

# Package ‘SimSurvey’

October 12, 2022

**Type** Package

**Title** Test Surveys by Simulating Spatially-Correlated Populations

**Version** 0.1.5

**Maintainer** Paul Regular <Paul.Regular@dfo-mpo.gc.ca>

**Description** Simulate age-structured populations that vary in space and time and explore the efficacy of a range of built-in or user-defined sampling protocols to reproduce the population parameters of the known population. (See Regular et al. (2020) <[doi:10.1371/journal.pone.0232822](https://doi.org/10.1371/journal.pone.0232822)> for more details).

**Depends** R (>= 3.3.0)

**License** GPL-3

**Additional\_repositories** <https://inla.r-inla-download.org/R/stable/>

**LazyData** true

**ByteCompile** true

**URL** <https://paulregular.github.io/SimSurvey/>

**BugReports** <https://github.com/PaulRegular/SimSurvey/issues>

**Imports** sp, raster, data.table, magrittr, progress, doParallel, parallel, foreach, plotly, rlang

**Suggests** fields, rmarkdown, flexdashboard, shiny, crosstalk, htmltools, viridis, lme4, ggplot2, INLA, rgdal, rgeos, knitr, bezier

**RoxygenNote** 7.1.2

**VignetteBuilder** knitr

**NeedsCompilation** no

**Author** Paul Regular [aut, cre] (<<https://orcid.org/0000-0003-0318-2615>>),  
Jonathan Babyn [ctb],  
Greg Robertson [ctb]

**Repository** CRAN

**Date/Publication** 2022-04-06 11:12:29 UTC

**R topics documented:**

bathy	2
convert_N	3
error_stats	3
expand_surveys	4
fibonacci	4
group_lengths	5
icc	5
land	6
make_grid	6
make_mesh	7
object_size	8
plot_trend	9
round_sim	10
run_strat	11
sim_abundance	12
sim_ays_covar	14
sim_ays_covar_spde	14
sim_distribution	16
sim_logistic	17
sim_parabola	18
sim_R	19
sim_sets	20
sim_survey	21
sim_survey_parallel	23
sim_vonB	25
strat_data	26
strat_error	26
strat_means	27
survey_grid	28
survey_lite_mesh	28
survey_mesh	29
test_surveys	29
vis_sim	32
<b>Index</b>	<b>34</b>

---

bathy	<i>Southern Newfoundland bathymetry</i>
-------	---

---

**Description**

Southern Newfoundland bathymetry

**Usage**

bathy

**Format**

A RasterLayer

Derived from data downloaded from <http://www.gebco.net/>. Details provided in the data-raw folder for this package.

---

convert_N	<i>Convert abundance-at-age matrix to abundance-at-length</i>
-----------	---

---

**Description**

Function for converting abundance-at-age matrix to abundance-at-length given a length-age-key. Expects matrices to be named.

**Usage**

```
convert_N(N_at_age = NULL, lak = NULL)
```

**Arguments**

N_at_age	Abundance-at-age matrix
lak	Length-age-key (i.e. probability of being in a specific length group given age)

**Value**

Returns abundance-at-length matrix

---

error_stats	<i>Calculate common error statistics</i>
-------------	--

---

**Description**

Calculate common error statistics

**Usage**

```
error_stats(error)
```

**Arguments**

error	Vector of errors
-------	------------------

**Value**

Returns a named vector of error statistics including mean error ("ME"), mean absolute error ("MAE"), mean squared error ("MSE") and root mean squared error ("RMSE")

---

expand_surveys	<i>Set-up a series of surveys from all combinations of settings supplied</i>
----------------	--

---

**Description**

Function is simply a wrapper for [expand.grid](#) that adds a survey number to the returned object

**Usage**

```
expand_surveys(
  set_den = c(0.5, 1, 2, 5, 10)/1000,
  lengths_cap = c(5, 10, 20, 50, 100, 500, 1000),
  ages_cap = c(2, 5, 10, 20, 50)
)
```

**Arguments**

set_den	Vector of set densities (number of sets per [grid unit] squared)
lengths_cap	Vector of maximum number of lengths measured per set
ages_cap	Vector of maximum number of otoliths to collect per length group per division per year

---

fibonacci	<i>Generate Fibonacci sequence</i>
-----------	------------------------------------

---

**Description**

Generate Fibonacci sequence

**Usage**

```
fibonacci(from, to)
```

**Arguments**

from, to	Approximate start and end values of the sequence
----------	--

**Examples**

```
fibonacci(2, 200)
```

---

group_lengths	<i>Convert length to length group</i>
---------------	---------------------------------------

---

**Description**

Helper function for converting lengths to length groups (Note: this isn't a general function; the output midpoints defining the groups aligns with DFO specific method/labeling)

**Usage**

```
group_lengths(length, group)
```

**Arguments**

length	Interval from <a href="#">findInterval</a>
group	Length group used to cut the length data

---

icc	<i>Calculate intraclass correlation</i>
-----	---

---

**Description**

This is a simple function for calculating intraclass correlation. It uses [lmer](#) to run the formula described here: [https://en.wikipedia.org/wiki/Intraclass\\_correlation](https://en.wikipedia.org/wiki/Intraclass_correlation)

**Usage**

```
icc(x, group)
```

**Arguments**

x	Response variable
group	Group

---

land	<i>Southern Newfoundland coastline</i>
------	--

---

**Description**

Southern Newfoundland coastline

**Usage**

land

**Format**

A SpatialPolygons object

Derived from global administrative boundaries data (<http://gadm.org/>) downloaded using the [getData](#) function. Details provided in the data-raw folder for this package.

---

make_grid	<i>Make a depth stratified survey grid</i>
-----------	--

---

**Description**

This function sets up a depth stratified survey grid. A simple gradient in depth is simulated using [spline](#) with a shallow portion, shelf and deep portion. Adding covariance to the depth simulation is an option.

