

brooktroutRivAllLtoe15CMt5mEC model summary

Contents

| | |
|---|----|
| Overview | 2 |
| Variables: | 2 |
| Components: | 4 |
| Model equation: | 4 |
| Global sensitivity and uncertainty analysis: | 4 |
| Model uncertainty | 4 |
| Model sensitivity | 6 |
| Original model | 7 |
| Arithmetic mean model | 8 |
| Geometric mean model | 9 |
| Limiting factor model | 10 |
| Multiplicative model | 11 |
| Summary of influential variables | 12 |
| References | 13 |

Overview

This document summarizes the results of a global sensitivity and uncertainty analysis for the **brook-troutRivAllLtoe15CMt5mEC** habitat suitability index (HSI) model for *Salvelinus fontinalis*. Metadata for the model is stored in the `ecorest` package in R.

The original documentation for this model can be found here¹.

Sub-model: **Brook trout, riverine, all life stages, less than or equal to 15 degrees Celsius, stream width more than 5m, equal component method**

The brooktroutRivAllLtoe15CMt5mEC model is comprised of **19** variables and **5** components.

Variables:

Table 1. SIV variables included in the brooktroutRivAllLtoe15CMt5mEC model. Type indicates whether a variable is numeric or categorical and breakpoints indicates the number of distinct breakpoints in suitability graphs.

| | Variable name | Type | Breakpoints |
|--------|-----------------------------|-------------|-------------|
| SIV1 | max.temp.ad.juv.fry.SIV | numeric | 16 |
| SIV2 | max.temp.emb.SIV | numeric | 18 |
| SIV3 | min.DO.growing.season.SIV | numeric | 11 |
| SIV4 | avg.thalweg.d.SIV | numeric | 13 |
| SIV5 | avg.vel.spwn.SIV | numeric | 5 |
| SIV6 | instream.cov.pct.juv.SIV | numeric | 9 |
| SIV6B | instream.cov.pct.adult.SIV | numeric | 9 |
| SIV7 | avg.size.subs.SIV | numeric | 16 |
| SIV8 | subs.size.class.winter.SIV | numeric | 3 |
| SIV9 | dominant.subs.rffl.run.SIV | categorical | 3 |
| SIV10 | pls.late.growing.season.SIV | numeric | 14 |
| SIV11 | veg.pct.SIV | numeric | 11 |
| SIV12 | rooted.veg.SIV | numeric | 12 |
| SIV13 | max.min.pH.SIV | numeric | 5 |
| SIV14 | base.flow.late.summer.SIV | numeric | 3 |
| SIV15 | pl.aug.to.oct.SIV | categorical | 3 |
| SIV16 | fines.spwn.SIV | numeric | 13 |
| SIV16B | fines.rffl.run.SIV | numeric | 13 |
| SIV17 | strm.area.shaded.SIV | numeric | 8 |

¹<https://ecolibrary.sec.usace.army.mil/resource/5043a6c7-294c-4b04-afc5-0bff612fd648>

