

Package ‘ecorest’

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Title Conducts Analyses Informing Ecosystem Restoration Decisions

Version 1.0.0

Description Three sets of data and functions for informing ecosystem restoration decisions, particularly in the context of the U.S. Army Corps of Engineers. First, model parameters are compiled as a data set and associated metadata for over 500 habitat suitability models developed by the U.S. Fish and Wildlife Service (USFWS 1980) <<https://www.fws.gov/policy/ESMindex.html>>. Second, functions for conducting habitat suitability analyses both for the models described above as well as generic user-specified model parameterizations. Third, a suite of decision support tools for conducting cost-effectiveness and incremental cost analyses (Robinson et al. 1995) <<https://www.iwr.usace.army.mil/Portals/70/docs/iwrreports/95-R-1.pdf>>.

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annualizer	<i>Time-averaged restoration project outcomes</i>
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Description

annualizer computes time-averaged quantities based on linear interpolation.

Usage

```
annualizer(timevec, benefits)
```

Arguments

timevec	numeric vector of time intervals.
benefits	numeric vector of values to be interpolated.

Value

A time-averaged value over the specified time horizon.

References

Robinson R., Hansen W., and Orth K. 1995. Evaluation of environmental investments procedures manual interim: Cost effectiveness and incremental cost analyses. IWR Report 95-R-1. Institute for Water Resources, U.S. Army Corps of Engineers, Alexandria, Virginia.

Examples

```
#Constant value through time
annualizer(c(0,50), c(100,100))
annualizer(seq(0,50), rep(100,51))

#Simple time series
annualizer(seq(0,50), seq(0,50))

#User-specified time intervals
```

```
demo.timevec <- c(0,2,20,50)
demo.ben <- c(0,100,90,80)
annualizer(demo.timevec, demo.ben)
```

BBfinder	<i>Identifies "best buy" actions</i>
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Description

BBfinder this analysis examines the slope of the cost-effectiveness frontier to isolate how unit cost (cost/benefit) increases with increasing environmental benefit. Restoration actions with the lowest slope of unit cost are considered "best buys".

Usage

```
BBfinder(benefit, cost, CE)
```

Arguments

benefit	a vector of restoration benefits. Typically, these are time-averaged ecological outcomes (e.g., average annual habitat units). Often project benefits are best presented as the "lift" associated with a restoration action (i.e., the benefits of an alternative minus the benefits of a "no action" plan).
cost	a vector of restoration costs. Typically, these are monetary costs associated with a given restoration action such as project first cost or annualized economic cost. Notably, these functions are agnostic to units, so costs could also be non-monetary such as lost political capital or social costs of each alternative.
CE	numeric vector of 0's and 1's indicating whether a plan is cost-effective (1) or non-cost-effective (0). Can be derived from ecorest::CEfinder.

Value

A list with summaries of all restoration actions as well as best buy plans only.

References

Robinson R., Hansen W., and Orth K. 1995. Evaluation of environmental investments procedures manual interim: Cost effectiveness and incremental cost analyses. IWR Report 95-R-1. Institute for Water Resources, U.S. Army Corps of Engineers, Alexandria, Virginia

Examples

```
#Identify cost-effective actions based on random vectors of benefits and costs
benefit <- runif(50,min=0,max=10)
cost <- runif(50, min=0,max=1000)
CE <- CEfinder(benefit, cost)
BBfinder(benefit, cost, CE)

#Identify cost-effective actions based on a small number of user-specified benefits and costs
restben <- c(0, 10, 5, 20, 20)
restcost <- c(0, 100, 100, 200, 150)
restCE <- CEfinder(restben, restcost)
BBfinder(restben, restcost, restCE)
```

CEfinder

Finds cost-effective frontier

Description

CEfinder returns cost-effectiveness analysis for a particular set of alternatives.

Usage

```
CEfinder(benefit, cost)
```

Arguments

benefit	a vector of restoration benefits. Typically, these are time-averaged ecological outcomes (e.g., average annual habitat units). Often project benefits are best presented as the "lift" associated with a restoration action (i.e., the benefits of an alternative minus the benefits of a "no action" plan).
cost	a vector of restoration costs. Typically, these are monetary costs associated with a given restoration action such as project first cost or annualized economic cost. Notably, these functions are agnostic to units, so costs could also be non-monetary such as lost political capital or social costs of each alternative.

