

Package ‘ecostate’

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Type Package

Title State-Space Mass-Balance Model for Marine Ecosystems

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Description Fits a state-space mass-balance model for marine ecosystems, which implements dynamics derived from 'Ecopath with Ecosim' ('EwE') <<https://ecopath.org/>> while fitting to time-series of fishery catch, biomass indices, age-composition samples, and weight-at-age data. 'Ecostate' fits biological parameters (e.g., equilibrium mass) and measurement parameters (e.g., catchability coefficients) jointly with residual variation in process errors, and can include Bayesian priors for parameters.

License GPL-3

Depends R (>= 4.1.0), RTMB (>= 1.5.0),

Imports TMB, MASS, checkmate, ggplot2, ggnetwork, igraph

Suggests knitr, rmarkdown

RoxygenNote 7.3.2

VignetteBuilder knitr

LazyData true

URL <https://james-thorson-noaa.github.io/ecostate/>

BugReports <https://github.com/James-Thorson-NOAA/ecostate/issues>

NeedsCompilation no

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abm3pc_sys	<i>Adams-Bashford-Moulton for system of equations</i>
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Description

Third-order Adams-Bashford-Moulton predictor-corrector method.

Usage

abm3pc_sys(f, a, b, y0, n, Pars, ...)

Arguments

f	function in the differential equation $y' = f(x, y)$; defined as a function $R \times R^m \rightarrow R^m$, where m is the number of equations.
a	starting time for the interval to integrate
b	ending time for the interval to integrate.
y0	starting values at time a
n	number of steps
Pars	named list of parameters passed to f
...	additional inputs to function f

Details

Combined Adams-Bashford and Adams-Moulton (or: multi-step) method of third order with corrections according to the predictor-corrector approach. Copied from pracma under GPL-3, with small modifications to work with RTMB

Value

List with components x for grid points between a and b and y an n-by-m matrix with solutions for variables in columns, i.e. each row contains one time stamp.

add_equilibrium	<i>Compute equilibrium values</i>
-----------------	-----------------------------------

Description

Compute equilibrium values

Usage

```
add_equilibrium(ecoparams, scale_solver, noB_i, type_i)
```

Arguments

ecoparams	list of parameters
scale_solver	Whether to solve for ecotrophic efficiency EE given biomass B (scale_solver="simple") or solve for a combination of EE and B values
noB_i	Boolean vector indicating which taxa have no B value
type_i	character vector indicating whether a taxon is "hetero", "auto", or "detritus"

Details

Replaces NA values in ecotrophic efficiency and/or biomass with equilibrium solution, and then calculates equilibrium consumption, natural mortality, and other rates.

Value

the list of parameters with missing values in ecoparams\$B_i and/or ecoparams\$EE_i filled in, as well as additional values Qe_ij, m0_i, and GE_i

compute_nll

Compute negative log-likelihood for EcoState model

Description

Compute negative log-likelihood for EcoState model

Usage

```
compute_nll(
  p,
  taxa,
  years,
  noB_i,
  type_i,
  n_species,
  project_vars,
  Bobs_ti,
  Cobs_ti,
  Nobs_ta_g2,
  Wobs_ta_g2,
  log_prior,
  fit_eps,
  fit_nu,
  stanza_data,
  settings,
  control,
  simulate_data = FALSE,
  simulate_random = FALSE
)
```

Arguments

p	list of parameters
taxa	Character vector of taxa included in model.
years	Integer-vector of years included in model
noB_i	Boolean vector indicating which taxa have no B value
type_i	character vector indicating whether a taxon is "hetero", "auto", or "detritus"
n_species	number of species
project_vars	function to integrate differential equation
Bobs_ti	formatted matrix of biomass data
Cobs_ti	formatted matrix of catch data
Nobs_ta_g2	formatted list of age-comp data
Wobs_ta_g2	formatted list of weight-at-age data

log_prior	A user-provided function that takes as input the list of parameters <code>out\$obj\$env\$parList()</code> where <code>out</code> is the output from <code>ecostate()</code> , and returns a numeric vector where the sum is the log-prior probability. For example <code>log_prior = function(p) dnorm(p\$logq_i[1], mean=0, sd=0.1, log=TRUE)</code> specifies a lognormal prior probability for the catchability coefficient for the first taxa with logmean of zero and logsd of 0.1
fit_eps	Character-vector listing taxa for which the model should estimate annual process errors in dB/dt
fit_nu	Character-vector listing taxa for which the model should estimate annual process errors in consumption Q_{ij}
stanza_data	output from <code>make_stanza_data</code>
settings	Output from <code>stanza_settings()</code> , used to define age-structured dynamics (called stanza-groups).
control	output from <code>ecostate_control</code>
simulate_data	Whether to simulate new data instead of computing the objective function, as used in the <code>ecostate</code> simulator routine
simulate_random	Whether to simulate new values of random effects. Only applies when <code>simulate_data==TRUE</code>