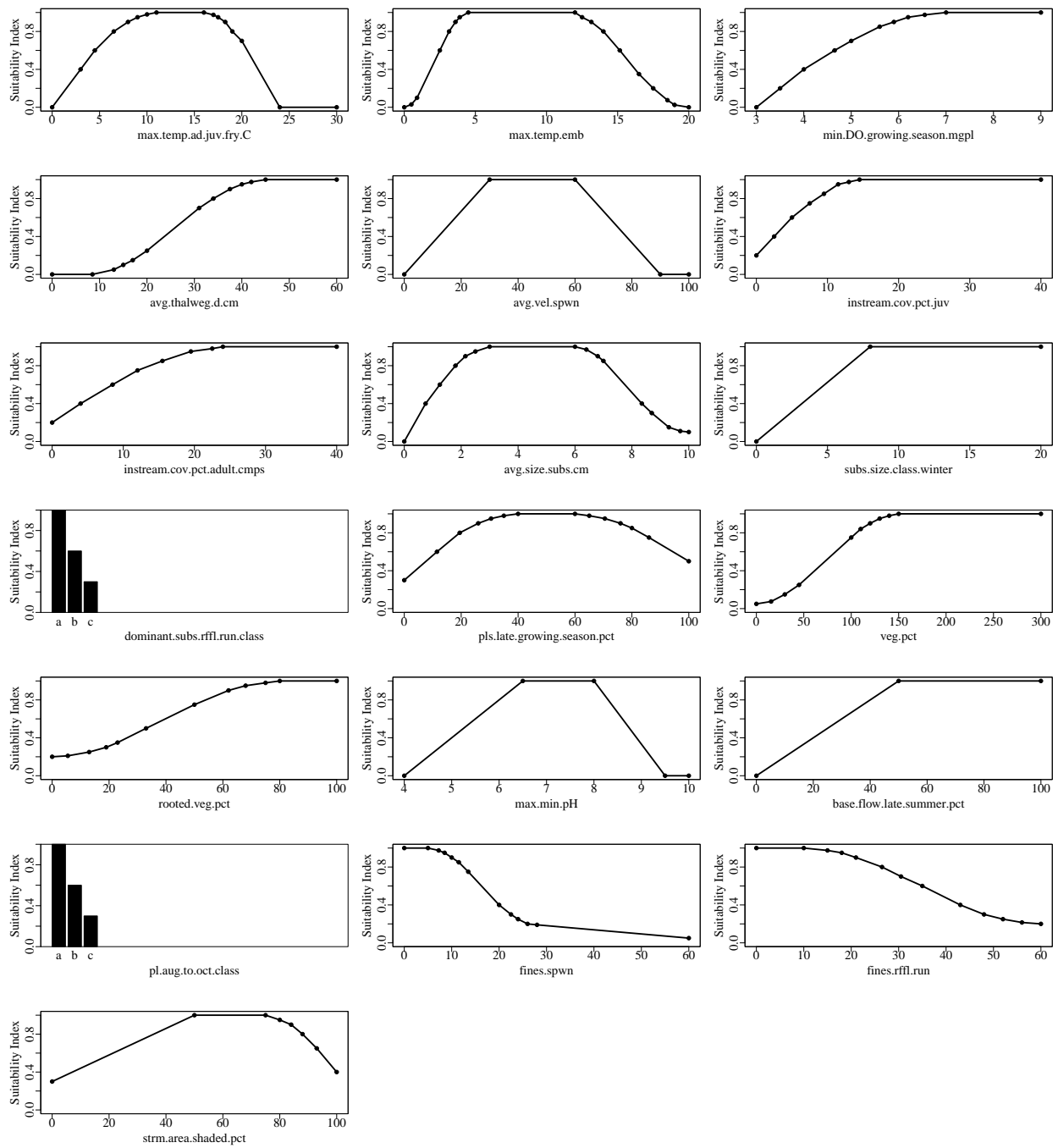


Figure 1. Suitability index graphs for variables included in the brooktroutRivAllLtoe15CMt5mEC model in ecorest.

Components:

Table 2. Components included in the brooktroutRivAllLtoe15CMt5mEC model in ecorest.

| | Component | Equation |
|-----|--------------------|---|
| COT | Other component | $(((((SIV9 * SIV16B)^{(1/2)} + SIV11)/2) * (\text{prod}(c(SIV1, SIV3, SIV12, SIV13, SIV14, SIV17), na.rm=TRUE)^{(1/\text{length}(na.omit(c(SIV1, SIV3, SIV12, SIV13, SIV14, SIV17))))))^{(1/2)}))$ |
| CE | Embryo component | $\min(SIV2, SIV3, ((SIV5 * SIV7 * SIV16)^{(1/3)}))$ |
| CJ | Juvenile component | $\text{ifelse}(SIV6 \leq 0.4 SIV10 \leq 0.4 SIV15 \leq 0.4, \min(SIV4, SIV10, SIV15), ((SIV6 + SIV10 + SIV15)/3))$ |
| CFr | Fry component | $\text{ifelse}(SIV10 \leq 0.4 ((SIV8 * SIV16B)^{(1/2)}) \leq 0.4, \min(SIV10, SIV8, SIV16B), ((SIV10 * ((SIV8 * SIV16B)^{(1/2)}))^{(1/2)}))$ |
| CA | Adult component | $\text{ifelse}(SIV4 \leq 0.4 ((SIV10 * SIV15)^{(1/2)}) \leq 0.4, \min(SIV4, ((SIV10 * SIV15)^{(1/2)})), \text{ifelse}(SIV6B > ((SIV10 * SIV15)^{(1/2)}), ((SIV4 * SIV6B * ((SIV10 * SIV15)^{(1/2)}))^{(1/3)}), ((SIV4 * ((SIV10 * SIV15)^{(1/2)}))^{(1/3)}))^{(1/2)}))$ |

Model equation:

The equation to calculate an overall HSI index for the brooktroutRivAllLtoe15CMt5mEC model is:

$$\text{prod}(CA, CJ, CFr, CE, COT, na.rm=TRUE)^{(1/\text{length}(na.omit(c(CA, CJ, CFr, CE, COT))))}$$

According to our classification, this model's format is: **author-specified**

Global sensitivity and uncertainty analysis:

We ran global sensitivity and uncertainty analyses on the brooktroutRivAllLtoe15CMt5mEC model using the sensobol package in R (Puy et al. 2022). The following parameters were used for the sensobol analysis:

Table 3. Parameters and settings used for sensobol sensitivity and uncertainty analyses.

| Parameter | Equation | Value |
|----------------------------------|-----------------------|--------------|
| Number of input variables (M) | - | 19 |
| Base sample size (n) | - | 10000 |
| Number of model evaluations (N) | $n * (M + 2)$ | 210000 |
| First order estimator | See Puy et al. (2022) | Saltelli |
| Total order estimator | See Puy et al. (2022) | Jansen |
| Number of bootstrap replications | - | 1000 |
| Sampling scheme | - | Quasi-random |
| Matrices | - | A, B, AB |

We ran a sensitivity and uncertainty analysis for the brooktroutRivAllLtoe15CMt5mEC model using the original equation outlined in the documentation from Raleigh (1982) and using arithmetic mean, geometric mean, limiting factor, and multiplicative equations to contrast the results across different equation structures.