Value

A numeric vector identifying each plan as cost-effective (1) or non-cost-effective (0). The cost-effective actions comprise the Pareto frontier of non-dominated alternatives at a given level of cost or benefit.

References

Robinson R., Hansen W., and Orth K. 1995. Evaluation of environmental investments procedures manual interim: Cost effectiveness and incremental cost analyses. IWR Report 95-R-1. Institute for Water Resources, U.S. Army Corps of Engineers, Alexandria, Virginia

Examples

```
#Identify cost-effective actions based on random vectors of benefits and costs
CEfinder(runif(50,min=0,max=10), runif(50, min=0,max=1000))

#Identify cost-effective actions based on a small number of user-specified benefits and costs
restben <- c(0, 10, 5, 20, 20)
restcost <- c(0, 100, 100, 200, 150)
CEfinder(restben, restcost)
```

CEICApplotter

Plots cost-effectiveness and incremental cost analysis

Description

CEICApplotter Plots Cost-effective Incremental Cost Analysis (CEICA) in *.jpeg format.

Usage

```
CEICApplotter(altnames, benefit, cost, CE, BB, figure.name)
```

Arguments

altnames	vector of numerics or characters as unique restoration action identifiers.
benefit	a vector of restoration benefits. Typically, these are time-averaged ecological outcomes (e.g., average annual habitat units). Often project benefits are best presented as the "lift" associated with a restoration action (i.e., the benefits of an alternative minus the benefits of a "no action" plan).
cost	a vector of restoration costs. Typically, these are monetary costs associated with a given restoration action such as project first cost or annualized economic cost. Notably, these functions are agnostic to units, so costs could also be non-monetary such as lost political capital or social costs of each alternative.
CE	numeric vector of 0's and 1's indicating whether a plan is cost-effective (1) or non-cost-effective (0). Can be derived from ecorest::CEfinder.
BB	numeric vector of 0's and 1's indicating whether a plan is a best buy (1) or not (0). Can be derived from ecorest::BBfinder.
figure.name	output figure file name structured as "filename.jpeg".

Value

A multi-panel *.jpeg figure summarizing cost-effectiveness and incremental cost analyses.

References

Robinson R., Hansen W., and Orth K. 1995. Evaluation of environmental investments procedures manual interim: Cost effectiveness and incremental cost analyses. IWR Report 95-R-1. Institute for Water Resources, U.S. Army Corps of Engineers, Alexandria, Virginia

Examples

```
#Identify cost-effective actions based on random vectors of benefits and costs
altnames<- paste("Alt",seq(1,50), sep="")
benefit <- runif(50,min=0,max=10)
cost <- runif(50, min=0,max=1000)
CE <- CEfinder(benefit, cost)
BB <- BBfinder(benefit, cost, CE)[[1]][,4]
CEICAplotter(altnames, benefit, cost, CE, BB, tempfile("CEICAexample",fileext=".jpeg"))
```

HSIarimean

Computes Habitat Suitability Index with Arithmetic Mean

Description

HSIarimean uses arithmetic mean to combine suitability indices into an overarching habitat suitability index.

Usage

```
HSIarimean(x)
```

Arguments

x a vector of suitability indices.

Value

A value of habitat quality from 0 to 1 ignoring NA values.

References

US Fish and Wildlife Service. (1980). Habitat as a basis for environmental assessment. Ecological Services Manual, 101.

US Fish and Wildlife Service. (1980). Habitat Evaluation Procedures (HEP). Ecological Services Manual, 102.

US Fish and Wildlife Service. (1981). Standards for the Development of Habitat Suitability Index Models. Ecological Services Manual, 103.

Examples

```
#Determine patch quality based on a vector of four suitability indices.
HSIarimean(c(0.25, 0.25, 0.25, 0.25))
```

```
#Determine patch quality based on a vector of suitability indices with an NA.
HSIarimean(c(0.25, 0.25, NA, 0.25))
```

```
#Demonstrate error message associated with out of range outcomes.
HSIarimean(c(0.25, 0.25, 10.00, 0.25))
```

HSIeqtn	<i>Computes Habitat Suitability Index based on Model-Specified Equation</i>
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Description

HSIeqtn computes a habitat suitability index based on equations specified in U.S. Fish and Wildlife Service habitat suitability models contained within ecorest via HSImodels and HSImetadata. Habitat suitability indices represent an overall assessment of habitat quality from combining individual suitability indices for multiple independent variables. The function computes an overall habitat suitability index.

