must correspond to existing habitat. Cells with the value 0 must correspond to degraded (or simply non-habitat) areas. Finally, NA (or NO_DATA) cells are considered to be outside of the landscape. This raster can have a high resolution, the aggregation_factor and the habitat_threshold parameters, described below, will be used to down sample the habitat raster to a tractable resolution for the optimization engine, and automatically derive the restorable habitat raster.

- **habitat_threshold**
  numeric number between 0 and 1, which corresponds to the minimum proportion of habitat that must be present within an aggregated pixel to consider it as an habitat pixel.

- **aggregation_factor**
  Integer Integer greater than 1, which corresponds to the aggregation factor for down sampling the data. For example, if aggregation_factor = 2, aggregated pixel will contain 4 original pixel. See `terra::aggregate()` for more details.

**Details**

This function creates the base restoration optimization problem object, that can be further extended with constraints and optimization objectives. One input rasters is necessary to instantiate a restopt problem: the existing_habitat raster (potentially with high resolution). This raster must contains data about where are habitat areas (raster value 1), non-habitat areas (raster value 0), and areas that must not be considered during the solving procedure (NA or NO_DATA). The aggregation_factor parameter is used to down sample the existing_habitat to a resolution
that will be tractable for the optimization engine, and the habitat_threshold parameter indicates the minimum proportion of habitat required in aggregated habitat pixels to consider them as habitat. Note that an aggregated pixel will contain at most aggregation_factor^2 pixels from the input habitat raster (cell_area raster in this function outputs). If an aggregated pixel is close to the spatial boundaries of the problem (i.e. NA cells), it can contain less than aggregation_factor^2 fine grained pixel. You can get the results of this preprocessing phase using the following methods: get_original_habitat() (original habitat), get_existing_habitat() (aggregated habitat), get_cell_area() (number of pixels in each aggregated cells), and get_restorable_area() (amount of restorable area – in number of original raster pixels).

Value

A new restoration problem (RestoptProblem) object.

None.

Examples

```r
# load data
habitat_data <- rast(
    system.file("extdata", "habitat_hi_res.tif", package = "restoptr")
)

# create problem
p <- restopt_problem(
    existing_habitat = habitat_data,
    aggregation_factor = 4,
    habitat_threshold = 0.7
)

# Plot down sampled data
plot(c(p$data$existing_habitat, p$data$restorable_habitat))

# print problem
print(p)
```

Description

An object representing a restopt problem solution. It is basically a SpatRaster with a few metadata attributes added.

Usage

```r
restopt_solution(restopt_problem, solution_raster, metadata, id_solution = 1)
```
Arguments

restopt_problem

restopt_problem() Reference to the problem corresponding to this solution.

solution_raster

terra::rast() Solution raster.

metadata

list List containing metadata attributes of the solution.

id_solution

integer Identifier of the solution.

Value

A new restoration problem solution (restopt_solution()).

Description

Specify that a restoration problem (restopt_problem()) should the integral index of connectivity (IIC).

Usage

set_max_iic_objective(problem, distance_threshold = -1, unit = "m")

Arguments

problem

restopt_problem() Restoration problem object.

distance_threshold

numeric greater than 0. Minimum distance (in unit) between two patches to consider them connected in the computation of the IIC. The default value -1 causes the function to use 1 aggregated cell as the distance threshold.

unit

unit object or a character that can be coerced to a distance unit (see unit package), or "cells" for cell width of aggregated habitat raster. Units of the distance_threshold parameter. If the input habitat raster does not use a projected coordinate system, only "cells" is available. Meters by default, expected if distance_threshold is set to its default value (-1), which causes the function to use 1 cell by default.