Model uncertainty

We ran the brooktroutRivAllLtoe15CMt5mEC model using 210000 combinations of its SIV variables, which were sampled from a uniform distribution spanning the range of possible values listed in the brooktroutRivAl-

ILtoe15CMt5mEC documentation. We limited the range of possible values for each parameter to the range in which the SIV values were greater than zero to prevent HSI score distributions with primarily zero values.

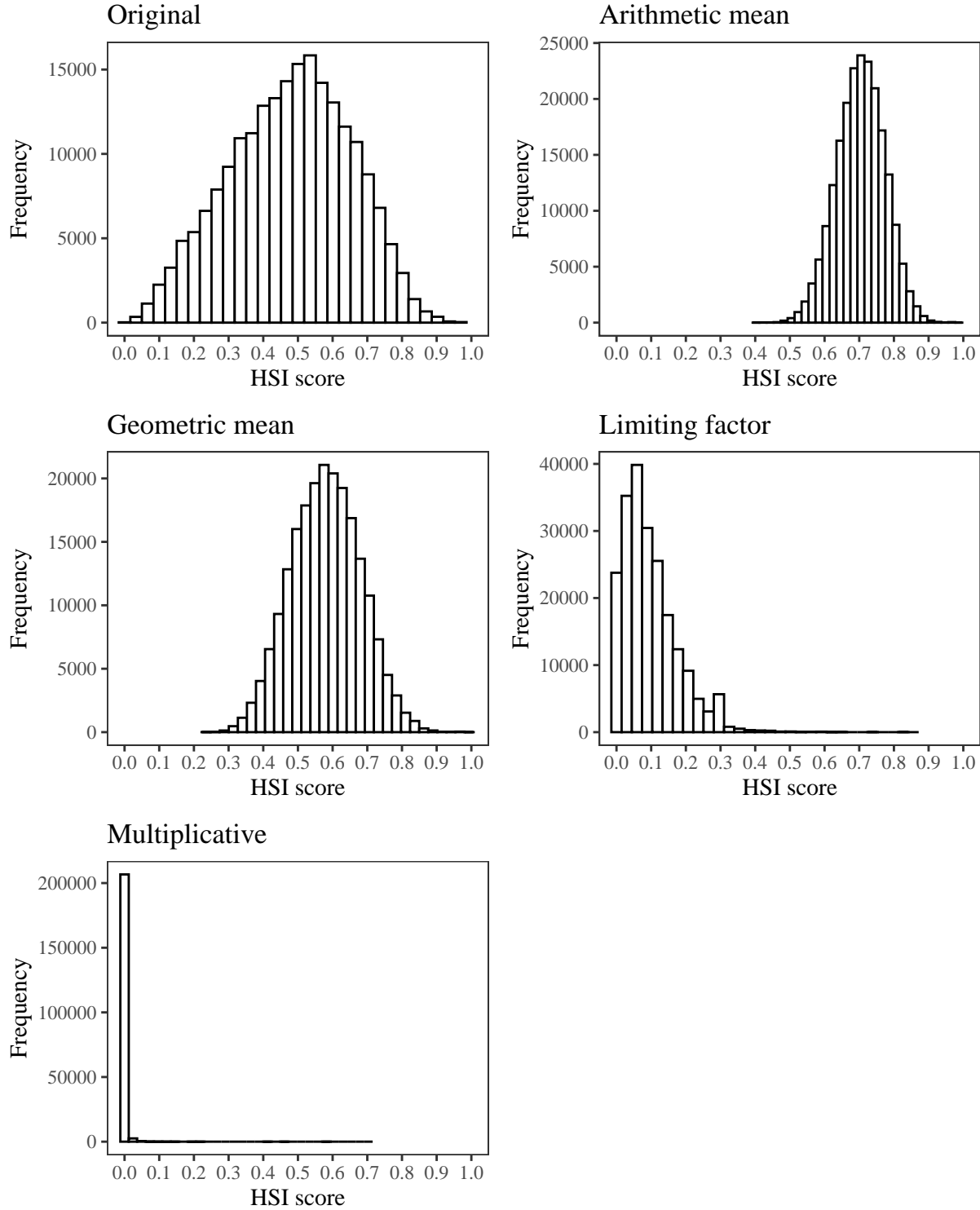


Figure 2. Empirical distributions of HSI scores for the brooktroutRivAllLtoe15CMt5mEC model using the original author-specified model equation from Raleigh (1982), and an arithmetic mean, geometric mean, limiting factor, and multiplicative structure incorporating all SIV variables. Note differences in the y axis.