Usage

```
HSIeqtn(HSImodelName, SIV, HSImetadata)
```

Arguments

HSImodelName	a character string in quotations that must match an existing model name in HSImetadata.
SIV	a vector of suitability index values used in the model specified in HSImodelName.
HSImetadata	a data frame of HSI model metadata within the ecorest package.

Value

A numeric of the habitat suitability index ranging from 0 to 1.

References

US Fish and Wildlife Service. (1980). Habitat as a basis for environmental assessment. Ecological Services Manual, 101.

US Fish and Wildlife Service. (1980). Habitat Evaluation Procedures (HEP). Ecological Services Manual, 102.

US Fish and Wildlife Service. (1981). Standards for the Development of Habitat Suitability Index Models. Ecological Services Manual, 103.

Examples

```
#Compute patch quality for the Barred Owl model (no components)
#Allen A.W. 1982. Habitat Suitability Index Models: Barred owl. FWS/OBS 82/10.143.
#U.S. Fish and Wildlife Service. https://pubs.er.usgs.gov/publication/fwsobs82_10_143.
#Suitability indices relate to density of large trees, mean diameter of overstory trees,
#and percent canopy cover of overstory.
#Example suitability vectors
HSIeqtn("barredowl", c(1,1,1), HSImetadata) #c(1,1,1) should result in 1.00
HSIeqtn("barredowl", c(0.5,1,1), HSImetadata) #c(0.5,1,1) should result in 0.707
HSIeqtn("barredowl", c(0,1,1), HSImetadata) #c(0,1,1) should result in 0.00
HSIeqtn("barredowl", c(0,NA,1), HSImetadata) #c(0,NA,1) should return error message
HSIeqtn("barredowl", c(NA,1,1,1), HSImetadata) #c(NA,1,1,1) should return error message

#Compute patch quality for the Juvenile Alewife mode (two components)
#Pardue, G.B. 1983. Habitat Suitability index models: alewife and blueback herring.
#U.S. Dept. Int. Fish Wildl. Serv. FWS/OBS-82/10.58. 22pp.
#Suitability indices relate to zooplankton density, salinity, and water temperature
#Example suitability vectors are c(1,1,1), c(0.5,1,1), and c(0,1,1)
HSIeqtn("alewifeJuv", c(1,1,1), HSImetadata) #c(1,1,1) should result in 1.00
HSIeqtn("alewifeJuv", c(0.5,1,1), HSImetadata) #c(0.5,1,1) should result in 0.50
HSIeqtn("alewifeJuv", c(0,1,1), HSImetadata) #c(0,1,1) should result in 0.00
HSIeqtn("alewifeJuv", c(1,NA,1), HSImetadata) #c(1,NA,1) returns error message
HSIeqtn("alewifeJuv", c(1,1,1,NA), HSImetadata) #c(1,1,1,NA) returns error message
```

HSIgeomean

Habitat Suitability Index with Geometric Mean

Description

HSIgeomean uses geometric mean to combine suitability indices into an overarching habitat suitability index.

Usage

```
HSIgeomean(x)
```

Arguments

x a vector of suitability indices

Value

A value of habitat quality from 0 to 1 ignoring NA values.

References

US Fish and Wildlife Service. (1980). Habitat as a basis for environmental assessment. Ecological Services Manual, 101.

US Fish and Wildlife Service. (1980). Habitat Evaluation Procedures (HEP). Ecological Services Manual, 102.

US Fish and Wildlife Service. (1981). Standards for the Development of Habitat Suitability Index Models. Ecological Services Manual, 103.