Details

Given a list of parameters, calculates the joint negative log-likelihood, where the Laplace approximation is then used to marginalize across random effects to calculate the log-marginal likelihood of fixed effects. The joint likelihood includes the fit to fishery catches, biomass indices, age-composition data, weight-at-age data, priors, and the distribution for random effects.

Value

The joint negative log-likelihood including contribution of priors and fit to data.

compute_tracer	<i>Calculate tracers, e.g., trophic level</i>
----------------	---

Description

Calculate how a tracer propagates through consumption.

Usage

```
compute_tracer(
  Q_ij,
  inverse_method = c("Penrose_moore", "Standard"),
  type_i,
  tracer_i = rep(1, nrow(Q_ij))
)
```

Arguments

Q _{i,j}	Consumption of each prey <i>i</i> by predator <i>j</i> in units biomass.
inverse_method	whether to use pseudoinverse or standard inverse
type_i	character vector indicating whether a taxon is "hetero", "auto", or "detritus"
tracer_i	an indicator matrix specifying the tracer value

Details

Trophic level y_i for each predator *i* is defined as:

$$y = I Q^* + 1$$

where Q^* is the proportion consumption for each predator (column) of different prey (rows). We identify primary producers as any taxa with no consumption (a column of 0s), and assign them as the first trophic level.

More generically, a tracer might be used to track movement of biomass through consumption. For example, if we have a tracer x_i that is 1 for the base of the pelagic food chain, and 0 otherwise, then we can calculate the proportion of pelagic vs. nonpelagic biomass for each taxon:

$$y = I Q^* + x$$

This then allows us to separate alternative components of the foodweb.

Value

The vector	y_i
resulting from tracer	x_i

dBdt	<i>Dynamics from EcoSim</i>
------	-----------------------------

Description

Compute system of differential equations representing EcoState dynamics derived from EcoSim.

Usage

```
dBdt(  
  Time,  
  State,  
  Pars,  
  type_i,  
  n_species,  
  F_type = "integrated",  
  what = "dBdt"  
)
```

Arguments

Time	not used
State	vector of state variables to integrate
Pars	list of parameters governing the ODE
type_i	type for each taxon
n_species	number of species
F_type	whether to integrate catches along with biomass ("integrated") or calculate catches from the Baranov catch equation applied to average biomass ("averaged")
what	what output to produce

Details

This function has syntax designed to match pracma solvers.

Value

An object (list) of ranges. Elements include:

- G_i** Biomass growth per time
- g_i** Biomass growth per time per biomass
- M2_i** Consumptive mortality per time
- m2_i** Consumptive mortality per time per biomass
- M_i** Natural mortality per time
- m_i** Natural mortality per time per biomass (i.e., $m2_i + m0_i$)
- Q_ij** Consumption per time for prey (rows) by predator (columns)

ddirmult

Dirichlet-multinomial

Description

Allows data-weighting as parameter

Usage

```
ddirmult(x, prob, ln_theta, log = TRUE)
```

Arguments

x	numeric vector of observations across categories
prob	numeric vector of category probabilities
ln_theta	logit-ratio of effective and input sample size
log	whether to return the log-probability or not

Value

The log-likelihood resulting from the Dirichlet-multinomial distribution

Examples

```
library(RTMB)
prob = rep(0.1,10)
x = rmultinom( n=1, prob=prob, size=20 )[,1]
f = function( ln_theta ) ddirmult(x, prob, ln_theta)
f( 0 )
F = MakeTape(f, 0)
F$jacfun()(0)
```

eastern_bering_sea	<i>eastern Bering Sea ecosystem data</i>
--------------------	--

Description

Data used to demonstrate a Model of Intermediate Complexity (MICE) for the eastern Bering Sea. `data(eastern_bering_sea)` loads a list that includes four components:

- Survey is a long-form data-frame with three columns, providing the Year, Mass (in relative units for most taxa, and million metric tons for Pollock, Cod, Arrowtooth, and NFS), and Taxon for each year with available data
- Catch is a long-form data-frame with three columns, providing the Year, Mass (in million metric tons), and Taxon for each year with available data
- P_over_B is a numeric vector with the unitless ratio of biomass production to population biomass for each taxon (as vector names)
- Q_over_B is a numeric vector with the unitless ratio of biomass consumption to population biomass for each taxon (as vector names)
- Diet_proportions is a numeric matrix where each column lists the proportion of biomass consumed for each predator (column names) that is provided by each prey (row names)

Usage

```
data(eastern_bering_sea)
```

Details

The data compiled come from a variety of sources:

- Northern fur seal (NFS) survey is an absolute index, corrected for proportion of time spent in the eastern Bering Sea. NFS QB is developed from a bioenergetic model and also corrected for seasonal residency. Both are provided by Elizabeth McHuron. It is post-processed in a variety of ways, and not to be treated as an index of abundance for NFS for other uses.

- Pollock, cod, and arrowtooth surveys are from a bottom trawl survey, and cod and arrowtooth are treated as an absolute index.
- Copepod and other zooplankton are from an oblique tow bongo net survey, with data provided by Dave Kimmel. It is then post-processed to account for spatially and seasonally imbalanced data.
- Other P_over_B , Q_over_B and $Diet_proportions$ values are derived from Rpath models, provided by Andy Whitehouse.
- Primary producers is an annual index of relative biomass, developed from monthly satellite measurements and provided by Jens Nielsen. See Thorson et al. (2025) for more details regarding data standardization and sources

ecostate

fit EcoState model

Description

Estimate parameters for an EcoState model

Usage

```
ecostate(
  taxa,
  years,
  catch = data.frame(Year = numeric(0), Mass = numeric(0), Taxon = numeric(0)),
  biomass = data.frame(Year = numeric(0), Mass = numeric(0), Taxon = numeric(0)),
  agecomp = list(),
  weight = list(),
  PB,
  QB,
  B,
  DC,
  EE,
  X,
  type,
  U,
  fit_B = vector(),
  fit_Q = vector(),
  fit_B0 = vector(),
  fit_EE = vector(),
  fit_PB = vector(),
  fit_QB = vector(),
  fit_eps = vector(),
  fit_nu = vector(),
  log_prior = function(p) 0,
  settings = stanza_settings(taxa = taxa),
  control = ecostate_control()
)
```

Arguments

taxa	Character vector of taxa included in model.
years	Integer-vector of years included in model
catch	long-form data frame with columns Mass, Year and Taxon
biomass	long-form data frame with columns Mass, Year and Taxon, where Mass is assumed to have the same units as catch
agecomp	a named list, with names corresponding to stanza_groups, where each list-element is a matrix with rownames for years and colnames for integer ages, where NA excludes the entry from inclusion and the model computes the likelihood across included ages in a given year, and the rowsum is the input-sample size for a given year
weight	a named list, with names corresponding to stanza_groups, where each list-element is a matrix with rownames for years and colnames for integer ages, where NA excludes the entry from inclusion and the model computes the log-normal likelihood for weight-at-age in each specified age-year combination
PB	numeric-vector with names matching taxa, providing the ratio of production to biomass for each taxon
QB	numeric-vector with names matching taxa, providing the ratio of consumption to biomass for each taxon
B	numeric-vector with names matching taxa, providing the starting (or fixed) value for equilibrium biomass for each taxon
DC	numeric-matrix with rownames and colnames matching taxa, where each column provides the diet proportion for a given predator
EE	numeric-vector with names matching taxa, providing the proportion of proportion of production that is subsequently modeled (termed ecotrophic efficiency)
X	numeric-matrix with rownames and colnames matching taxa, where each element gives the vulnerability parameter for a given interaction.
type	character-vector with names matching taxa and elements c("auto", "hetero", "detritus"), indicating whether each taxon is a primary producer, consumer/predator, or detritus, respectively.
U	numeric-vector with names matching taxa, providing the proportion of consumption that is unassimilated and therefore exported to detritus
fit_B	Character-vector listing taxa for which equilibrium biomass is estimated as a fixed effect
fit_Q	Character-vector listing taxa for which the catchability coefficient is estimated as a fixed effect
fit_B0	Character-vector listing taxa for which the ratio of initial to equilibrium biomass is estimated as a fixed effect
fit_EE	Character-vector listing taxa for which ecotrophic efficiency is estimated.
fit_PB	Character-vector listing taxa for which equilibrium production per biomass is estimated. Note that it is likely a good idea to include a prior for any species for which this is estimated.