We assumed a uniform distribution for all parameters because we evaluated all ecores models in batch. Should you decide to run your own sensitivity analysis, this assumption should be evaluated independently for each parameter in the model.

Table 4. Quantiles from the empirical distribution of HSI scores for the original brooktroutRivAllLtoe15CMt5mEC model structure, an arithmetic mean equation, a geometric mean equation, a limiting factor equation, and a multiplicative equation structure.

| | 1% | 2.5% | 5% | 25% | 50% | 75% | 95% | 97.5% | 99% | 100% |
|----------------|------|------|------|------|------|------|------|-------|------|------|
| Original | 0.09 | 0.13 | 0.18 | 0.35 | 0.49 | 0.61 | 0.75 | 0.79 | 0.83 | 0.98 |
| Arithmetic | 0.54 | 0.57 | 0.59 | 0.66 | 0.71 | 0.75 | 0.82 | 0.84 | 0.86 | 0.98 |
| Geometric | 0.36 | 0.39 | 0.42 | 0.51 | 0.58 | 0.65 | 0.74 | 0.78 | 0.81 | 0.98 |
| Limiting | 0.00 | 0.00 | 0.01 | 0.04 | 0.08 | 0.14 | 0.26 | 0.30 | 0.32 | 0.86 |
| Multiplicative | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.02 | 0.70 |

The empirical distribution of the original brooktroutRivAllLtoe15CMt5mEC model has a coefficient of variation (CV) of **0.364**, while the arithmetic mean model has a CV of **0.098**, the geometric mean model has a CV of **0.173**, the limiting factor model has a CV of **0.81**, and the multiplicative model has a CV of **8.658**. Hence, the **Multiplicative** model is the most uncertain, while the **Arithmetic mean** model is the least uncertain.

Model sensitivity

Below are the results of the global sensitivity analysis for the brooktroutRivAllLtoe15CMt5mEC model using the original equation, an arithmetic mean, a geometric mean, a limiting factor, and a multiplicative model structure. The sensobol package uses variance-based sensitivity metrics, so the model’s sensitivity to a given parameter is a measure of how much variance in the HSI score decreases in response to that parameter being fixed (Puy et al. 2022). For each parameter, the observed changes in the variance of the HSI score can be described with a first order sensitivity index (S_i) that accounts for the influence of a single parameter of interest on variance in HSI, or with a total order index (T_i) that accounts for the influence of a single parameter on its own and in combination with all other parameters (*i.e.*, interactions) (Puy et al. 2022). We can compare the 95% confidence intervals for the first and total order indices to a dummy parameter, which represents a parameter that has no influence on the variance in a model’s output. While an uninfluential variable should theoretically have an S_i and T_i of zero, small approximation errors can lead variables to have a non-zero influence on a model’s output (Puy et al. 2022). If the confidence interval of the S_i and T_i index for a given parameter overlaps the confidence interval of the dummy parameter, we can deduce that the parameter has a negligible effect on variance in HSI scores, both on its own and in combination with all other variables.