**Usage**

```
make_grid(  
  x_range = c(-140, 140),  
  y_range = c(-140, 140),  
  res = c(3.5, 3.5),  
  shelf_depth = 200,  
  shelf_width = 100,  
  depth_range = c(0, 1000),  
  n_div = 1,  
  strat_breaks = seq(0, 1000, by = 40),  
  strat_splits = 2,  
  method = "spline"  
)
```

**Arguments**

x_range	Range (min x, max x) in x dimension in km
y_range	Range (min y, max y) in y dimension in km
res	Resolution, in km, of the grid cells
shelf_depth	Approximate depth of the shelf in m
shelf_width	Approximate width of the shelf in km
depth_range	Range (min depth, max depth) in depth in m
n_div	Number of divisions to include
strat_breaks	Define strata given these depth breaks
strat_splits	Number of times to horizontally split strat (i.e. easy way to increase the number of strata)
method	Use a "spline", "loess" or "bezier" to generate a smooth gradient or simply use "linear" interpolation?

**Value**

Returns RasterBrick of the same structure as [survey\\_grid](#)

**Examples**

```
r <- make_grid(res = c(10, 10))
raster::plot(r)

p <- raster::rasterToPolygons(r$strat, dissolve = TRUE)
sp::plot(p)
```

---

make\_mesh

*Make an R-INLA mesh based off a grid*


---

**Description**

This will make a mesh based off a given grid. Ideally the mesh construction and validation should be done by hand, but this exists for convenience. Meshes are used for `sim_ays_covar_spde`. The defaults are designed for the default grid. Just a basic interface between the grid and `inla.mesh.2d`.

**Usage**

```
make_mesh(
  grid = make_grid(),
  max.edge = 50,
  bound.outer = 150,
  cutoff = 10,
  offset = c(max.edge, bound.outer),
  ...
)
```

**Arguments**

grid	grid object to make a mesh of
max.edge	The largest allowed triangle edge length. One or two values. This is passed to <code>inla.mesh.2d</code>
bound.outer	The optional outer extension value given to offset.
cutoff	Minimum distance allowed between points
offset	The automatic extension distance given to <code>inla.mesh.2d</code>
...	Other options to pass to <code>inla.mesh.2d</code>

**Examples**

```
basic_mesh <- make_mesh()
plot(basic_mesh)
```

---

object_size	<i>Print object size</i>
-------------	--------------------------

---

**Description**

A wrapper for [object.size](#) that prints in Mb by default

**Usage**

```
object_size(x, units = "Mb")
```

**Arguments**

x	an R object
units	the units to be used in printing the size



---

plot_trend	<i>Simple plotting functions</i>
------------	----------------------------------

---

**Description**

These functions are simple plotting helpers to get some quick visuals of values produced by [sim\\_abundance](#), [sim\\_distribution](#), etc.

**Usage**

```
plot_trend(sim, sum_ages = sim$ages, col = viridis::viridis(1), ...)  
  
plot_surface(sim, mat = "N", xlab = "Age", ylab = "Year", zlab = mat, ...)  
  
plot_grid(grid, ...)  
  
plot_distribution(  
  sim,  
  ages = sim$ages,  
  years = sim$years,  
  type = "contour",  
  scale = "natural",  
  ...  
)  
  
plot_survey(sim, which_year = 1, which_sim = 1)  
  
plot_total_strat_fan(sim, surveys = 1:5, quants = seq(90, 10, by = -10), ...)  
  
plot_length_strat_fan(  
  sim,  
  surveys = 1:5,  
  years = 1:10,  
  lengths = 1:50,  
  select_by = "year",  
  quants = seq(90, 10, by = -10),  
  ...  
)  
  
plot_age_strat_fan(  
  sim,  
  surveys = 1:5,  
  years = 1:10,  
  ages = 1:10,  
  select_by = "year",  
  quants = seq(90, 10, by = -10),  
  ...  
)
```

```
)
plot_error_surface(sim, plot_by = "rule")
plot_survey_rank(sim, which_strat = "age")
```

### Arguments

sim	Object returned by <a href="#">sim_abundance</a> , <a href="#">sim_distribution</a> , etc.
sum_ages	Sum across these ages
col	Plot color
...	Additional arguments to pass to <a href="#">plot_ly</a> .
mat	Name of matrix in sim list to plot.
xlab, ylab, zlab	Axes labels.
grid	Grid produced by <a href="#">make_grid</a> .
ages	Subset data to one or more ages.
years	Subset data to one or more years.
type	Plot type: "contour" or "heatmap".
scale	Plot response on "natural" or "log" scale?
which_year	Subset to specific year
which_sim	Subset to specific sim
surveys	Subset data to one or more surveys.
quants	Quantile intervals to display on fan plot
lengths	Subset data to one or more length groups.
select_by	Select plot by "age", "length" or "year"?
plot_by	Plot error surface by "rule" or "samples"?
which_strat	Which strat values to focus on? (total, length, or age)

---

round_sim	<i>Round simulated population</i>
-----------	-----------------------------------

---

### Description

Round simulated population

### Usage

```
round_sim(sim)
```

### Arguments

sim	Simulation from <a href="#">sim_distribution</a>
-----	--

---

run_strat	<i>Run stratified analysis on simulated data</i>
-----------	--

---

## Description

Run stratified analysis on simulated data

## Usage

```
run_strat(  
  sim,  
  length_group = "inherit",  
  alk_scale = "division",  
  strat_data_fun = strat_data,  
  strat_means_fun = strat_means  
)
```

## Arguments

sim	Simulation from <a href="#">sim_survey</a>
length_group	Size of the length frequency bins for both abundance at length calculations and age-length-key construction. By default this value is inherited from the value defined in <a href="#">sim_abundance</a> from the closure supplied to <code>sim_length</code> ("inherit"). A numeric value can also be supplied, however, a mismatch in length groupings will cause issues with <a href="#">strat_error</a> as true vs. estimated length groupings will be mismatched.
alk_scale	Spatial scale at which to construct and apply age-length-keys: "division" or "strat".
strat_data_fun	Function for preparing data for stratified analysis (e.g. <a href="#">strat_data</a> )
strat_means_fun	Function for calculating stratified means (e.g. <a href="#">strat_means</a> )

## Details

The "strat\_data\_fun" and "strat\_means\_fun" allow the use of custom [strat\\_data](#) and [strat\\_means](#) functions.

## Value

Adds stratified analysis results for the total population ("total\_strat") and the population aggregated by length group and age ("length\_strat" and "age\_strat", respectively) to the sim list.