Examples

```
#Determine patch quality based on a vector of four suitability indices.
HSIgeomean(c(0.25, 0.25, 0.25, 0.25))
```

```
#Determine patch quality based on a vector of suitability indices with an NA.
HSIgeomean(c(0.25, 0.25, NA, 0.25))
```

```
#Determine patch quality based on a vector of suitability indices with a zero-value.
HSIgeomean(c(0.25, 0.25, 0.0, 0.25))
```

```
#Demonstrate error message associated with out of range outcomes.
HSIgeomean(c(2, 2, NA, 3))
```

HSImetadata

Habitat suitability index (HSI) model metadata

Description

Metadata for 519 U.S. Fish and Wildlife Service Habitat suitability index (HSI) models

Usage

```
HSImetadata
```

Format

A data frame with 519 rows and 55 variables:

model Model name

submodel Model specifications

species Scientific nomenclature of modeled taxa

geography Geographic range of organism

ecosystem Type of habitat

documentation Citation of original model

note Conditions under which model may be applied

website Link to original individual model source

SIV1 Suitability index values for each organism specific condition

SIV2 Suitability index values for each organism specific condition

SIV3 Suitability index values for each organism specific condition

SIV4 Suitability index values for each organism specific condition

SIV5 Suitability index values for each organism specific condition

SIV6 Suitability index values for each organism specific condition

SIV7 Suitability index values for each organism specific condition

SIV8 Suitability index values for each organism specific condition

SIV9 Suitability index values for each organism specific condition

SIV10 Suitability index values for each organism specific condition

SIV11 Suitability index values for each organism specific condition

SIV12 Suitability index values for each organism specific condition

SIV13 Suitability index values for each organism specific condition

SIV14 Suitability index values for each organism specific condition

SIV15 Suitability index values for each organism specific condition

SIV16 Suitability index values for each organism specific condition

SIV17 Suitability index values for each organism specific condition

SIV18 Suitability index values for each organism specific condition

SIV19 Suitability index values for each organism specific condition

SIV20 Suitability index values for each organism specific condition

SIV21 Suitability index values for each organism specific condition

SIV22 Suitability index values for each organism specific condition

CF Food component equation

CC Cover component equation

CCF Cover-food component equation

CWF Winter food component

CW Water component

CCB Cover breeding component

CCN Cover nesting component

CWQ Water quality component

CR Reproduction component

CCR Cover reproduction component

CD Disturbance component

COT Other component

CL Larval component

CEL Embryo and larval component

CE Embryo component
CJ Juvenile component
CFr Fry component
CS Spawning component
CA Adult component
CI Island component
CNI Non-island component
CWFC Winter cover food component
CT Topography component
CJA Juvenile adult component
Eqtn HSI overarching model equation in R syntax

Source

<https://pubs.er.usgs.gov/>

HSImin

Habitat Suitability Index with Minimum

Description

HSImin uses the minimum of given suitability indices to calculate an overarching habitat suitability index.

Usage

HSImin(x)

Arguments

x a vector of suitability indices

Value

A value of habitat quality from 0 to 1 ignoring NA values.

References

- US Fish and Wildlife Service. (1980). Habitat as a basis for environmental assessment. Ecological Services Manual, 101.
- US Fish and Wildlife Service. (1980). Habitat Evaluation Procedures (HEP). Ecological Services Manual, 102.
- US Fish and Wildlife Service. (1981). Standards for the Development of Habitat Suitability Index Models. Ecological Services Manual, 103.

Examples

```
#Determine patch quality based on a vector of four suitability indices.
HSImin(c(0.1, 0.25, 0.25, 0.25))

#Determine patch quality based on a vector of suitability indices with an NA.
HSImin(c(0.1, 0.25, NA, 0.25))

#Demonstrate error message associated with out of range outcomes.
HSImin(c(2, 4, NA, 3))
```

HSImodels

Habitat suitability index (HSI) models

Description

This list of data frames contains 519 U.S. Fish and Wildlife Service Habitat suitability index (HSI) models

Usage

```
HSImodels
```

Format

An object of class `list` of length 519.

Details

@format A list with 519 data frames each containing an HSI model with multiple independent variables and associated habitat suitability indices (a 0 to 1 value). Data represent break points in curves with linear extrapolation between. Categorical input variables are coded as letters.

variable1 independent variable for assessing habitat suitability

SIV1 suitability index value relative to variable1

... additional variables and suitability indices

Source

<https://pubs.er.usgs.gov/>

HSIplotter

Plots habitat suitability index curves

Description

HSIplotter plots all suitability curves.

Usage

```
HSIplotter(SI, figure.name)
```

Arguments

SI	matrix of suitability curves ordered as parameter breakpoints and associated suitability indices for each parameter with appropriate column names.
figure.name	output figure file name structured as "filename.jpeg".

