

Package ‘NetIndices’

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Title Estimating Network Indices, Including Trophic Structure of Foodwebs in R

Author Karline Soetaert <karline.soetaert@nioz.nl>,
Julius Kipyegon Kones <jkones@uonbi.ac.ke>,
Dick van Oevelen <dick.vanoevelen@nioz.nl>

Maintainer Karline Soetaert <karline.soetaert@nioz.nl>

Depends R (>= 2.01), MASS

Suggests LIM

Description Given a network (e.g. a food web), estimates several network indices. These include: Ascendency network indices, Direct and indirect dependencies, Effective measures, Environ network indices, General network indices, Pathway analysis, Network uncertainty indices and constraint efficiencies and the trophic level and omnivory indices of food webs.

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NetIndices-package *Estimates network indices, including trophic structure of foodwebs*

Description

Given a network (e.g. a food web), estimates several network indices.

These include:

- ascendancy network indices,
- direct and indirect dependencies,
- effective measures,
- environ network indices,
- general network indices,
- pathway analysis,
- network uncertainty indices and constraint efficiencies
- the trophic level and omnivory indices of food webs.

Details

Package: NetIndices
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Author(s)

Karline Soetaert (Maintainer), Netherlands Institute of Ecology

Julius Kipyegon Kones, University of Nairobi

References

Kones, J.K., Soetaert, K., van Oevelen, D. and J.Owino (2009). Are network indices robust indicators of food web functioning? a Monte Carlo approach. *Ecological Modelling*, 220, 370-382.

Examples

```
## Not run:  
## show examples (see respective help pages for details)  
example(AscInd)
```

```

example(TrophInd)
example(Takapoto)

## open the directory with script used to write the Kones et al. (2009) article
browseURL(paste(system.file(package="NetIndices"), "/EcologicalModelling", sep=""))

## open the directory with documents
browseURL(paste(system.file(package="NetIndices"), "/doc", sep=""))

## the vignette
vignette("NetIndices")

## End(Not run)

```

AscInd

Ascendency network indices

Description

Calculates measures of system growth and development: Ascendency, Overhead and Capacity for several (sub)networks.

Usage

```

AscInd(Flow = NULL, Tij = t(Flow), Import = NULL,
       Export = NULL, Dissipation = NULL)

```

Arguments

Flow	network matrix with Flow[i,j] the flow from i (row) to j (column); component positions in rows and columns must be the same; if present, rownames or columnnames denote the compartment names.
Tij	network matrix where connectance is from column j to row i; component positions in rows and columns must be the same ; if present, rownames or columnnames denote the compartment names.
Import	vector with either the <i>*indices*</i> or the <i>*names*</i> of <i>external</i> compartments from where flow enters the network; the indices point to the column positions in Tij (and the row positions in Flow).
Export	vector with either the <i>*indices*</i> or the <i>*names*</i> of <i>external</i> compartments to where flow leaves the network; the indices point to the row positions in Tij (and the column positions in Flow).
Dissipation	vector with either the <i>*indices*</i> or the <i>*names*</i> to <i>external</i> compartments that dissipate flows (e.g. respiration); the indices point to the row positions in Tij (and the column positions in Flow).

Details

The mathematical formulation of these indices can be found in the package vignette - *vignette("NetIndices")*.
The PDF can be found in the subdirectory 'doc' of the NetIndices package.

Value

A matrix with ascendancy values (columns) for several subnetworks (rows).

The subnetworks (rows) are:

total	network
internal	network (excluding flows from and to external)
import	flows
export	flows; this includes the usable and unusable flows (i.e. +dissipation)
dissipation	flows

The ascendancy indices comprise (columns:)

asc	the ascendancy of the network, a measure of growth and development.
overh	the overhead of the network.
cap	the development capacity of the network, an upper bound on ascendancy.
ACratio	the ratio of ascendancy and capacity.