## Examples

```
sim <- sim_abundance(ages = 1:5, years = 1:5,
                    R = sim_R(log_mean = log(1e+7)),
                    growth = sim_vonB(length_group = 1)) %>%
  sim_distribution(grid = make_grid(res = c(12, 12)),
                 ays_covar = sim_ays_covar(sd = 1)) %>%
  sim_survey(n_sims = 1, q = sim_logistic(k = 2, x0 = 3)) %>%
  run_strat()
```

---

 sim\_abundance

*Simulate basic population dynamics model*


---

## Description

Simulate basic population dynamics model

## Usage

```
sim_abundance(
  ages = 1:20,
  years = 1:20,
  Z = sim_Z(),
  R = sim_R(),
  N0 = sim_N0(),
  growth = sim_vonB()
)
```

## Arguments

ages	Ages to include in the simulation.
years	Years to include in the simulation.
Z	Total mortality function, like <a href="#">sim_Z</a> , for generating mortality matrix.
R	Recruitment (i.e. abundance at <code>min(ages)</code> ) function, like <a href="#">sim_R</a> , for generating recruitment vector.
N0	Starting abundance (i.e. abundance at <code>min(years)</code> ) function, like <a href="#">sim_N0</a> , for generating starting abundance vector.
growth	Closure, such as <a href="#">sim_vonB</a> , for simulating length given age. The function is used here to generate a abundance-at-age matrix and it is carried forward for later use in <a href="#">sim_survey</a> to simulate lengths from survey catch at age.

## Details

Abundance from is calculated using a standard population dynamics model. An abundance-at-length matrix is generated using a growth function coded as a closure like [sim\\_vonB](#). The function is retained for later use in [sim\\_survey](#) to simulate lengths given simulated catch at age in a simulated survey. The ability to simulate distributions by length is yet to be implemented.

**Value**

A list of length 9:

- ages - Vector of ages in the simulation
- lengths - Vector of length groups (depends on growth function)
- years - Vector of years in the simulation
- R - Vector of recruitment values
- N0 - Vector of starting abundance values
- Z - Matrix of total mortality values
- N - Matrix of abundance values
- N\_at\_length - Abundance at length matrix
- sim\_length - Function for simulating lengths given ages

**Examples**

```
R_fun <- sim_R(log_mean = log(100000), log_sd = 0.1, random_walk = TRUE, plot = TRUE)
R_fun(years = 1:100)
sim_abundance(R = sim_R(log_mean = log(100000), log_sd = 0.5))
sim_abundance(years = 1:20,
               R = sim_R(log_mean = log(c(rep(100000, 10), rep(10000, 10))), plot = TRUE))

Z_fun <- sim_Z(log_mean = log(0.5), log_sd = 0.1, phi_age = 0.9, phi_year = 0.9, plot = TRUE)
Z_fun(years = 1:100, ages = 1:20)
sim_abundance(Z = sim_Z(log_mean = log(0.5), log_sd = 0.1, plot = TRUE))
Za_dev <- c(-0.2, -0.1, 0, 0.1, 0.2, 0.3, 0.3, 0.2, 0.1, 0)
Zy_dev <- c(-0.2, -0.2, -0.2, -0.2, -0.2, 2, 2, 2, 2, 0.2, 0.2, 0.2, 0.2, 0.2, 0, 0, 0, 0, 0, 0)
Z_mat <- outer(Za_dev, Zy_dev, "+") + 0.5
sim_abundance(ages = 1:10, years = 1:20,
               Z = sim_Z(log_mean = log(Z_mat), plot = TRUE))
sim_abundance(ages = 1:10, years = 1:20,
               Z = sim_Z(log_mean = log(Z_mat), log_sd = 0, phi_age = 0, phi_year = 0, plot = TRUE))

N0_fun <- sim_N0(N0 = "exp", plot = TRUE)
N0_fun(R0 = 1000, Z0 = rep(0.5, 20), ages = 1:20)
sim_abundance(N0 = sim_N0(N0 = "exp", plot = TRUE))

growth_fun <- sim_vonB(Linf = 100, L0 = 5, K = 0.2, log_sd = 0.05, length_group = 1, plot = TRUE)
growth_fun(age = rep(1:15, each = 100))
growth_fun(age = 1:15, length_age_key = TRUE)
sim_abundance(growth = sim_vonB(plot = TRUE))

sim <- sim_abundance()
plot_trend(sim)
plot_surface(sim, mat = "N")
plot_surface(sim, mat = "Z")
plot_surface(sim, mat = "N_at_length", xlab = "Length", zlab = "N")
```

---

sim_ays_covar	<i>Simulate age-year-space covariance</i>
---------------	---

---

### Description

These functions return a function to use inside [sim\\_distribution](#).

### Usage

```
sim_ays_covar(
  sd = 2.8,
  range = 300,
  lambda = 1,
  model = "matern",
  phi_age = 0.5,
  phi_year = 0.9,
  group_ages = 5:20,
  group_years = NULL
)
```

### Arguments

sd	Variance (can be age specific).
range	Decorrelation range
lambda	Controls the degree of smoothness of Matern covariance process
model	String indicating either "exponential" or "matern" as the correlation function
phi_age	Defines autocorrelation through ages. Can be one value or a vector of the same length as ages
phi_year	Defines autocorrelation through years. Can be one value or a vector of the same length as years
group_ages	Make space-age-year noise equal across these ages
group_years	Make space-age-year noise equal across these years

---

sim_ays_covar_spde	<i>Simulate age-year-space covariance using SPDE approach</i>
--------------------	---

---

### Description

Returns a function to use inside [sim\\_distribution](#) to generate the error term.

**Usage**

```
sim_ays_covar_spde(
  sd = 2.8,
  range = 300,
  model = "barrier",
  phi_age = 0.5,
  phi_year = 0.9,
  group_ages = 5:20,
  group_years = NULL,
  mesh,
  barrier.triangles
)
```

**Arguments**

sd	Variance (can be age specific)
range	Decorrelation range
model	String indicating "barrier" or "spde" to generate Q with
phi_age	Defines autocorrelation through ages. Can be one value or a vector of the same length as ages.
phi_year	Defines autocorrelation through years. Can be one value or a vector of the same length as years.
group_ages	Make space-age-year variance equal across these ages
group_years	Make space-age-year variance equal across these years
mesh	The mesh used to generate the precision matrix
barrier.triangles	the set of triangles in the barrier of the mesh for the barrier model

**Value**

Returns a function for use in [sim\\_distribution](#).