<code>fit_QB</code>	Character-vector listing taxa for which equilibrium consumption per biomass is estimated. Note that it is likely a good idea to include a prior for any species for which this is estimated.
<code>fit_eps</code>	Character-vector listing taxa for which the model should estimate annual process errors in dB/dt
<code>fit_nu</code>	Character-vector listing taxa for which the model should estimate annual process errors in consumption Q_{ij}
<code>log_prior</code>	A user-provided function that takes as input the list of parameters <code>out\$obj\$env\$parList()</code> where <code>out</code> is the output from <code>ecostate()</code> , and returns a numeric vector where the sum is the log-prior probability. For example <code>log_prior = function(p) dnorm(p\$logq_i[1], mean=0, sd=0.1, log=TRUE)</code> specifies a lognormal prior probability for the catchability coefficient for the first taxa with logmean of zero and logsd of 0.1
<code>settings</code>	Output from <code>stanza_settings()</code> , used to define age-structured dynamics (called stanza-groups).
<code>control</code>	Output from <code>ecostate_control()</code> , used to define user settings.

Details

All taxa must be included in QB, PB, B, and DC, but additional taxa can be in QB, PB, B, and DC that are not in taxa. So `taxa` can be used to redefine the set of modeled species without changing other inputs

Value

An object (list) of S3-class `ecostate`. Elements include:

obj RTMB object from `MakeADFun`

tmb_inputs The list of inputs passed to `MakeADFun`

opt The output from `nlminb`

sdrep The output from `sdreport`

internal Objects useful for package function, i.e., all arguments passed during the call

rep report file, including matrix B_{ti} for biomass in each year t and taxon i , g_{ti} for growth rate per biomass, and see $dBdt$ for other quantities reported by year

derived derived quantity estimates and standard errors, for `rep` objects as requested

call function call record

run_time Total runtime

This S3 class then has functions `summary`, `print`, and `logLik`

References

Introducing the state-space mass-balance model:

Thorson, J. Kristensen, K., Aydin, K., Gaichas, S., Kimmel, D.G., McHuron, E.A., Nielsen, J.N., Townsend, H., Whitehouse, G.A (In press). The benefits of hierarchical ecosystem models: demonstration using a new state-space mass-balance model `EcoState`. *Fish and Fisheries*.

ecostate_control	<i>Detailed control for ecostate structure</i>
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Description

Define a list of control parameters.

Usage

```
ecostate_control(
  nlminb_loops = 1,
  newton_loops = 0,
  eval.max = 1000,
  iter.max = 1000,
  getsd = TRUE,
  silent = getOption("ecostate.silent", TRUE),
  trace = getOption("ecostate.trace", 0),
  verbose = getOption("ecostate.verbose", FALSE),
  profile = c("logF_ti", "log_winf_z", "s50_z", "srate_z"),
  random = c("epsilon_ti", "alpha_ti", "nu_ti", "phi_tg2"),
  tmb_par = NULL,
  map = NULL,
  getJointPrecision = FALSE,
  integration_method = c("ABM", "RK4", "ode23", "rk4", "lsoda"),
  process_error = c("epsilon", "alpha"),
  n_steps = 10,
  F_type = c("integrated", "averaged"),
  derived_quantities = c("h_g2", "B_ti", "B0_i"),
  scale_solver = c("joint", "simple"),
  inverse_method = c("Standard", "Penrose_moore"),
  tmbad.sparse_hessian_compress = 1,
  start_tau = 0.001
)
```

Arguments

nlminb_loops	Integer number of times to call <code>stats::nlminb()</code> .
newton_loops	Integer number of Newton steps to do after running <code>stats::nlminb()</code> .
eval.max	Maximum number of evaluations of the objective function allowed. Passed to control in <code>stats::nlminb()</code> .
iter.max	Maximum number of iterations allowed. Passed to control in <code>stats::nlminb()</code> .
getsd	Boolean indicating whether to call <code>TMB::sdreport()</code>
silent	Disable terminal output for inner optimizer?
trace	Parameter values are printed every trace iteration for the outer optimizer. Passed to control in <code>stats::nlminb()</code> .