Author(s)

Karline Soetaert <karline.soetaert@nioz.nl>, Julius Kipyegon Kones<jkones@uonbi.ac.ke>

References

- Latham LG. 2006. Network flow analysis algorithms. *Ecological Modelling* 192: 586-600.
- Ulanowicz RE. 2000. Ascendancy: a measure of ecosystem performance. Jorgensen SE, Muller F, editors. *Handbook of Ecosystem Theories and Management*. Lewis Publishers, Boca Raton, p303-315.
- Ulanowicz RE, Norden JS. 1990. Symmetrical overhead in flow networks. *International Journal of System Science* 21: 429-437.
- Kones, J.K., Soetaert, K., van Oevelen, D. and J.Owino (2009). Are network indices robust indicators of food web functioning? a Monte Carlo approach. *Ecological Modelling*, 220, 370-382.

Examples

```
# The takapoto atoll network
AscInd(Takapoto, Import = "CO2",
       Export = c("CO2", "Sedimentation", "Grazing"),
       Dissipation = "CO2")

# Conesprings is the example set 1a from Latham 2006.
as.data.frame(
```

```
AscInd(Tij = Conesprings, Import = "Inflows",  
Export = c("Export", "Dissipation"),  
Dissipation = "Dissipation")  
)
```

Conesprings

Cone Spring ecosystem.

Description

Cone spring ecosystem (Tilly, 1968) adapted for input - output analysis by Williams & Crouthamel (1972) in Szyrmer & Ulanowicz (1987, Fig. 1, p. 129) and Ulanowicz & Norden (1990, Fig. 1, p. 435).

This is example 1a from Latham (2006).

The food web comprises 5 functional compartments:

- Plants
- Detritus
- Bacteria
- Detritus feeders
- Carnivores

and two export compartments

- usable export
- dissipation

and one import compartment

- Inflows

Usage

Conesprings

Format

matrix with Tij values, where element (i,j) denotes flow from compartment j to i
rownames and columnnames are the components.

Author(s)

Karline Soetaert <karline.soetaert@nioz.nl>

References

- Latham LG. 2006. Network flow analysis algorithms. *Ecological Modelling* 192: 586-600.
- Szyrmer, J., & Ulanowicz, R. E. (1987). Total flows in ecosystems. *Ecol. Model.* 35, 123..136.
- Tilly, L. J. (1968). The structure and dynamics of Cone Spring. *Ecol. Monogr.* 38, 169..197.
- Ulanowicz, R. E., & Norden, J. S. (1990). Symmetrical overhead in flow networks. *Int. J. Systems Sci.* 21, 429..437.
- Williams, M., & Crouthamel, D. (1972). Systems analysis of Cone Spring. Unpublished manuscript. University of Georgia, Athens, Georgia.

Examples

```
GenInd(Tij = Conesprings, Import = "Inflows",
       Export = c("Export", "Dissipation"))

AscInd(Tij = Conesprings, Import = "Inflows",
       Export = c("Export", "Dissipation"),
       Dissipation = "Dissipation")

UncInd(Tij = Conesprings, Import="Inflows",
       Export = c("Export", "Dissipation"))

EffInd(Tij = Conesprings, Import = "Inflows",
       Export = c("Export", "Dissipation"))

EnvInd(Tij = Conesprings, Import = "Inflows",
       Export = c("Export", "Dissipation"),
       full = TRUE)
```

Dependency

Direct and indirect dependency analysis

Description

Calculates for each component in a flow network the direct+indirect dependency on the other components.

Usage

```
Dependency(Flow = NULL, Tij = t(Flow),
           Import = NULL, Export = NULL)
```

Arguments

Flow network matrix with Flow[i,j] the flow from i (row) to j (column); component positions in rows and columns must be the same; if present, rownames or columnnames denote the compartment names.