**Examples**

```
##SPDE Approach

## Make a grid
my_grid <- make_grid(res = c(10,10))

## Make a mesh based off it
my_mesh <- make_mesh(my_grid)
sim <- sim_abundance(ages = 1:10, years = 1:10) %>%
  sim_distribution(grid = my_grid,
```

```

ays_covar = sim_ays_covar_spde(phi_age = 0.8,
                              phi_year = 0.1,
                              model = "spde",
                              mesh = my_mesh),
depth_par = sim_parabola(mu = 200,
                        sigma = 50))
plot_distribution(sim, ages = 1:5, years = 1:5, type = "heatmap")

## Barrier Approach
sim <- sim_abundance(ages = 1:10, years = 1:10) %>%
  sim_distribution(grid = survey_grid,
                 ays_covar = sim_ays_covar_spde(phi_age = 0.8,
                                                phi_year = 0.1,
                                                model = "barrier",
                                                mesh = survey_lite_mesh$mesh,
                                                barrier.triangles =
                                                  survey_lite_mesh$barrier_tri),
                 depth_par = sim_parabola())
plot_distribution(sim, ages = 1:5, years = 1:5, type = "heatmap")

```

---

sim\_distribution

*Simulate spatial and temporal distribution*


---

## Description

Provided an abundance at age matrix and a survey grid to populate, this function applies correlated space, age and year error to simulate the distribution of the population. The ability to simulate distributions by length is yet to be implemented.

## Usage

```

sim_distribution(
  sim,
  grid = make_grid(),
  ays_covar = sim_ays_covar(),
  depth_par = sim_parabola()
)

```

## Arguments

sim	A list with ages, years and an abundance at age matrix like produced by <a href="#">sim_abundance</a> .
grid	A raster object defining the survey grid, like <a href="#">survey_grid</a> or one produced by <a href="#">make_grid</a>
ays_covar	Closure for simulating age-year-space covariance, like <a href="#">sim_ays_covar</a>
depth_par	Closure for defining relationship between abundance and depth, like <a href="#">sim_parabola</a>



**Details**

This function simulates the probability of simulated fish inhabiting a cell as a function of a parabolic relationship with depth and space, age, and year autocorrelated errors. **WARNING:** it make take a long time to simulate abundance in a large grid across many ages and years - start small first.

**Value**

Appends three objects to the sim list:

- grid - RasterBrick with the grid details
- grid\_xy - Grid details as a data.table in xyz format
- sp\_N - A data.table with abundance split by age, year and cell

**Examples**

```
sim <- sim_abundance(ages = 1:10, years = 1:10) %>%
  sim_distribution(grid = make_grid(res = c(12, 12)),
                 ays_covar = sim_ays_covar(phi_age = 0.8,
                                           phi_year = 0.1),
                 depth_par = sim_parabola(mu = 200,
                                          sigma = 50))

head(sim$sp_N)
head(sim$grid_xy)
```

---

 sim\_logistic

*Closure for simulating logistic curve*


---

**Description**

This closure is useful for simulating q inside the [sim\\_survey](#) function

**Usage**

```
sim_logistic(k = 2, x0 = 3, plot = FALSE)
```

**Arguments**

k	The steepness of the curve
x0	The x-value of the sigmoid's midpoint
plot	Plot relationship

**Examples**

```
logistic_fun <- sim_logistic(k = 2, x0 = 3, plot = TRUE)
logistic_fun(x = 1:10)
```

---

sim_parabola	<i>Define relationships with covariates</i>
--------------	---

---

### Description

Closure to be used in [sim\\_distribution](#). Form is based on the bi-gaussian function described here: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2993707/>.

### Usage

```
sim_parabola(
  alpha = 0,
  mu = 200,
  sigma = 70,
  sigma_right = NULL,
  log_space = FALSE,
  plot = FALSE
)
```

### Arguments

alpha, mu, sigma	Parameters that control the shape of the parabola. Can be one value or a vector of equal length to the number of ages in the simulation (e.g. age-specific depth associations can be specified).
sigma_right	Optional parameter to impose asymmetry by supplying a sigma parameter for the right side. If used, 'sigma' will be used to define the width of the left side. Ignored if 'NULL'.
log_space	Should shape of the parabola be defined in log space? If 'TRUE', logged parameters are assumed to be supplied and x values used in the parabola equation are log transformed. This allows a more lognormal curve to be defined and, hence, allows a heavier tail and it forces very low values near zero.
plot	Produce a simple plot of the simulated values?

### Examples

```
parabola_fun <- sim_parabola(mu = 50, sigma = 5, plot = TRUE)
parabola_fun(x = 0:100)

parabola_fun <- sim_parabola(mu = log(40), sigma = 0.5, log_space = FALSE, plot = TRUE)
parabola_fun(x = 1:1000)

parabola_fun <- sim_parabola(mu = c(50, 120), sigma = c(5, 3), plot = TRUE)
parabola_fun(x = rep(1:200, 2), age = rep(c(1, 2), each = 200))
```

---

sim\_R *Simulate starting abundance, random recruitment and total mortality*

---

### Description

These functions return a function to use inside [sim\\_abundance](#). Given parameters, it generates N0, R and Z values.

### Usage

```
sim_R(log_mean = log(3e+07), log_sd = 0.5, random_walk = TRUE, plot = FALSE)
```

```
sim_Z(
  log_mean = log(0.5),
  log_sd = 0.2,
  phi_age = 0.9,
  phi_year = 0.5,
  plot = FALSE
)
```

```
sim_N0(N0 = "exp", plot = FALSE)
```

### Arguments

log_mean	One mean value or a vector of means, in log scale, of length equal to years for sim_R or a matrix of means with rows equaling the number of ages and columns equaling the number of years for sim_Z.
log_sd	Standard deviation of the variable in the log scale.
random_walk	Simulate recruitment as a random walk?
plot	produce a simple plot of the simulated values?
phi_age	Autoregressive parameter for the age dimension.
phi_year	Autoregressive parameter for the year dimension.
N0	Either specify "exp" or numeric vector of starting abundance excluding the first age. If "exp" is specified using sim_N0, then abundance at age are calculated using exponential decay.