Original model

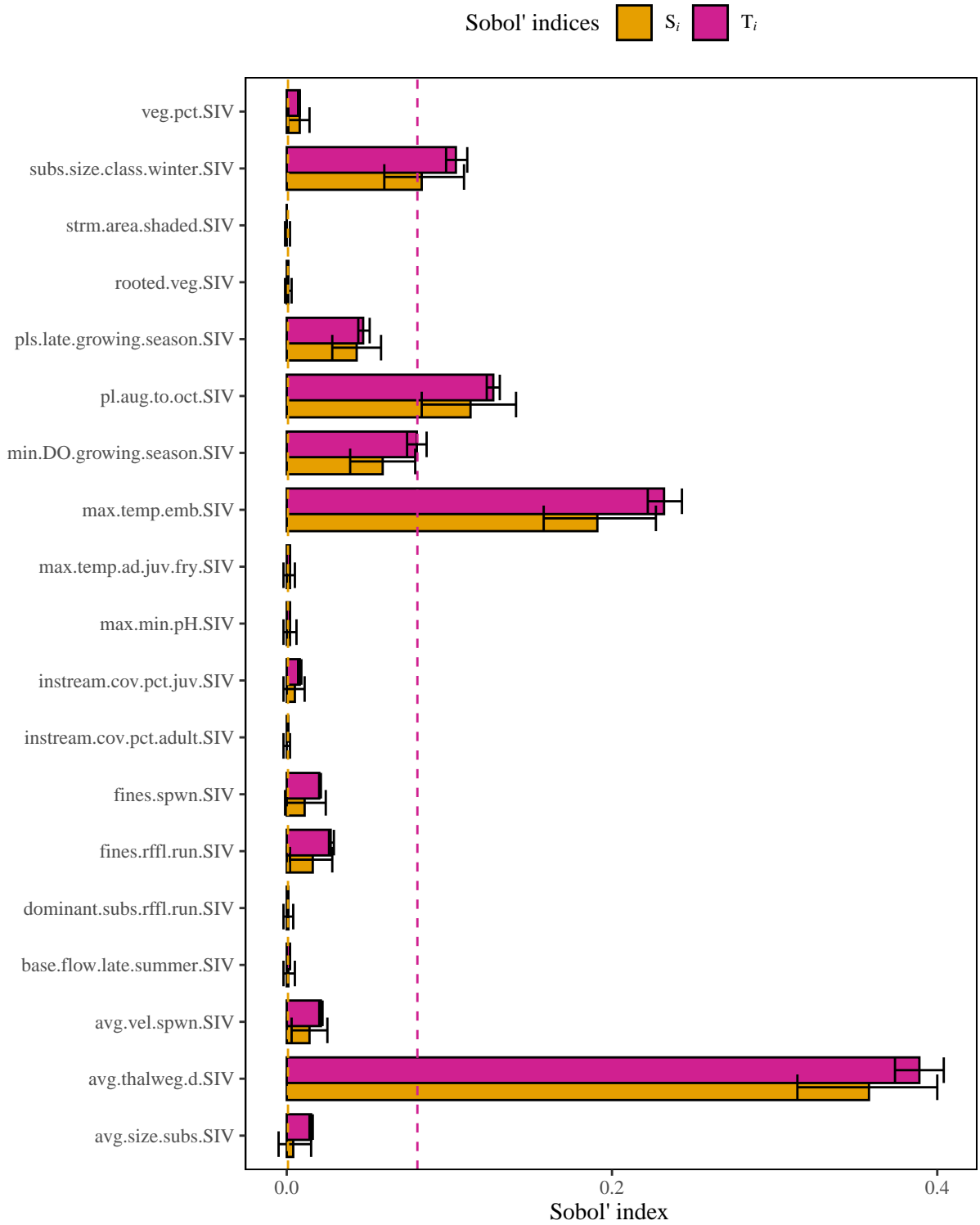


Figure 3. Results of a sensitivity analysis for the brooktroutRivAllLtoe15CMt5mEC model based on the original author-specified model outlined in Raleigh (1982). Dashed lines represent baseline numerical approximation error for S_i and T_i (*i.e.*, dummy variables).