Tij	network matrix where connectance is from column j to row i; component positions in rows and columns must be the same ; if present, rownames or columnnames denote the compartment names.
Import	vector with either the <i>*indices*</i> or the <i>*names*</i> of <i>external</i> compartments from where flow enters the network; the indices point to the column positions in Tij (and the row positions in Flow).
Export	vector with either the <i>*indices*</i> or the <i>*names*</i> of <i>external</i> compartments to where flow leaves the network; the indices point to the row positions in Tij (and the column positions in Flow).

Value

A matrix with dependency of component i on component j

Author(s)

Karline Soetaert <karline.soetaert@nioz.nl>, Julius Kipyegon Kones<jkones@uonbi.ac.ke>

References

Kones, J.K., Soetaert, K., van Oevelen, D. and J.Owino (2009). Are network indices robust indicators of food web functioning? a Monte Carlo approach. *Ecological Modelling*, 220, 370-382.

Examples

```
# The takapoto atoll network
Dependency(Takapoto, Import = "CO2",
           Export = c("CO2", "Sedimentation", "Grazing"))

# making "Bacteria" a "primary food source"
TAK <- Takapoto
TAK[, "Bacteria"] <- c(0, 0, 0, 0, 0, 0, 1, 0)

# first two columns
DD <- Dependency(TAK, Import = c("CO2", "DOC"),
                Export = c("CO2", "DOC", "Sedimentation", "Grazing"))
DD

barplot(t(DD[3:nrow(DD), 1:2]), beside = TRUE, ylab = "-",
        legend = c("Phytoplankton", "Bacteria"),
        main = "dependency on (primary) food sources")
```

Description

Calculates effective connectivity, effective flows, effective nodes and effective roles of a network.

Usage

```
EffInd(Flow = NULL, Tij = t(Flow),
       Import = NULL, Export = NULL)
```

Arguments

Flow	network matrix with Flow[i,j] the flow from i (row) to j (column); component positions in rows and columns must be the same; if present, rownames or columnnames denote the compartment names.
Tij	network matrix where connectance is from column j to row i; component positions in rows and columns must be the same ; if present, rownames or columnnames denote the compartment names.
Import	vector with either the <i>*indices*</i> or the <i>*names*</i> of <i>external</i> compartments from where flow enters the network; the indices point to the column positions in Tij (and the row positions in Flow).
Export	vector with either the <i>*indices*</i> or the <i>*names*</i> of <i>external</i> compartments from where flow leaves the network; the indices point to the row positions in Tij (and the column positions in Flow).

Details

The mathematical formulation of these indices can be found in the package vignette - *vignette("NetIndices")*.

The PDF can be found in the subdirectory 'doc' of the NetIndices package.

Value

a list with the following items:

CZ	Effective connectance
FZ	Effective Flows
NZ	Effective nodes
RZ	Effective roles

Author(s)

Karline Soetaert <karline.soetaert@nioz.nl>, Julius Kipyegon Kones<jkones@uonbi.ac.ke>

References

- Latham LG. 2006. Network flow analysis algorithms. *Ecological Modelling* 192: 586-600.
- Zorach and Ulanowicz, 2003. Quantifying the complexity of flow networks: how many roles are there?. *Complexity* 8,68-76.
- Kones, J.K., Soetaert, K., van Oevelen, D. and J.Owino (2009). Are network indices robust indicators of food web functioning? a Monte Carlo approach. *Ecological Modelling*, 220, 370-382.

Examples

```
# The takapoto atoll network
EffInd(Takapoto, Import = "CO2",
       Export = c("CO2", "Sedimentation", "Grazing"))

# Conesprings is the example set 1a from Latham 2006.
as.data.frame(
  EffInd(Tij = Conesprings, Import = "Inflows",
        Export = c("Export", "Dissipation"))
)
```

 EnvInd

Environ network indices

Description

Calculates the indices of homogenization, synergism index, dominance of indirect effects,... of a network.