Details

The integral index of connectivity (IIC) is a graph-based inter-patch connectivity index based on a binary connection model (Pascual-Hortal & Saura, 2006). Its maximization in the context of restoration favours restoring the structural connectivity between large patches. IIC is unitless and comprised between 0 (no connectivity) and 1 (all the landscape is habitat, thus fully connected). The distance_threshold parameter indicates to the solver how to construct the habitat graph, i.e. what is the minimum distance between two patches to consider them as connected. Note that, as the computation occurs on aggregated cells, if distance_threshold is used with a different unit than "cells", it will be rounded to the closest corresponding number of cells.
set_max_iic_objective

Value

An updated restoration problem (restopt_problem()) object.

References


See Also

Other objectives: set_max_mesh_objective(), set_max_nb_pus_objective(), set_max_restore_objective(), set_min_nb_pus_objective(), set_min_restore_objective(), set_no_objective()

Examples

```r
# load data
habitat_data <- rast(
  system.file("extdata", "habitat_hi_res.tif", package = "restoptr")
)

locked_out_data <- rast(
  system.file("extdata", "locked_out.tif", package = "restoptr")
)

# create problem with locked out constraints
p <- restopt_problem(
  existing_habitat = habitat_data,
  aggregation_factor = 16,
  habitat_threshold = 0.7
) %>%
  set_max_iic_objective() %>%
  add_restorable_constraint(
    min_restore = 5,
    max_restore = 5,
  ) %>%
  add_locked_out_constraint(data = locked_out_data) %>%
  add_settings(time_limit = 1)

# print problem
print(p)

# solve problem
s <- solve(p)

# plot solution
plot(s)
```
set_max_mesh_objective

Set an objective to maximize effective mesh size

Description

Specify that a restoration problem (restopt_problem()) should maximize effective mesh size.

Usage

set_max_mesh_objective(problem)

Arguments

problem       restopt_problem() Restoration problem object.

Details

The effective mesh size (MESH) is a measure of landscape fragmentation based on the probability that two randomly chosen points are located in the same patch (Jaeger, 2000). Maximizing it in the context of restoration favours fewer and larger patches.

Value

An updated restoration problem (restopt_problem()) object.

References


See Also

Other objectives: set_max_iic_objective(), set_max_nb_pus_objective(), set_max_restore_objective(), set_min_nb_pus_objective(), set_min_restore_objective(), set_no_objective()

Examples

# load data
habitat_data <- rast(
  system.file("extdata", "habitat_hi_res.tif", package = "restoptr")
)

locked_out_data <- rast(
  system.file("extdata", "locked_out.tif", package = "restoptr")
)

# plot data
set_max_nb_pus_objective

Set an objective to maximize the number of planning units

Description

Specify that a restoration problem (restopt_problem()) should maximize the number of planning units.

Usage

set_max_nb_pus_objective(problem)

Arguments

problem restopt_problem() Restoration problem object.

Details

Planning units correspond to aggregated cells from the original dataset. Maximizing the number of planning units increased the spatial extent of the restoration area. This can be useful when the budget is limited and the aim is to restore the largest possible extent.
Value

An updated restoration problem (\texttt{restopt_problem()}) object.

See Also

Other objectives: \texttt{set_max_iic_objective()}, \texttt{set_max_mesh_objective()}, \texttt{set_max_restore_objective()}, \texttt{set_min_nb_pus_objective()}, \texttt{set_min_restore_objective()}, \texttt{set_no_objective()}

Examples

```r
# load data
habitat_data <- rast(
  system.file("extdata", "habitat_hi_res.tif", package = "restoptr")
)
locked_out_data <- rast(
  system.file("extdata", "locked_out.tif", package = "restoptr")
)

# plot data
plot(rast(list(habitat_data, locked_out_data)), nc = 2)

# create problem with locked out constraints
p <- restopt_problem(
  existing_habitat = habitat_data,
  aggregation_factor = 16,
  habitat_threshold = 0.7
) %>%
  set_max_nb_pus_objective() %>%
  add_restorable_constraint(
    min_restore = 5,
    max_restore = 5,
  ) %>%
  add_locked_out_constraint(data = locked_out_data) %>%
  add_settings(time_limit = 1)

# print problem
print(p)

# solve problem
s <- solve(p)

# plot solution
plot(s)
```
set_max_restore_objective

Set an objective to maximize the amount restoration area.