Arithmetic mean model

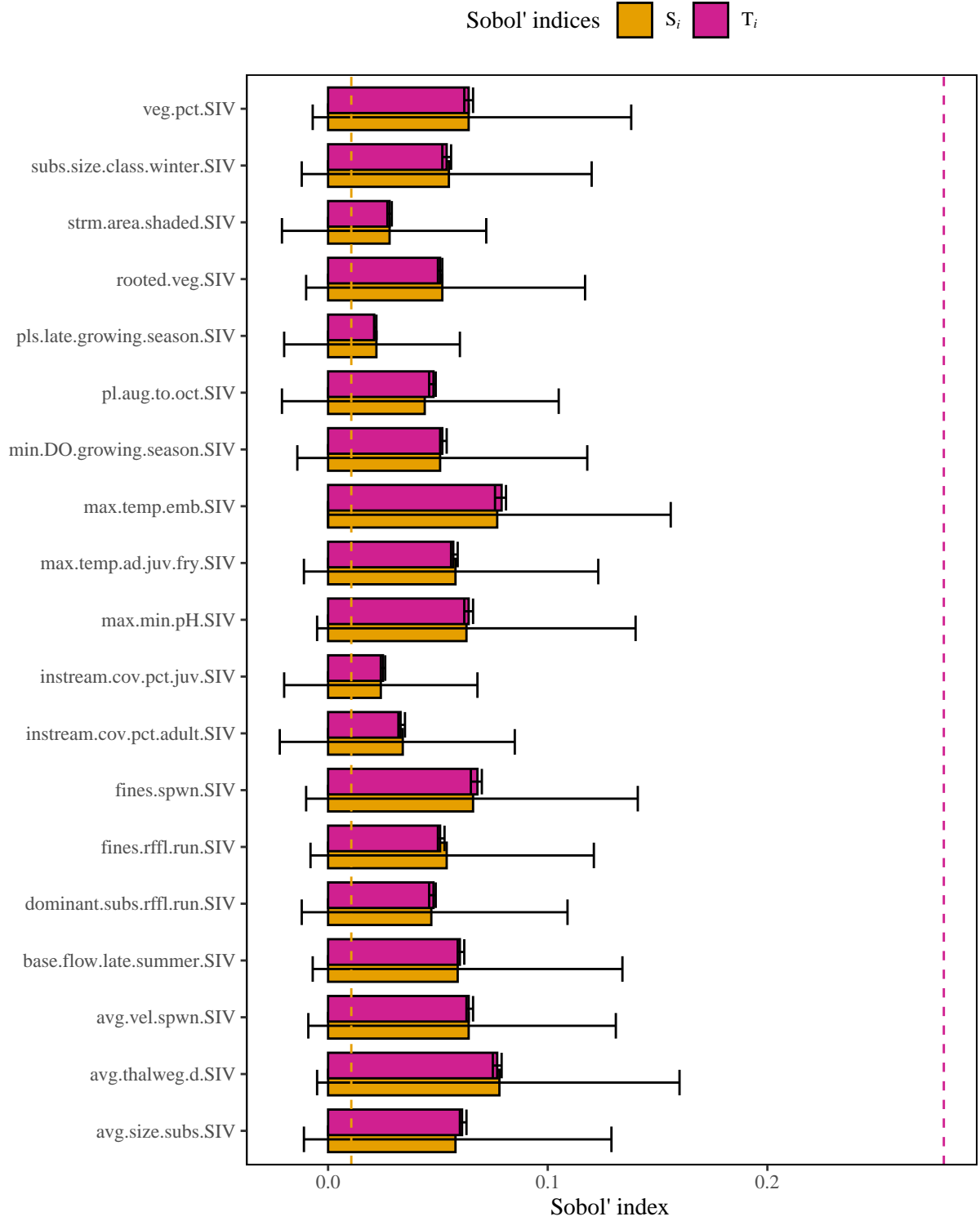


Figure 4. Results of a sensitivity analysis for the brooktroutRivAllLtoe15CMt5mEC model based on an arithmetic mean structure. Dashed lines represent baseline numerical approximation error for S_i and T_i (*i.e.*, dummy variables).

Geometric mean model

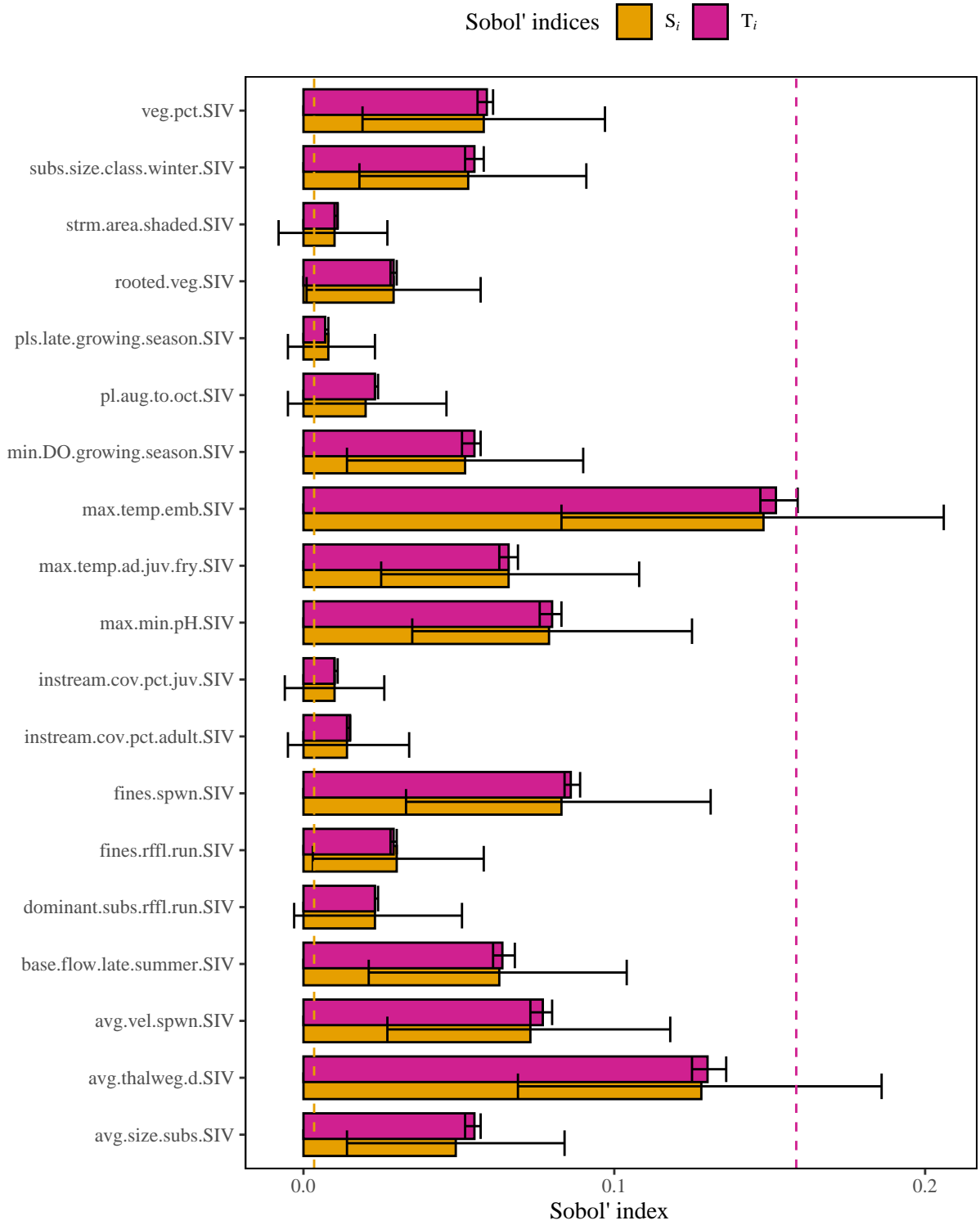


Figure 5. Results of a sensitivity analysis for the brooktroutRivAllLtoe15CMt5mEC model based on a geometric mean structure. Dashed lines represent baseline numerical approximation error for S_i and T_i (*i.e.*, dummy variables).