Usage

```
EnvInd(Flow = NULL, Tij = t(Flow), Import = NULL,
       Export = NULL, full = FALSE)
```

Arguments

Flow	network matrix with Flow[i,j] the flow from i (row) to j (column); component positions in rows and columns must be the same; if present, rownames or columnnames denote the compartment names.
Tij	network matrix where connectance is from column j to row i; component positions in rows and columns must be the same ; if present, rownames or columnnames denote the compartment names.
Import	vector with either the <i>*indices*</i> or the <i>*names*</i> of <i>external</i> compartments from where flow enters the network; the indices point to the column positions in Tij (and the row positions in Flow).
Export	vector with either the <i>*indices*</i> or the <i>*names*</i> of <i>external</i> compartments to where flow leaves the network; the indices point to the row positions in Tij (and the column positions in Flow).
full	if TRUE, also returns matrices.

Details

The mathematical formulation of these indices can be found in the package vignette - *vignette("NetIndices")*.

The PDF can be found in the subdirectory 'doc' of the NetIndices package.

Value

A list with the following items:

NAG	Network aggradation = average path length.
HP	Homogenization index.
BC	Synergism.
ID	Dominance of Indirect effects.
MN	Mean of non-dimensional flow-matrix (N).
MG	Mean of direct flow-matrix (G).
CVN	Coefficient of variation of non-dimensional flow-matrix (N).
CVG	Coefficient of variation of direct flow-matrix (G).
U	Only if Full == TRUE: The Utility non-dimensional matrix.
N1	Only if Full == TRUE: The Integral non-dimensional Flow Matrix.
G	Only if Full == TRUE: The Normalized direct flow (or transitive closure) matrix.

Author(s)

Karline Soetaert <karline.soetaert@nioz.nl>, Julius Kipyegon Kones<jkones@uonbi.ac.ke>

References

- Patten BC, Barber MC, Richardson TH. 1982. Path analysis of a reservoir ecosystem model.
- Fath BD, Patten BC. 1999. Review of the foundations of network environ analysis. *Ecosystems* 2: 167-179.
- Fath BD, Patten BC. 1999. Quantifying resource homogenization using network flow analysis. *Ecological Modelling* 123: 193-205.
- Patten BC, Higashi M. 1984. Modified cycling index for ecological applications. *Ecological Modelling* 25: 69-83.
- Higashi M, Patten BC. 1989. Dominance of indirect causality in ecosystems. *The American Naturalist* 133: 288-302.
- Kones, J.K., Soetaert, K., van Oevelen, D. and J.Owino (2009). Are network indices robust indicators of food web functioning? a Monte Carlo approach. *Ecological Modelling*, 220, 370-382.

Examples

```
# The takapoto atoll network
EnvInd(Takapoto, Import = "CO2",
       Export = c("CO2", "Sedimentation", "Grazing"))

as.data.frame(
  EnvInd(Tij = Conesprings, Import = "Inflows",
        Export = c("Export", "Dissipation"))
)

EnvInd(Tij = Conesprings, Import = "Inflows",
       Export = c("Export", "Dissipation"), full = TRUE)
```

GenInd *General network indices.*

Description

Calculates general network indices such as system throughputs, link density, connectance,... of a network.

Usage

```
GenInd(Flow = NULL, Tij = t(Flow),
       Import = NULL, Export = NULL, tol = 0)
```

Arguments

Flow	network matrix with Flow[i,j] the flow from i (row) to j (column); component positions in rows and columns must be the same; if present, rownames or columnnames denote the compartment names.
Tij	network matrix where connectance is from column j to row i; component positions in rows and columns must be the same ; if present, rownames or columnnames denote the compartment names.
Import	vector with either the <i>*indices*</i> or the <i>*names*</i> of <i>external</i> compartments from where flow enters the network; the indices point to the column positions in Tij (and the row positions in Flow).
Export	vector with either the <i>*indices*</i> or the <i>*names*</i> of <i>external</i> compartments to where flow leaves the network; the indices point to the row positions in Tij (and the column positions in Flow).
tol	flows that are smaller or equal to tol are assumed to be absent.