verbose	Output additional messages about model steps during fitting?
profile	parameters that are profiled across, passed to MakeADFun
random	parameters that are treated as random effects, passed to MakeADFun
tmb_par	list of parameters for starting values, with shape identical to <code>tinyVAST(...)\$internal\$parlist</code>
map	list of mapping values, passed to RTMB::MakeADFun
getJointPrecision	whether to get the joint precision matrix. Passed to sdreport .
integration_method	What numerical integration method to use. "ABM" uses a native-R versions of Adam-Bashford, "RK4" uses a native-R version of Runge-Kutta-4, and "ode23" uses a native-R version of adaptive Runge-Kutta-23, where all are adapted from <code>pracma</code> functions. "rk4" and <code>lsoda</code> use those methods from <code>deSolve::ode</code> as implemented by <code>RTMBoDE::ode</code>
process_error	Whether to include process error as a continuous rate (i.e., an "innovation" parameterization, <code>process_error="epsilon"</code>) or as a discrete difference between expected and predicted biomass (i.e., a "state-space" parameterization), <code>process_error="alpha"</code> The former is more interpretable, whereas the latter is much more computationally efficient.
n_steps	number of steps used in the ODE solver for biomass dynamics
F_type	whether to integrate catches along with biomass ("integrated") or calculate catches from the Baranov catch equation applied to average biomass ("averaged")
derived_quantities	character-vector listing objects to ADREPORT
scale_solver	Whether to solve for ecotrophic efficiency EE given biomass B (<code>scale_solver="simple"</code>) or solve for a combination of EE and B values
inverse_method	whether to use pseudoinverse or standard inverse
tmbad.sparse_hessian_compress	passed to TMB::config() , and enabling an experimental feature to save memory when first computing the inner Hessian matrix. Using <code>tmbad.sparse_hessian_compress=1</code> seems to have no effect on the MLE (although users should probably confirm this), and hugely reduces memory use in both small and large models. Using <code>tmbad.sparse_hessian_compress=1</code> seems to hugely speed up the model-fitting with a large model but results in a small decrease in speed for model-fitting with a small model.
start_tau	Starting value for the standard deviation of process errors

Value

An S3 object of class "ecostate_control" that specifies detailed model settings, allowing user specification while also specifying default values

ginv	<i>Penrose-Moore pseudoinverse</i>
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Description

Extend MASS:ginv to work with RTMB

Usage

```
ginv(x)
```

Arguments

x	Matrix used to compute pseudoinverse
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gulf_of_alaska	<i>eastern Gulf of Alaska data</i>
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Description

Data used to demonstrate size-structured modelling including bottom-up linkages. `data(gulf_of_alaska)` loads a list that includes four components:

- `years` the set of years modeled
- `taxa` the set of taxa (including each stanza for age-structured populations)
- `type` is a character vector indicating for each taxon (as vector names) whether it is a heterotroph, autotroph, or detritus pool
- `biomass_data` is a long-form data-frame with three columns, providing the Year, Mass (in relative units for copepods and euphausiids, and million metric tons for Pollock and sablefish), and Taxon for each year with available data
- `catch_data` is a long-form data-frame with three columns, providing the Year, Mass (in million metric tons), and Taxon for each year with available data
- `P_over_B` is a numeric vector with the unitless ratio of biomass production to population biomass for each taxon (as vector names)
- `Q_over_B` is a numeric vector with the unitless ratio of biomass consumption to population biomass for each taxon (as vector names)
- `EE` is a numeric vector with the ecotrophic efficiency for each taxa, in this case provided only for the detritus pool and determining its turn-over rate
- `Diet_proportions` is a numeric matrix where each column lists the proportion of biomass consumed for each predator (column) that is provided by each prey (row)
- `agecomp_data` is a named list with age-composition samples for any age-structured population (named list element), where each list element is a matrix with named rows indicating years, and columns indicating integer ages