### Details

sim\_R generates uncorrelated recruitment values or random walk values from a log normal distribution. sim\_Z does the same as sim\_R when phi\_age and phi\_year are both 0, otherwise values are correlated in the age and/or year dimension. The covariance structure follows that described in Cadigan (2015).

## References

Cadigan, Noel G. 2015. A State-Space Stock Assessment Model for Northern Cod, Including Under-Reported Catches and Variable Natural Mortality Rates. *Canadian Journal of Fisheries and Aquatic Sciences* 73 (2): 296-308.

## Examples

```
R_fun <- sim_R(log_mean = log(100000), log_sd = 0.1, random_walk = TRUE, plot = TRUE)
R_fun(years = 1:100)
sim_abundance(R = sim_R(log_mean = log(100000), log_sd = 0.5))
sim_abundance(years = 1:20,
               R = sim_R(log_mean = log(c(rep(100000, 10), rep(10000, 10))), plot = TRUE))

Z_fun <- sim_Z(log_mean = log(0.5), log_sd = 0.1, phi_age = 0.9, phi_year = 0.9, plot = TRUE)
Z_fun(years = 1:100, ages = 1:20)
sim_abundance(Z = sim_Z(log_mean = log(0.5), log_sd = 0.1, plot = TRUE))
Za_dev <- c(-0.2, -0.1, 0, 0.1, 0.2, 0.3, 0.3, 0.2, 0.1, 0)
Zy_dev <- c(-0.2, -0.2, -0.2, -0.2, -0.2, 2, 2, 2, 2, 0.2, 0.2, 0.2, 0.2, 0.2, 0, 0, 0, 0, 0, 0)
Z_mat <- outer(Za_dev, Zy_dev, "+") + 0.5
sim_abundance(ages = 1:10, years = 1:20,
               Z = sim_Z(log_mean = log(Z_mat), plot = TRUE))
sim_abundance(ages = 1:10, years = 1:20,
               Z = sim_Z(log_mean = log(Z_mat), log_sd = 0, phi_age = 0, phi_year = 0, plot = TRUE))

N0_fun <- sim_N0(N0 = "exp", plot = TRUE)
N0_fun(R0 = 1000, Z0 = rep(0.5, 20), ages = 1:20)
sim_abundance(N0 = sim_N0(N0 = "exp", plot = TRUE))
```

---

sim\_sets

*Simulate survey sets*

---

## Description

Simulate survey sets

## Usage

```
sim_sets(
  sim,
  subset_cells,
  n_sims = 1,
  trawl_dim = c(1.5, 0.02),
  min_sets = 2,
  set_den = 2/1000,
  resample_cells = FALSE
)
```

**Arguments**

sim	Simulation object from <a href="#">sim_distribution</a>
subset_cells	Logical expression indicating the elements (x, y, depth, cell, division, strat, year) of the survey grid to keep (e.g., cell < 100)
n_sims	Number of simulations to produce
trawl_dim	Trawl width and distance (same units as grid)
min_sets	Minimum number of sets per strat
set_den	Set density (number of sets per grid unit squared)
resample_cells	Allow resampling of sampling units (grid cells)? (Note: allowing resampling may create bias because depletion is imposed at the cell level)

**Examples**

```
sim <- sim_abundance(ages = 1:10, years = 1:5) %>%
  sim_distribution(grid = make_grid(res = c(12, 12)))

## Multiple calls can be useful for defining a custom series of sets
standard_sets <- sim_sets(sim, year <= 2, set_den = 2 / 1000)
reduced_sets <- sim_sets(sim, year > 2 & !cell %in% 1:100, set_den = 1 / 1000)
sets <- rbind(standard_sets, reduced_sets)
sets$set <- seq(nrow(sets)) # Important - make sure set has a unique ID.

survey <- sim_survey(sim, custom_sets = sets)
plot_survey(survey, which_year = 4, which_sim = 1)
```

---

sim\_survey

*Simulate stratified-random survey*


---

**Description**

Simulate stratified-random survey

**Usage**

```
sim_survey(
  sim,
  n_sims = 1,
  q = sim_logistic(),
  trawl_dim = c(1.5, 0.02),
  resample_cells = FALSE,
  binom_error = TRUE,
  min_sets = 2,
  set_den = 2/1000,
```

```

lengths_cap = 500,
ages_cap = 10,
age_sampling = "stratified",
age_length_group = 1,
age_space_group = "division",
custom_sets = NULL,
light = TRUE
)

```

## Arguments

sim	Simulation from <a href="#">sim_distribution</a>
n_sims	Number of surveys to simulate over the simulated population. Note: requesting a large number of simulations may max out your RAM. Use <a href="#">sim_survey_parallel</a> if many simulations are required.
q	Closure, such as <a href="#">sim_logistic</a> , for simulating catchability at age (returned values must be between 0 and 1)
trawl_dim	Trawl width and distance (same units as grid)
resample_cells	Allow resampling of sampling units (grid cells)? Setting to TRUE may introduce bias because depletion is imposed at the cell level.
binom_error	Impose binomial error? Setting to FALSE may introduce bias in stratified estimates at older ages because of more frequent rounding to zero.
min_sets	Minimum number of sets per strat
set_den	Set density (number of sets per [grid unit] squared). WARNING: may return an error if set_den is high and resample_cells = FALSE because the number of sets allocated may exceed the number of cells in a strata.
lengths_cap	Maximum number of lengths measured per set
ages_cap	If age_sampling = "stratified", this cap represents the maximum number of ages to sample per length group (defined using the age_length_group argument) per division or strat (defined using the age_space_group argument) per year. If age_sampling = "random", it is the maximum number of ages to sample from measured fish per set.
age_sampling	Should age sampling be "stratified" (default) or "random"?
age_length_group	Numeric value indicating the size of the length bins for stratified age sampling. Ignored if age_sampling = "random".
age_space_group	Should age sampling occur at the "division" (default), "strat" or "set" spatial scale? That is, age sampling can be spread across each "division", "strat" or "set" in each year to a maximum number within each length bin (cap is defined using the age_cap argument). Ignored if age_sampling = "random".
custom_sets	Supply an object of the same structure as returned by <a href="#">sim_sets</a> which specifies a custom series of set locations to be sampled. Set locations are automated if custom_sets = NULL.
light	Drop some objects from the output to keep object size low?