Details

The mathematical formulation of these indices can be found in the package vignette - *vignette("NetIndices")*.

The PDF can be found in the subdirectory 'doc' of the NetIndices package.

Value

A list that contains:

N	number of compartments, excluding the externals.
T..	total System Throughput.
TST	total System Throughflow.
Lint	number of Internal links.
Ltot	total number of links.
LD	link Density.

C	connectance (internal).
Tijbar	average Link Weight.
TSTbar	average Compartment Throughflow .
Cbar	compartmentalization, [0,1], the degree of connectedness of subsystems within a network.

Author(s)

Karline Soetaert <karline.soetaert@nioz.nl>, Julius Kipyegon Kones<jkones@uonbi.ac.ke>

References

- Latham LG. 2006. Network flow analysis algorithms. *Ecological Modelling* 192: 586-600.
- Hirata H, Ulanowicz RE. 1984. Informational theoretical analysis of ecological networks. *International journal of systems science* 15 (3): 261-270
- Pimm SL, Lawton JH. 1980. Are food webs divided into compartments? *Journal of Animal Ecology* 49: 879-898.
- Kones, J.K., Soetaert, K., van Oevelen, D. and J.Owino (2009). Are network indices robust indicators of food web functioning? a Monte Carlo approach. *Ecological Modelling*, 220, 370-382.

Examples

```
# The takapoto atoll network
(GI<- GenInd(Takapoto, Import = "CO2",
            Export = c("CO2", "Sedimentation", "Grazing")))
as.data.frame(GI)

# a simple system
as.data.frame(GenInd(diag(5)))

# Conesprings is the example set 1a from Latham 2006.
as.data.frame(
  GenInd(Tij = Conesprings, Import = "Inflows",
        Export = c("Export", "Dissipation"))
)
```

PathInd

Pathway analysis

Description

Calculates the direct and indirect pathways in a network, i.e. the total system cycled throughflow, Finn's cycling index and average pathlength,...

Based on Finn(1980) (and not Finn (1976))

Usage

```
PathInd(Flow = NULL, Tij = t(Flow), Import = NULL, Export = NULL)
```

Arguments

Flow	network matrix with Flow[i,j] the flow from i (row) to j (column); component positions in rows and columns must be the same; if present, rownames or columnnames denote the compartment names.
Tij	network matrix where connectance is from column j to row i; component positions in rows and columns must be the same ; if present, rownames or columnnames denote the compartment names.
Import	vector with either the <i>*indices*</i> or the <i>*names*</i> of <i>external</i> compartments from where flow enters the network; the indices point to the column positions in Tij (and the row positions in Flow).
Export	vector with either the <i>*indices*</i> or the <i>*names*</i> of <i>external</i> compartments to where flow leaves the network; the indices point to the row positions in Tij (and the column positions in Flow).

Details

The mathematical formulation of these indices can be found in the package vignette - *vignette("NetIndices")*.
The PDF can be found in the subdirectory 'doc' of the NetIndices package.

Value

A list with the following items:

TSTC	total system cycled throughflow.
TSTS	non-cycled throughflow.
FCI	Finn's cycling index (1980).
FCIb	revised Finn's cycling index, sensu Allesina and Ulanowicz, 2004.
APL	average pathlength, also known as Network Aggradation (Sum of APLc and APLs in Latham 2006).

Author(s)

Karline Soetaert <karline.soetaert@nioz.nl>, Julius Kipyegon Kones<jkones@uonbi.ac.ke>

References

- Finn JT. 1980. Flow analysis of models of the Hubbard Brook ecosystem. *Ecology* 61: 562-571.
- Patten BC, Higashi M. 1984. Modified cycling index for ecological applications. *Ecological Modelling* 25: 69-83.
- Patten BC, Bosserman RW, Finn JT, Cale WG. 1976. Propagation of cause in ecosystems. Patten BC, editor. *Systems Analysis and Simulation in Ecology*, vol. 4. Academic Press, New York. p457-579.