Description

Specify that a restoration problem (restopt_problem()) should maximize the restoration area needed to reach the habitat proportion threshold specified in the problem description.

Usage

set_max_restore_objective(problem)

Arguments

problem  
restopt_problem() Restoration problem object.

Details

The restoration area corresponds to the minimum amount of area that must be restored in the selected planning units to reach the minimum habitat proportion threshold specified in the problem description.

Value

An updated restoration problem (restopt_problem()) object.

See Also

Other objectives: set_max_iic_objective(), set_max_mesh_objective(), set_max_nb_pus_objective(), set_min_nb_pus_objective(), set_min_restore_objective(), set_no_objective()

Examples

# load data
habitat_data <- rast(
  system.file("extdata", "habitat_hi_res.tif", package = "restoptr")
)

locked_out_data <- rast(
  system.file("extdata", "locked_out.tif", package = "restoptr")
)

# plot data
plot(rast(list(habitat_data, locked_out_data)), nc = 2)

# create problem with locked out constraints
p <- restopt_problem(
existing_habitat = habitat_data,
aggregation_factor = 16,
habitat_threshold = 0.7
) %>%
set_max_restore_objective() %>%
add_restorable_constraint(
  min_restore = 5,
  max_restore = 5,
) %>%
add_locked_out_constraint(data = locked_out_data) %>%
add_settings(time_limit = 1)

# print problem
print(p)

# solve problem
s <- solve(p)

# plot solution
plot(s)

---

**set_min_nb_pus_objective**

*Set an objective to minimize the number of planning units*

**Description**

Specify that a restoration problem (`restopt_problem()`) should minimize the number of planning units.

**Usage**

```
set_min_nb_pus_objective(problem)
```

**Arguments**

- `problem` *restopt_problem()* Restoration problem object.

**Details**

Planning units correspond to aggregated cells from the original dataset. Minimizing the number of planning units reduces the spatial extent of the restoration area.

**Value**

An updated restoration problem (`restopt_problem()`) object.
set_min_restore_objective

See Also

Other objectives: set_max_iic_objective(), set_max_mesh_objective(), set_max_nb_pus_objective(), set_max_restore_objective(), set_min_restore_objective(), set_no_objective()

Examples

```r
# load data
habitat_data <- rast(
  system.file("extdata", "habitat_hi_res.tif", package = "restoptr")
)

locked_out_data <- rast(
  system.file("extdata", "locked_out.tif", package = "restoptr")
)

# plot data
plot(rast(list(habitat_data, locked_out_data)), nc = 2)

# create problem with locked out constraints
p <- restopt_problem(
  existing_habitat = habitat_data,
  aggregation_factor = 16,
  habitat_threshold = 0.7
)  
set_min_nb_pus_objective()  
add_restorable_constraint(
  min_restore = 5,
  max_restore = 5,
)  
add_locked_out_constraint(data = locked_out_data)  
add_settings(time_limit = 1)

# print problem
print(p)

# solve problem
s <- solve(p)

# plot solution
plot(s)
```

set_min_restore_objective

Set an objective to minimize the amount restoration area.
Description

Specify that a restoration problem (`restopt_problem()`) should minimize the restoration area needed to reach the habitat proportion threshold specified in the problem description.

Usage

```r
set_min_restore_objective(problem)
```

Arguments


Details

The restoration area corresponds to the minimum amount of area that must be restored in the selected planning units to reach the minimum habitat proportion threshold specified in the problem description.

Value

An updated restoration problem (`restopt_problem()`) object.