**Value**

A list including rounded population simulation, set locations and details and sampling details. Note that that  $N$  = "true" population,  $I$  = population available to the survey,  $n$  = number caught by survey.

**Examples**

```
sim <- sim_abundance(ages = 1:10, years = 1:5) %>%
  sim_distribution(grid = make_grid(res = c(12, 12))) %>%
  sim_survey(n_sims = 5, q = sim_logistic(k = 2, x0 = 3))
plot_survey(sim, which_year = 4, which_sim = 1)
```

---

sim\_survey\_parallel *Simulate stratified random surveys using parallel computation*

---

**Description**

This function is a wrapper for [sim\\_survey](#) except it allows for many more total iterations to be run than [sim\\_survey](#) before running into RAM limitations. Unlike [test\\_surveys](#), this function retains the full details of the survey and it may therefore be more useful for testing alternate approaches to a stratified analysis for obtaining survey indices.

**Usage**

```
sim_survey_parallel(
  sim,
  n_sims = 1,
  n_loops = 100,
  cores = 1,
  quiet = FALSE,
  ...
)
```

**Arguments**

sim	Simulation from <a href="#">sim_distribution</a>
n_sims	Number of times to simulate a survey over the simulated population. Requesting a large number of simulations here may max out your RAM.
n_loops	Number of times to run the <a href="#">sim_survey</a> function. Total simulations run will be the product of n_sims and n_loops arguments. Low numbers of n_sims and high numbers of n_loops will be easier on RAM, but may be slower.
cores	Number of cores to use in parallel. More cores should speed up the process.
quiet	Print message on what to expect for duration?
...	Arguments passed on to <a href="#">sim_survey</a>

**q** Closure, such as `sim_logistic`, for simulating catchability at age (returned values must be between 0 and 1)  
**trawl\_dim** Trawl width and distance (same units as grid)  
**resample\_cells** Allow resampling of sampling units (grid cells)? Setting to TRUE may introduce bias because depletion is imposed at the cell level.  
**binom\_error** Impose binomial error? Setting to FALSE may introduce bias in stratified estimates at older ages because of more frequent rounding to zero.  
**min\_sets** Minimum number of sets per strat  
**set\_den** Set density (number of sets per [grid unit] squared). WARNING: may return an error if `set_den` is high and `resample_cells = FALSE` because the number of sets allocated may exceed the number of cells in a strata.  
**lengths\_cap** Maximum number of lengths measured per set  
**ages\_cap** If `age_sampling = "stratified"`, this cap represents the maximum number of ages to sample per length group (defined using the `age_length_group` argument) per division or strat (defined using the `age_space_group` argument) per year. If `age_sampling = "random"`, it is the maximum number of ages to sample from measured fish per set.  
**age\_sampling** Should age sampling be "stratified" (default) or "random"?  
**age\_length\_group** Numeric value indicating the size of the length bins for stratified age sampling. Ignored if `age_sampling = "random"`.  
**age\_space\_group** Should age sampling occur at the "division" (default), "strat" or "set" spatial scale? That is, age sampling can be spread across each "division", "strat" or "set" in each year to a maximum number within each length bin (cap is defined using the `age_cap` argument). Ignored if `age_sampling = "random"`.  
**custom\_sets** Supply an object of the same structure as returned by `sim_sets` which specifies a custom series of set locations to be sampled. Set locations are automated if `custom_sets = NULL`.  
**light** Drop some objects from the output to keep object size low?

## Details

`sim_survey` is hard-wired here to be "light" to minimize object size.

## Examples

```

## This call runs a total of 25 simulations of the same survey over
## the same population (Note: total number of simulations are low to
## decrease computation time for the example)
sim <- sim_abundance(ages = 1:20, years = 1:5) %>%
  sim_distribution(grid = make_grid(res = c(10, 10))) %>%
  sim_survey_parallel(n_sims = 5, n_loops = 5, cores = 1,
                    q = sim_logistic(k = 2, x0 = 3),
                    quiet = FALSE)

```



---

 sim\_vonB

*Closure for simulating length given age using von Bertalanffy notation*


---

### Description

This function outputs a function which holds the parameter values supplied and the function either simulates lengths given ages or generates a length age key give a sequence of ages.

### Usage

```
sim_vonB(
  Linf = 120,
  L0 = 5,
  K = 0.1,
  log_sd = 0.1,
  length_group = 3,
  digits = 0,
  plot = FALSE
)
```

### Arguments

Linf	Mean asymptotic length
L0	Length at birth
K	Growth rate parameter
log_sd	Standard deviation of the relationship in log scale
length_group	Length group for length age key. Note that labels on the matrix produced are midpoints using the DFO conventions; see <a href="#">group_lengths</a> . Also note that this length group will dictate the length group used in the stratified analysis run by <a href="#">run_strat</a> .
digits	Integer indicating the number of decimal places to round the values to
plot	Produce a simple plot of the simulated values?

### Examples

```
growth_fun <- sim_vonB(Linf = 100, L0 = 5, K = 0.2, log_sd = 0.05, length_group = 1, plot = TRUE)
growth_fun(age = rep(1:15, each = 100))
growth_fun(age = 1:15, length_age_key = TRUE)
sim_abundance(growth = sim_vonB(plot = TRUE))
```

---

strat_data	<i>Prepare simulated data for stratified analysis</i>
------------	---

---

**Description**

Generate set details (setdet), length-frequency (lf) and age-frequency (af) data for stratified analysis

**Usage**

```
strat_data(sim, length_group = 3, alk_scale = "division")
```

**Arguments**

sim	Simulation from <a href="#">sim_survey</a>
length_group	Size of the length frequency bins
alk_scale	Spatial scale at which to construct and apply age-length-keys: "division", "strat" or "set".