Allesina and Ulanowicz, 2004. Cycling in ecological networks: Finn's index revisited. *Computational Biology and Chemistry* 28, 227-233.

Kones, J.K., Soetaert, K., van Oevelen, D. and J.Owino (2009). Are network indices robust indicators of food web functioning? a Monte Carlo approach. *Ecological Modelling*, 220, 370-382.

Examples

```
# The takapoto atoll network
PathInd(Takapoto, Import = "CO2",
        Export = c("CO2", "Sedimentation", "Grazing"))

# Conesprings is the example set 1a from Latham 2006.
as.data.frame(
  PathInd(Tij = Conesprings, Import = "Inflows",
          Export = c("Export", "Dissipation"))
)
```

Takapoto

Takapoto atoll planktonic food web

Description

Carbon flux matrix of the Takapoto atoll planktonic food web as reconstructed by inverse modelling by Niquil et al. (1998).

The Takapoto Atoll lagoon is located in the French Polynesia of the South Pacific

The food web comprises 7 functional compartments:

- Phytoplankton
- Bacteria
- Protozoa
- Microzooplankton
- Mesozooplankton
- Detritus
- Dissolved organic carbon (DOC)

one external source:

- CO₂

and three external sinks:

- CO₂
- Sedimentation
- Grazing

These compartments are connected with 32 flows.

Units of the flows are mg C/m²/day

Usage

Takapoto

Format

matrix with flow values, where element ij denotes flow from compartment i to j
rownames and columnnames are the components.

Author(s)

Karline Soetaert <karline.soetaert@nioz.nl>

References

Niquil, N., Jackson, G.A., Legendre, L., Delesalle, B., 1998. Inverse model analysis of the planktonic food web of Takapoto Atoll (French Polynesia). *Marine Ecology Progress Series* 165, 17..29.

Examples

```
UncInd(Takapoto, Import = "CO2",
       Export = c("CO2", "Sedimentation", "Grazing"))
```

TrophInd

The trophic level and omnivory index

Description

Calculates the trophic level and omnivory index of each component of a food web.

Usage

```
TrophInd(Flow = NULL, Tij = t(Flow),
         Import = NULL, Export = NULL, Dead = NULL)
```

Arguments

Flow	network matrix with $Flow[i,j]$ the flow from i (row) to j (column); component positions in rows and columns must be the same; if present, rownames or columnnames denote the compartment names.
Tij	network matrix where connectance is from column j to row i ; component positions in rows and columns must be the same ; if present, rownames or columnnames denote the compartment names.
Import	vector with either the <i>*indices*</i> or the <i>*names*</i> of <i>external</i> compartments from where flow enters the network; the indices point to the column positions in Tij (and the row positions in $Flow$).

Export	vector with either the <i>*indices*</i> or the <i>*names*</i> of <i>external</i> compartments where flow leaves the network; the indices point to the row positions in T_{ij} (and the column positions in Flow).
Dead	vector with either the <i>*indices*</i> or the <i>*names*</i> of dead matter; the indices point to row positions in T_{ij} ; the trophic level of these components is assumed to be 1.

Details

Primary producers, defined as those compartments that do not receive matter from another internal compartment, will be assigned a trophic level of 1.

In many trophic level calculations, it is also assumed that TL of detritus, dissolved organic matter and other inert material (i.e. that does not feed) is also = 1.

If this is desired, these compartments have to be designated as "Dead" (i.e. Dead should contain an index to row positions in T_{ij} of these compartments).

If not specified as "Dead", these compartments will have a $TL > 1$ and consequently the TL of other compartments will be higher too.

The mathematical formulation of these indices can be found in the package vignette - *vignette("NetIndices")*.