- stanza_groups is a character vector with names matching taxa, and elements indicating multi-stanza groups (i.e., age-structured populations)
- Amax is a numeric vector indicating the maximum age (in years) for each stanza as indicated in names(stanza_groups).
- Leading is a Boolean vector indicating which stanza is used for estimating biomass (and therefore recruitment) for each names(stanza_groups).
- K is a numeric vector with the generalized von Bertalanffy growth coefficient (in weight not length) for each unique(stanza_groups)
- d is a numeric vector with the generalized von Bertalanffy growth coefficient (in weight not length) for each unique(stanza_groups)
- Amat is a numeric vector with the age at 50% maturity (in years) for each unique(stanza_groups). If provided, it is used to back-calculate and replace the value for Wmat
- Wmat is a numeric vector with the weight at 50% maturity (relative to W_inf) for each unique(stanza_groups).
- Wmatslope is a numeric vector with the slope of the logistic maturity at weight (relative to W_inf) for each unique(stanza_groups)

Usage

```
data(gulf_of_alaska)
```

Details

The data compiled come from a variety of sources:

- Sablefish biomass index and age-comps are from a cooperative longline survey, and the index is treated as a relative index.
- Pollock biomass index and age-comps are from a bottom trawl survey, and the index is treated as a relative index with a prior on the catchability coefficient.
- Copepod biomass is from an oblique tow bongo net survey, with data provided by Dave Kimmel.
- Euphausiid biomass is from the Seward Long-Term Ecological Research program, provided by Russ Hopcroft to the Ecological Status Report.
- Other P_over_B, Q_over_B and Diet_proportions values are derived from Rpath models, provided by Bia Dias.
- Age-structured inputs are determined based on life-history information and biological samples. See Thorson et al. (In review) for more details regarding data standardization and sources

logLik.ecostate	<i>Marginal log-likelihood</i>
-----------------	--------------------------------

Description

Extract the (marginal) log-likelihood of a ecostate model

Usage

```
## S3 method for class 'ecostate'  
logLik(object, ...)
```

Arguments

object	Output from ecostate
...	Not used

Value

object of class logLik with attributes

val	log-likelihood
df	number of parameters

Returns an object of class logLik. This has attributes "df" (degrees of freedom) giving the number of (estimated) fixed effects in the model, abd "val" (value) giving the marginal log-likelihood. This class then allows AIC to work as expected.

ode23	<i>Non-stiff (and stiff) ODE solvers</i>
-------	--

Description

Runge-Kutta (2, 3)-method with variable step size, resp

Usage

```
ode23(f, a, b, y0, n, Pars, rtol = 0.001, atol = 1e-06)
```

Arguments

f	function in the differential equation $y' = f(x, y)$; defined as a function $R \times R^m \rightarrow R^m$, where m is the number of equations.
a	starting time for the interval to integrate
b	ending time for the interval to integrate.
y0	starting values at time a
n	Not used
Pars	named list of parameters passed to f
rtol	relative tolerance.
atol	absolute tolerance.

Details

Copied from prasma under GPL-3, with small modifications to work with RTMB. This can be used to simulate dynamics, but not during estimation

Value

List with components t for time points between a and b and y an n-by-m matrix with solutions for variables in columns, i.e. each row contains one time stamp.

plot_foodweb	<i>Plot foodweb</i>
--------------	---------------------

Description

Plot consumption as a directed graph including all taxa (vertices) and biomass consumed (arrows). Taxa are located using tracers, where by default the y-axis is trophic level. #'

Usage

```
plot_foodweb(
  Q_ij,
  type_i,
  xtracer_i,
  ytracer_i = rep(1, nrow(Q_ij)),
  B_i = rep(1, nrow(Q_ij)),
  taxa_labels = letters[1:nrow(Q_ij)],
  xloc,
  yloc
)
```

Arguments

<code>Q_ij</code>	Consumption of each prey <i>i</i> by predator <i>j</i> in units biomass.
<code>type_i</code>	character vector indicating whether a taxon is "hetero", "auto", or "detritus"
<code>xtracer_i</code>	tracer to use when computing x-axis values
<code>ytracer_i</code>	tracer to use when computing y-axis values
<code>B_i</code>	biomass to use when weighting taxa in plot
<code>taxa_labels</code>	character vector of labels to use for each taxon
<code>xloc</code>	x-axis location (overrides calculation using <code>xtracer_i</code>)
<code>yloc</code>	y-axis location (overrides calculation using <code>ytracer_i</code>)

Details

Trophic level l_i for each predator *i* is defined as:

$$l - 1 = lQ^*$$

where Q^* is the proportion consumption for each predator (column) of different prey (rows). We identify primary producers as any taxa with no consumption (a column of 0s), and assign them as the first trophic level.