---

strat_error	<i>Calculate error of stratified estimates</i>
-------------	--

---

**Description**

Calculate error of stratified estimates

**Usage**

```
strat_error(sim)
```

**Arguments**

sim	Object from <a href="#">run_strat</a> (includes simulated population and survey along with stratified analysis results)
-----	---

**Value**

Adds details and summary stats of stratified estimate error to the sim list, ending with "\_strat\_error" or "\_strat\_error\_stats". Error statistics includes mean absolute error ("MAE"), mean squared error ("MSE"), and root mean squared error ("RMSE")

## Examples

```
sim <- sim_abundance(ages = 1:5, years = 1:5,
                    R = sim_R(log_mean = log(1e+7)),
                    growth = sim_vonB(length_group = 1)) %>%
  sim_distribution(grid = make_grid(res = c(12, 12)),
                 ays_covar = sim_ays_covar(sd = 1)) %>%
  sim_survey(n_sims = 1, q = sim_logistic(k = 2, x0 = 3)) %>%
  run_strat() %>%
  strat_error()
```

---

strat_means	<i>Calculate stratified means, variances and confidence intervals across groups</i>
-------------	---

---

## Description

Calculate stratified means, variances and confidence intervals across groups

## Usage

```
strat_means(
  data = NULL,
  metric = NULL,
  strat_groups = NULL,
  survey_groups = NULL,
  confidence = 95
)
```

## Arguments

data	Expects data.table with all grouping variables in stacked format (must include strat_area and tow_area for scaling values)
metric	Variable in specified data.table. e.g. "number", "mass"
strat_groups	Grouping variables for calculations of the fine-scale strat-level means (strat and strat_area are required). e.g. c("year", "species", "shiptrip", "NAFOdiv", "strat", "strat_area", "age")
survey_groups	Grouping variables for large-scale summary calculations. e.g. ("year", "species")
confidence	Percent for confidence limits

## Details

Function was mainly created for use in the `run_strat` function. It first calculates strat-level statistics and then the larger-scale statistics like total abundance

---

survey_grid	<i>Sample survey simulation grid.</i>
-------------	---------------------------------------

---

**Description**

A exemplar for the structure of a survey grid object to supply to the functions in this package.

**Usage**

survey\_grid

**Format**

A RasterStack with 4 variables:

**cell** Survey cell identifier

**division** NAFO division

**strat** Survey strata number

**depth** Mean depth of the waters under each cell, units = m

For further details on how this file was created, see the data-raw folder for this package.

---

survey_lite_mesh	<i>Lite sample survey mesh and related items</i>
------------------	--

---

**Description**

Lite sample survey mesh and related items

**Usage**

survey\_lite\_mesh

**Format**

A list containing the same items as survey\_mesh, but with fewer nodes to save on computational time

---

`survey_mesh`*Sample survey meshes and related items*

---

**Description**

@format A list containing the R-INLA survey mesh, the set of triangles in the barrier and the barrier polygons for plotting

**Usage**

```
survey_mesh
```

**Format**

An object of class `list` of length 3.

**Details**

An example of a mesh containing barrier information for use with `sim_ays_covar_spde`. Also derived from global administrative boundaries data (<http://gadm.org>). Details on creation provided in the `data-raw` folder of this package in the `survey_mesh.R` file. Includes the set of barrier triangles needed to use the barrier approach, barrier polygons for plotting and the set of triangles in the barrier.

---

`test_surveys`*Test sampling design of multiple surveys using a stratified analysis*

---

**Description**

This function allows a series of sampling design settings to be set and tested on the simulated population. True population values are compared to stratified estimates of abundance.

**Usage**

```
test_surveys(  
  sim,  
  surveys = expand_surveys(),  
  keep_details = 1,  
  n_sims = 1,  
  n_loops = 100,  
  cores = 2,  
  export_dir = NULL,  
  length_group = "inherit",  
  alk_scale = "division",  
  progress = TRUE,  
  ...  
)
```

```
)
resume_test(export_dir = NULL, ...)
```

### Arguments

sim	Simulation from <a href="#">sim_distribution</a> .
surveys	A data.frame or data.table with a sequence of surveys and their settings with a format like the data.table returned by <a href="#">expand_surveys</a> .
keep_details	Survey and stratified analysis details are dropped here to minimize object size. This argument allows the user to keep the details of one survey by specifying the survey number in the data.frame supplied to surveys.
n_sims	Number of times to simulate a survey over the simulated population. Requesting a large number of simulations here may max out your RAM.
n_loops	Number of times to run the <a href="#">sim_survey</a> function. Total simulations run will be the product of n_sims and n_loops arguments. Low numbers of n_sims and high numbers of n_loops will be easier on RAM, but may be slower.
cores	Number of cores to use in parallel. More cores should speed up the process.
export_dir	Directory for exporting results as they are generated. Main use of the export is to allow this process to pick up where test_survey left off by calling resume_test. If NULL, nothing is exported.
length_group	Size of the length frequency bins for both abundance at length calculations and age-length-key construction. By default this value is inherited from the value defined in <a href="#">sim_abundance</a> from the closure supplied to sim_length ("inherit"). A numeric value can also be supplied, however, a mismatch in length groupings will cause issues with <a href="#">strat_error</a> as true vs. estimated length groupings will be mismatched.
alk_scale	Spatial scale at which to construct and apply age-length-keys: "division" or "strat".
progress	Display progress bar and messages?
...	Arguments passed on to <a href="#">sim_survey</a>
q	Closure, such as <a href="#">sim_logistic</a> , for simulating catchability at age (returned values must be between 0 and 1)
trawl_dim	Trawl width and distance (same units as grid)
resample_cells	Allow resampling of sampling units (grid cells)? Setting to TRUE may introduce bias because depletion is imposed at the cell level.
binom_error	Impose binomial error? Setting to FALSE may introduce bias in stratified estimates at older ages because of more frequent rounding to zero.
min_sets	Minimum number of sets per strat
age_sampling	Should age sampling be "stratified" (default) or "random"?
age_length_group	Numeric value indicating the size of the length bins for stratified age sampling. Ignored if age_sampling = "random".

`age_space_group` Should age sampling occur at the "division" (default), "strat" or "set" spatial scale? That is, age sampling can be spread across each "division", "strat" or "set" in each year to a maximum number within each length bin (cap is defined using the `age_cap` argument). Ignored if `age_sampling = "random"`.