Limiting factor model

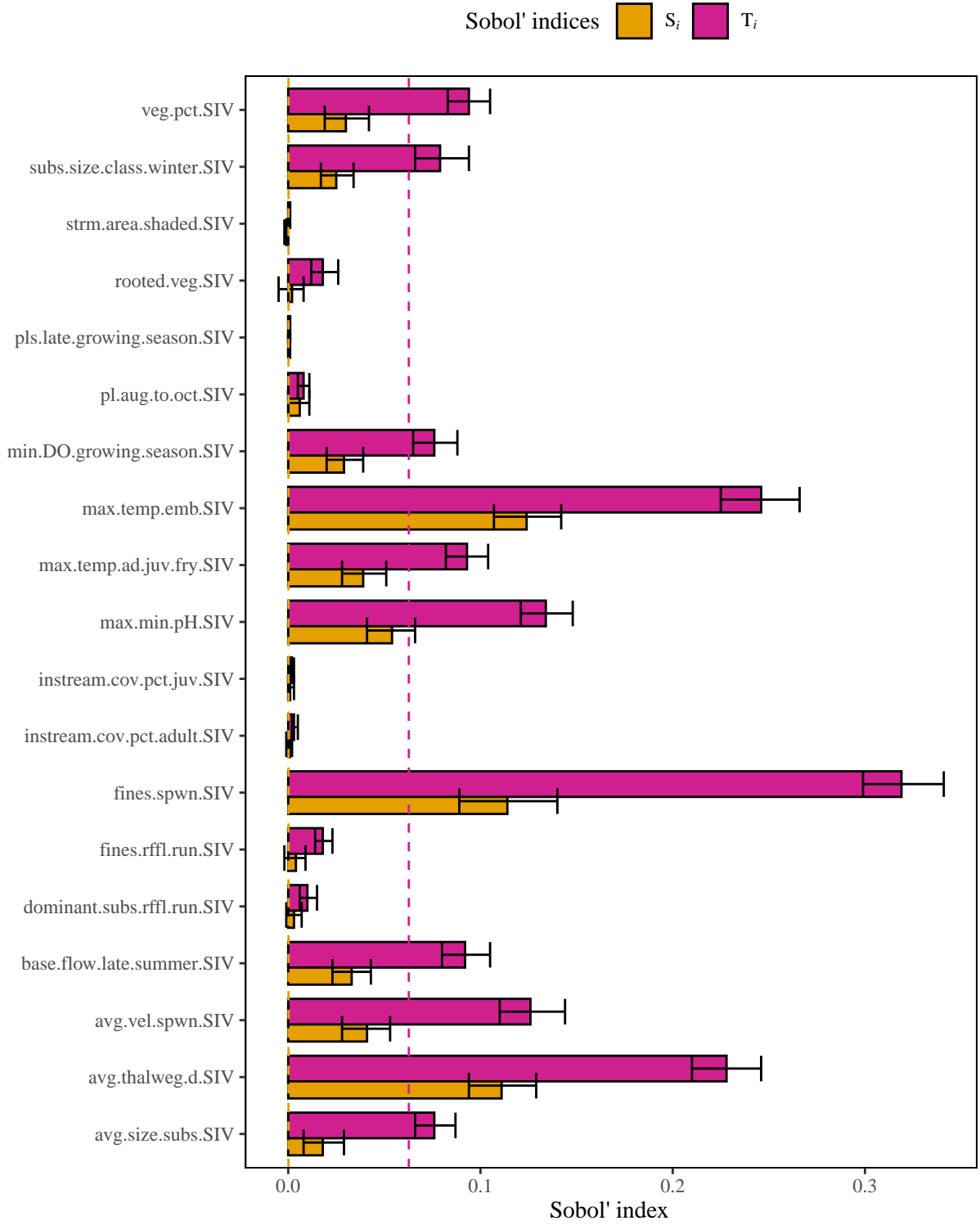


Figure 6. Results of a sensitivity analysis for the brooktroutRivAllLtoe15CMt5mEC model based on a limiting factor structure. Dashed lines represent baseline numerical approximation error for S_i and T_i (*i.e.*, dummy variables).