See Also

Other objectives: `set_max_iic_objective()`, `set_max_mesh_objective()`, `set_max_nb_pus_objective()`, `set_max_restore_objective()`, `set_min_nb_pus_objective()`, `set_no_objective()`

Examples

```r
# load data
habitat_data <- rast(
  system.file("extdata", "habitat_hi_res.tif", package = "restoptr")
)

locked_out_data <- rast(
  system.file("extdata", "locked_out.tif", package = "restoptr")
)

# plot data
plot(rast(list(habitat_data, locked_out_data)), nc = 2)

# create problem with locked out constraints
p <- restopt_problem(
  existing_habitat = habitat_data,
  aggregation_factor = 16,
  habitat_threshold = 0.7
) %>%
set_min_restore_objective() %>%
add_restorable_constraint(
  min_restore = 5,
```
```r
max_restore = 5,
  ) %>%
add_locked_out_constraint(data = locked_out_data) %>%
add_settings(time_limit = 1)

# print problem
print(p)

# solve problem
s <- solve(p)

# plot solution
plot(s)
```

---

**set_no_objective**

Configure the solver to only satisfy the constraints, without optimization objective.

**Description**

Specify that a restoration problem (`restopt_problem()`) should satisfy the constraints without optimization objective.

**Usage**

```r
set_no_objective(problem)
```

**Arguments**

- `problem` (restopt_problem()) Restoration problem object.

**Details**

Using `set_no_objective()` in a restopt problem, the solver will return the first solution found satisfying the constraint, without any optimization objective. This “no objective” setting is set by default when creating a restopt problem.

**Value**

An updated restoration problem (`restopt_problem()`) object.

**See Also**

Other objectives: `set_max_iic_objective()`, `set_max_mesh_objective()`, `set_max_nb_pus_objective()`, `set_max_restore_objective()`, `set_min_nb_pus_objective()`, `set_min_restore_objective()`
Examples

```r
# load data
habitat_data <- rast(
  system.file("extdata", "habitat_hi_res.tif", package = "restoptr")
)

# create problem
p <- restopt_problem(
  existing_habitat = habitat_data,
  aggregation_factor = 16,
  habitat_threshold = 0.7
) %>% set_no_objective()

# print problem
print(p)

# Solve problem
s <- solve(p)

# plot solution
plot(s)
```

---

**solve.RestoptProblem**

*Solve a restoration optimization problem*

**Description**

Solve a restoration optimization problem to generate a solution.

**Usage**

```r
## S3 method for class 'RestoptProblem'
solve(a, b, ...)
```

**Arguments**

- `a`  
  *restopt_problem()* Restoration problem object.

- `b`  
  Argument not used.

- `...`  
  Additional arguments: verbose: if TRUE, output solver logs. (FALSE by default)

**Details**

This function relies on the Choco-solver (https://choco-solver.org/) to solve a restoration optimization problem. If the solver finds a solution, it outputs a raster with 5 possible values: NA: NA (or NO_DATA) areas from the input habitat raster. 0: non-habitat areas that were locked out. 1
solve.RestoptProblem

: non-habitat areas that were available for selection. 2: habitat areas. 3: selected planning units for restoration. If the solve function return a no-solution error, it is either because the solver could not find a solution within the time limit that was set (see add_settings), or because the solver has detected that this is not possible to satisfy the constraints (the constraints are contradictory). In the first case, you can try to increase the time limit. In the second case, you should modify your targets.

Value

A restopt_solution() object.

Examples

```r
# load data
habitat_data <- rast(
  system.file("extdata", "habitat_hi_res.tif", package = "restoptr")
)

available <- vect(
  system.file("extdata", "accessible_areas.gpkg", package = "restoptr")
)

# create problem with locked out constraints
p <- restopt_problem(
  existing_habitat = habitat_data,
  aggregation_factor = 16,
  habitat_threshold = 0.7
) %>%
  set_max_mesh_objective() %>%
  add_restorable_constraint(
    min_restore = 5,
    max_restore = 5,
  ) %>%
  add_available_areas_constraint(available) %>%
  add_settings(time_limit = 1)

# print problem
print(p)

# solve problem
s <- solve(p)

# plot solution
plot(s)
```
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