`custom_sets` Supply an object of the same structure as returned by `sim_sets` which specifies a custom series of set locations to be sampled. Set locations are automated if `custom_sets = NULL`.

## Details

Depending on the settings, `test_surveys` may take a long time to run. The `resume_test` function is for resuming partial runs of `test_surveys`. Note that progress bar time estimates will be biased here by previous completions. `test_loop` is a helper function used in both `test_surveys` and `resume_test`. CAUTION: while the dots construct is available in the `resume_test` function, be careful adding arguments as it will change the simulation settings if the arguments added were not specified in the initial `test_surveys` run.

## Value

Adds a table of survey designs tested. Also adds details and summary stats of stratified estimate error to the `sim` list, ending with `"_strat_error"` or `"_strat_error_stats"`. Error statistics includes mean error ("ME"), mean absolute error ("MAE"), mean squared error ("MSE"), and root mean squared error ("RMSE"). Also adds a sample size summary table ("`samp_totals`") to the list. Survey and stratified analysis details are not kept to minimize object size.

## Examples

```
pop <- sim_abundance(ages = 1:20, years = 1:5) %>%
  sim_distribution(grid = make_grid(res = c(10, 10)))

surveys <- expand_surveys(set_den = c(1, 2) / 1000,
  lengths_cap = c(100, 500),
  ages_cap = c(5, 20))

## This call runs 25 simulations of 8 different surveys over the same
## population, and then runs a stratified analysis and compares true vs
## estimated values. (Note: total number of simulations are low to decrease
## computation time for the example)
tests <- test_surveys(pop, surveys = surveys, keep_details = 1,
  n_sims = 5, n_loops = 5, cores = 1)

library(plotly)
tests$total_strat_error %>%
  filter(survey == 8, sim %in% 1:50) %>%
  group_by(sim) %>%
  plot_ly(x = ~year) %>%
  add_lines(y = ~I_hat, alpha = 0.5, name = "estimated") %>%
  add_lines(y = ~I, color = I("black"), name = "true") %>%
```

```

    layout(xaxis = list(title = "Year"),
           yaxis = list(title = "Abundance index"))

plot_total_strat_fan(tests, surveys = 1:8)
plot_length_strat_fan(tests, surveys = 1:8)
plot_age_strat_fan(tests, surveys = 1:8)
plot_age_strat_fan(tests, surveys = 1:8, select_by = "age")

plot_error_surface(tests, plot_by = "rule")
plot_error_surface(tests, plot_by = "samples")

plot_survey_rank(tests, which_strat = "length")
plot_survey_rank(tests, which_strat = "age")

```

---

vis\_sim

*Make a flexdashboard for visualizing the simulation*


---

## Description

Assumes the working directory is the project directory

## Usage

```
vis_sim(sim, ...)
```

## Arguments

sim	Object produced by <a href="#">sim_abundance</a> , <a href="#">sim_distribution</a> , <a href="#">sim_survey</a> or <a href="#">test_surveys</a> .
...	Additional arguments to send to <a href="#">run</a>

## Examples

```

if (interactive()) {

  pop <- sim_abundance(ages = 1:20, years = 1:20)
  vis_sim(pop)

  dist <- sim_distribution(pop, grid = make_grid(res = c(10, 10)))
  vis_sim(dist)

  ## Run one survey design
  survey <- sim_survey(dist, n_sims = 5)
  vis_sim(survey)
}

```



```
## Run several survey designs and assess stratified estimates
## (Note: total number of simulations are low to decrease computation time for the example)
surveys <- expand_surveys(set_den = c(1, 2) / 1000,
                        lengths_cap = c(100, 500),
                        ages_cap = c(5, 20))
tests <- test_surveys(dist, surveys = surveys, keep_details = 1,
                    n_sims = 5, n_loops = 5, cores = 1)
vis_sim(tests)
}
```

# Index

- \* **datasets**
  - bathy, 2
  - land, 6
  - survey\_grid, 28
  - survey\_lite\_mesh, 28
  - survey\_mesh, 29
- bathy, 2
- convert\_N, 3
- error\_stats, 3
- expand\_grid, 4
- expand\_surveys, 4, 30
- fibonacci, 4
- findInterval, 5
- getData, 6
- group\_lengths, 5, 25
- icc, 5
- land, 6
- lmer, 5
- make\_grid, 6, 10, 16
- make\_mesh, 7
- object.size, 8
- object\_size, 8
- plot\_age\_strat\_fan (plot\_trend), 9
- plot\_distribution (plot\_trend), 9
- plot\_error\_surface (plot\_trend), 9
- plot\_grid (plot\_trend), 9
- plot\_length\_strat\_fan (plot\_trend), 9
- plot\_ly, 10
- plot\_surface (plot\_trend), 9
- plot\_survey (plot\_trend), 9
- plot\_survey\_rank (plot\_trend), 9
- plot\_total\_strat\_fan (plot\_trend), 9
- plot\_trend, 9
- resume\_test (test\_surveys), 29
- round\_sim, 10
- run, 32
- run\_strat, 11, 25–27
- sim\_abundance, 9–11, 12, 16, 19, 30, 32
- sim\_ays\_covar, 14, 16
- sim\_ays\_covar\_spde, 14
- sim\_distribution, 9, 10, 14, 15, 16, 18, 21–23, 30, 32
- sim\_logistic, 17, 22, 24, 30
- sim\_N0, 12
- sim\_N0 (sim\_R), 19
- sim\_parabola, 16, 18
- sim\_R, 12, 19
- sim\_sets, 20, 22, 24, 31
- sim\_survey, 11, 12, 17, 21, 23, 24, 26, 30, 32
- sim\_survey\_parallel, 22, 23
- sim\_vonB, 12, 25
- sim\_Z, 12
- sim\_Z (sim\_R), 19
- spline, 6
- strat\_data, 11, 26
- strat\_error, 11, 26, 30
- strat\_means, 11, 27
- survey\_grid, 7, 16, 28
- survey\_lite\_mesh, 28
- survey\_mesh, 29
- test\_surveys, 23, 29, 32
- vis\_sim, 32