Value

A multi-panel *.jpeg figure showing all suitability curves.

References

US Fish and Wildlife Service. (1980). Habitat as a basis for environmental assessment. Ecological Services Manual, 101.

US Fish and Wildlife Service. (1980). Habitat Evaluation Procedures (HEP). Ecological Services Manual, 102.

US Fish and Wildlife Service. (1981). Standards for the Development of Habitat Suitability Index Models. Ecological Services Manual, 103.

Examples

```
#Build and define a matrix of the Barred Owl suitability curves
#Allen A.W. 1982. Habitat Suitability Index Models: Barred owl. FWS/OBS 82/10.143.
#U.S. Fish and Wildlife Service. https://pubs.er.usgs.gov/publication/fwsobs82_10_143.
var1 <- cbind(c(0,2,4,NA), c(0.1,1,1,NA)) #Number of trees > 51cm diameter per 0.4 ha plot
var2 <- cbind(c(0,5,20,NA), c(0,0,1,NA)) #Mean diameter of overstory trees
var3 <- cbind(c(0,20,60,100), c(0,0,1,1)) #Percent canopy cover of overstory trees
barredowl <- cbind(var1, var2, var3)
colnames(barredowl)<- c("tree.num", "tree.num.SIV",
  "avg.dbh.in", "avg.dbh.SIV", "can.cov", "can.cov.SIV")

#Create suitability curve summary plot
HSIplotter(barredowl, tempfile("BarredOwl",fileext=".jpeg"))
```

HSIwarimean

Habitat Suitability Index with a Weighted Arithmetic Mean

Description

HSIwarimean uses a weighted arithmetic mean to combine suitability indices into an overarching habitat suitability index.

Usage

```
HSIwarimean(x, w)
```

Arguments

x is a vector of suitability indices.
w is a vector of weights (0 to 1 values that must sum to one).

Value

A value of habitat quality from 0 to 1 ignoring NA values.

References

US Fish and Wildlife Service. (1980). Habitat as a basis for environmental assessment. Ecological Services Manual, 101.
US Fish and Wildlife Service. (1980). Habitat Evaluation Procedures (HEP). Ecological Services Manual, 102.
US Fish and Wildlife Service. (1981). Standards for the Development of Habitat Suitability Index Models. Ecological Services Manual, 103.

Examples

```
#Determine patch quality based on a vector of four, equal-weight suitability indices.  
HSIwarimean(c(1, 0, 0, 0), c(0.25, 0.25, 0.25, 0.25))  
  
#Determine patch quality based on a vector of four, unequal-weight suitability indices.  
HSIwarimean(c(1, 0, 0, 0), c(1, 0, 0, 0))  
  
#Determine patch quality based on a vector of four, unequal-weight suitability indices.  
HSIwarimean(c(1, 0, 0, 0), c(0, 1, 0, 0))  
  
#Demonstrate error for mismatching inputs.  
HSIwarimean(c(1, 0, 0, 0), c(0, 0, 0))  
  
#Demonstrate error for incorrect weighting.  
HSIwarimean(c(1, 0, 0, 0), c(1, 1, 0, 0))  
  
#Demonstrate error for out of range output.
```

```
HSIwarimean(c(1, 1, 1, 10), c(0.2, 0.3, 0.3, 0.2))
```

HUcalc *Computes Habitat Quality, Quantity, and Units*

Description

HUcalc computes habitat units given a set of suitability indices, a habitat suitability index equation, and habitat quantity.

Usage

```
HUcalc(SI.out, habitat.quantity, HSIfunc, ...)
```

Arguments

SI.out	is a vector of application-specific suitability indices, which can be produced from SImean.
habitat.quantity	is a numeric of habitat size associated with these suitability indices (i.e., length, area, or volume).
HSIfunc	is a function for combination of the suitability indices.
...	optional arguments to HSIfunc.

Value

A vector of habitat quality, habitat quantity, and index units (quantity times quality).

References

US Fish and Wildlife Service. (1980). Habitat as a basis for environmental assessment. Ecological Services Manual, 101.

US Fish and Wildlife Service. (1980). Habitat Evaluation Procedures (HEP). Ecological Services Manual, 102.

US Fish and Wildlife Service. (1981). Standards for the Development of Habitat Suitability Index Models. Ecological Services Manual, 103.