The PDF can be found in the subdirectory 'doc' of the NetIndices package.

Value

a 2-columned data.frame with, for each compartment of the network the following:

TL	the trophic level of a compartment, defined as 1 + the weighted average of the trophic levels of its food items.
OI	the omnivory index, the variety in the trophic levels of a consumer's food.

Note

Up to version 1.4.1, the estimation of TL produced strange results in case compartments feed on themselves. Then it was possible to produce negative Trophic levels. From version 1.4.2, it is implemented that self-feeding does not affect the TL of the compartment. Because of that, results may be different from the initial versions in such cases.

Author(s)

Karline Soetaert <karline.soetaert@nioz.nl>, Julius Kipyegon Kones<jkones@uonbi.ac.ke>

References

- Christensen V, Pauly D. 1992. ECOPATH II - a software for balancing steady-state ecosystem models and calculating network characteristics. *Ecological Modelling* 61: 169-185.
- Lindeman RL. 1942. The trophic dynamic aspect of ecology. *Ecology* 23: 399-418.
- Kones, J.K., Soetaert, K., van Oevelen, D. and J.Owino (2009). Are network indices robust indicators of food web functioning? a Monte Carlo approach. *Ecological Modelling*, 220, 370-382.

Examples

```
# The takapoto atoll network
# First trophic level without assuming that TL of detritus and DOC is 1
TrophInd(Takapoto, Import = "CO2",
         Export = c("CO2", "Sedimentation", "Grazing"))

# Now imposing TL=1 for detritus and DOC
TrophInd(Takapoto, Import = "CO2",
         Export = c("CO2", "Sedimentation", "Grazing"),
         Dead = c("Detritus", "DOC"))
```

 UncInd

Network uncertainty indices and constraint efficiencies

Description

Calculates the statistical, conditional and realised uncertainty, the average mutual information index, and the network uncertainty, network constraint and constraint efficiency,...

Usage

```
UncInd(Flow = NULL, Tij = t(Flow),
       Import = NULL, Export = NULL)
```

Arguments

Flow	network matrix with Flow[i,j] the flow from i (row) to j (column); component positions in rows and columns must be the same; if present, rownames or columnnames denote the compartment names.
Tij	network matrix where connectance is from column j to row i; component positions in rows and columns must be the same ; if present, rownames or columnnames denote the compartment names.
Import	vector with either the <i>*indices*</i> or the <i>*names*</i> of <i>external</i> compartments from where flow enters the network; the indices point to the column positions in Tij (and the row positions in Flow).
Export	vector with either the <i>*indices*</i> or the <i>*names*</i> of <i>external</i> compartments to where flow leaves the network; the indices point to the row positions in Tij (and the column positions in Flow).

Details

The mathematical formulation of these indices can be found in the package vignette - *vignette("NetIndices")*.

The PDF can be found in the subdirectory 'doc' of the NetIndices package.

Value

a list with the following items:

AMI	the average mutual information; as a system matures to form a web-like pattern, the AMI drops.
HR	the statistical uncertainty, upper bound on AMI, a measure of diversity.
DR	the conditional uncertainty index, the difference between AMI and HR, a measure of stability.
RU	the realised uncertainty index, ratio of AMI and HR.
Hmax	maximum uncertainty.
Hc	constraint information.
Hsys	network uncertainty.
CE	constraint efficiency.

Author(s)

Karline Soetaert <karline.soetaert@nioz.nl>, Julius Kipyegon Kones<jkones@uonbi.ac.ke>

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Examples

```
# The takapoto atoll network
UncInd(Takapoto, Import = "CO2",
       Export = c("CO2", "Sedimentation", "Grazing"))

# Conesprings is the example set 1a from Latham 2006.
as.data.frame(
  UncInd(Tij = Conesprings, Import = "Inflows",
        Export = c("Export", "Dissipation"))
)
```

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