Value

invisibly return ggplot object for foodweb

<code>print.ecostate</code>	<i>Print fitted ecostate object</i>
-----------------------------	-------------------------------------

Description

Prints output from fitted ecostate model

Usage

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

Arguments

<code>x</code>	Output from <code>ecostate</code>
<code>...</code>	Not used

Value

No return value, called to provide clean terminal output when calling fitted object in terminal.

print_ecopars	<i>Print EcoSim parameters</i>
---------------	--------------------------------

Description

Prints parameters defining EcoSim dynamics

Usage

```
print_ecopars(x, silent = FALSE)
```

Arguments

x	Output from ecostate
silent	whether to print to terminal

Value

invisibly returns table printed

rk4sys	<i>Classical Runge-Kutta for system of equations</i>
--------	--

Description

Classical Runge-Kutta of order 4.

Usage

```
rk4sys(f, a, b, y0, n, Pars, ...)
```

Arguments

f	function in the differential equation $y' = f(x, y)$; defined as a function $R \times R^m \rightarrow R^m$, where m is the number of equations.
a	starting time for the interval to integrate
b	ending time for the interval to integrate.
y0	starting values at time a
n	the number of steps from a to b.
Pars	named list of parameters passed to f
...	additional inputs to function f

Details

Classical Runge-Kutta of order 4 for (systems of) ordinary differential equations with fixed step size. Copied from pracma under GPL-3, with small modifications to work with RTMB

Value

List with components x for grid points between a and b and y an n-by-m matrix with solutions for variables in columns, i.e. each row contains one time stamp.

stanza_settings	<i>Detailed control for stanza structure</i>
-----------------	--

Description

Define a list of control parameters.

Usage

```
stanza_settings(
  taxa,
  stanza_groups,
  K,
  d,
  Wmat,
  Amax,
  SpawnX,
  Leading,
  fit_K = c(),
  fit_d = c(),
  fit_phi = vector(),
  Amat = NULL,
  Wmatslope,
  STEPS_PER_YEAR = 1,
  comp_weight = c("multinom", "dir", "dirmult")
)
```

Arguments

taxa	Character vector of taxa included in model.
stanza_groups	character-vector with names corresponding to taxa and elements specifying the multi-stanza group (i.e., age-structured population) for a given taxa
K	numeric-vector with names matching unique(stanza_groups), providing the von Bertalanffy growth coefficient for length
d	numeric-vector with names matching unique(stanza_groups), providing the von Bertalanffy allometric consumption-at-weight (default is 2/3)

Wmat	numeric-vector with names matching unique(stanza_groups), providing the weight-at-maturity relative to asymptotic weight
Amax	numeric-vector with names matching names(stanza_groups), providing the maximum age (in units years) for a given taxon (and the oldest taxon for a given stanza_group is treated as a plus-group)
SpawnX	numeric-vector with names matching unique(stanza_groups), providing the larval vulnerability (density dependence) parameter
Leading	Boolean vector with names matching names(stanza_groups), with TRUE for the taxon for which scale (B or EE) is specified or estimated, where this is then calculated deterministically for other taxa for a given stanza_group
fit_K	Character-vector listing stanza_groups for which K is estimated
fit_d	Character-vector listing stanza_groups for which d is estimated (note that this currently does not work)
fit_phi	Character-vector listing stanza_groups for which the model should estimate annual recruitment deviations, representing nonconsumptive variation in larval survival (e.g., oceanographic advection)
Amat	numeric-vector with names matching unique(stanza_groups), providing the integer age-at-maturity (in units years)
Wmatslope	numeric-vector with names matching unique(stanza_groups), providing the slope at 0.5 maturity for a logistic maturity-at-weight ogive
STEPS_PER_YEAR	integer number of Euler steps per year for calculating integrating individual weight-at-age
comp_weight	method used for weighting age-composition data

Value

An S3 object of class "stanza_settings" that specifies detailed model settings related to age-structured dynamics (e.g., stanzas), allowing user specification while also specifying default values

whitehouse_2021

Full rpath inputs for eastern Bering Sea

Description

All Rpath inputs from Whitehouse et al. 2021

Usage

```
data(whitehouse_2021)
```

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