Examples

```
#Summarize habitat outcomes based on a vector of two suitability indices
#using multiple combination equations.
HUcalc(c(0.1,1), 100, HSIarimean)
HUcalc(c(0.1,1), 100, HSIgeomean)
HUcalc(c(0.1,1), 100, HSImin)
HUcalc(c(0.1,1), 100, HSIwarimean, c(1,0))
HUcalc(c(0.1,1), 100, HSIwarimean, c(0,1))
```

```
#HSIfunc can also represent functions outside of the ecorest package
HUcalc(c(0.1,1), 100, mean)
HUcalc(c(0.1,1), 100, max)
```

Sicalc

Computes Suitability Indices

Description

Sicalc computes suitability indices given a set of suitability curves and project-specific inputs. Suitability indices may be computed based on either linear interpolation (for continuous variables) or a lookup method (for categorical variables).

Usage

```
Sicalc(SI, input.proj)
```

Arguments

SI	matrix of suitability curves ordered as parameter breakpoints and associated suitability indices for each parameter.
input.proj	numeric or categorical vector of application-specific input parameters associated with the suitability curve data from SI.

Value

A vector of the suitability index values that match given user inputs. Values are returned as equal to the extreme of a range if inputs are outside of model range.

References

US Fish and Wildlife Service. (1980). Habitat as a basis for environmental assessment. Ecological Services Manual, 101.

US Fish and Wildlife Service. (1980). Habitat Evaluation Procedures (HEP). Ecological Services Manual, 102.

US Fish and Wildlife Service. (1981). Standards for the Development of Habitat Suitability Index Models. Ecological Services Manual, 103.

Examples

```
#Build and define a matrix of the Barred Owl suitability curves
#Allen A.W. 1982. Habitat Suitability Index Models: Barred owl. FWS/OBS 82/10.143.
#U.S. Fish and Wildlife Service. https://pubs.er.usgs.gov/publication/fwsobs82\_10\_143.
var1 <- cbind(c(0,2,4,NA), c(0.1,1,1,NA)) #Number of trees > 51cm diameter per 0.4 ha plot
var2 <- cbind(c(0,5,20,NA), c(0,0,1,NA)) #Mean diameter of overstory trees
var3 <- cbind(c(0,20,60,100), c(0,0,1,1)) #Percent canopy cover of overstory trees
```



```
barredowl <- cbind(var1, var2, var3)
colnames(barredowl)<- c("tree.num", "tree.num.SIV",
  "avg.dbh.in", "avg.dbh.SIV", "can.cov", "can.cov.SIV")

#Set user input variables that should return (1, 0, 0)
input.demo1 <- c(2, 5, 20)
Sicalc(barredowl, input.demo1)

#Set user input variables that should return (1, 1, 1)
input.demo2 <- c(4, 20, 60)
Sicalc(barredowl, input.demo2)

#Set user input variables that should return (1, 1, 0.5)
input.demo3 <- c(4, 20, 40)
Sicalc(barredowl, input.demo3)

#Set user input variables that should return (0.1, 0.5, 0.5)
input.demo4 <- c(0, 12.5, 40)
Sicalc(barredowl, input.demo4)

#Set user input variables that should return (1, 1, 1)
input.demo5 <- c(4, 40, 60)
Sicalc(barredowl, input.demo5)

#Set user input variables that should return (1, NA, 1)
input.demo6 <- c(4, NA, 60)
Sicalc(barredowl, input.demo6)

#Suitability curves may also be drawn from HSImodels (data within ecorest)
#Import Barred Owl suitability curves with HSImodels$barredowl
#The input examples are repeated from above

#Set user input variables that should return (1, 0, 0)
Sicalc(HSImodels$barredowl, input.demo1)

#Set user input variables that should return (1, 1, 1)
Sicalc(HSImodels$barredowl, input.demo2)

#Set user input variables that should return (1, 1, 0.5)
Sicalc(HSImodels$barredowl, input.demo3)

#Set user input variables that should return (0.1, 0.5, 0.5)
Sicalc(HSImodels$barredowl, input.demo4)

#Set user input variables that should return (1, 1, 1)
Sicalc(HSImodels$barredowl, input.demo5)

#Set user input variables that should return (1, NA, 1)
Sicalc(HSImodels$barredowl, input.demo6)
```

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