Multiplicative model

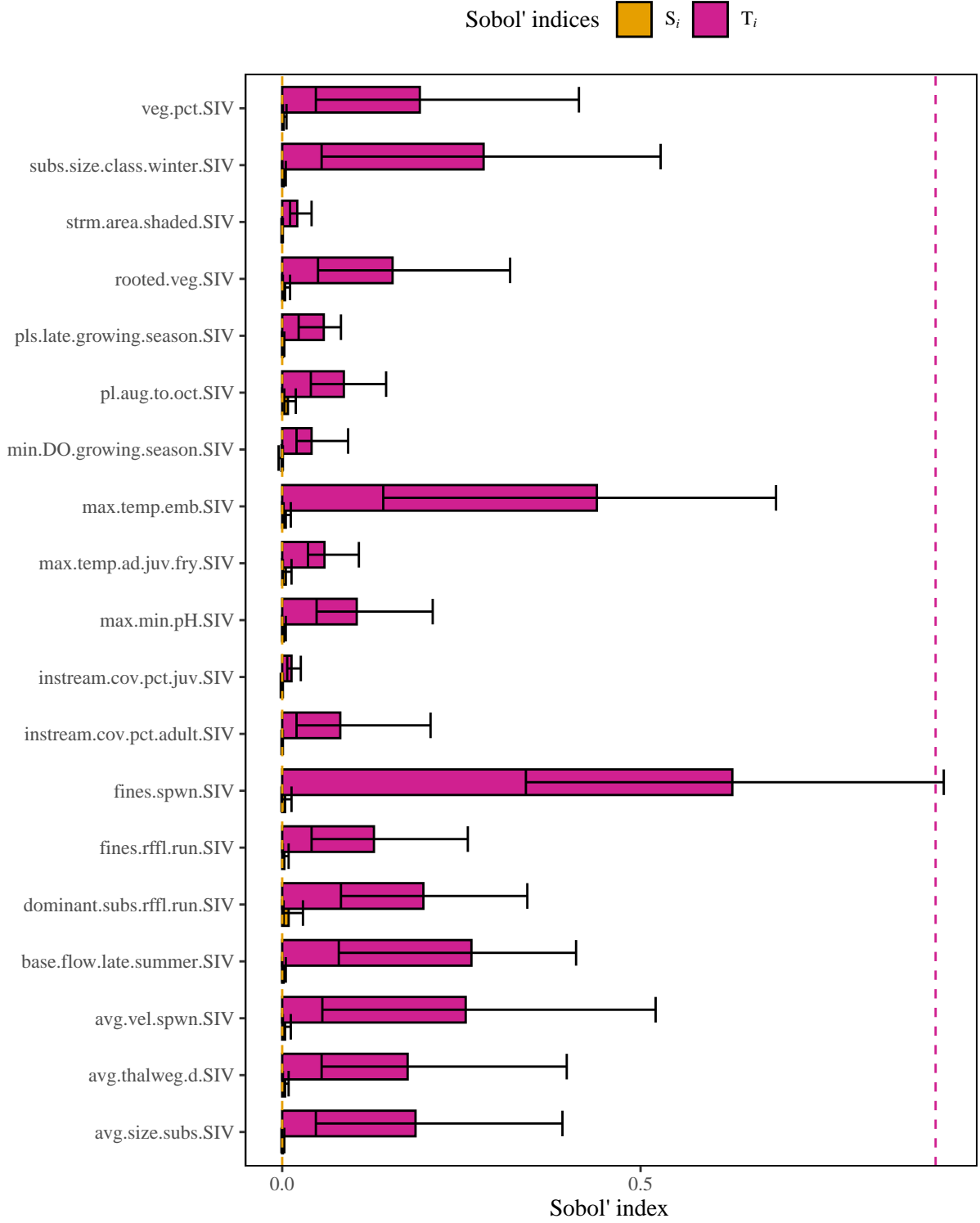


Figure 7. Results of a sensitivity analysis for the brooktroutRivAllLtoe15CMt5mEC model based on a multiplicative mean structure. Dashed lines represent baseline numerical approximation error for S_i and T_i (*i.e.*, dummy variables).

Summary of influential variables

Original model In the **original brooktroutRivAllLtoe15CMt5mEC** model, **9 of 19** variables are influential and **avg.thalweg.d.SIV** has the highest first order sensitivity. In addition, **avg.thalweg.d.SIV** has the highest total order sensitivity.

Un-influential variables in original model:

max.temp.ad.juv.fry.SIV
instream.cov.pct.juv.SIV
instream.cov.pct.adult.SIV
avg.size.subs.SIV
dominant.subs.rffl.run.SIV
rooted.veg.SIV
max.min.pH.SIV
base.flow.late.summer.SIV
fines.spwn.SIV
strm.area.shaded.SIV

Arithmetic mean model In the **arithmetic mean brooktroutRivAllLtoe15CMt5mEC** model, **0 of 19** variables are influential and **avg.thalweg.d.SIV** has the highest first order sensitivity. In addition, **max.temp.emb.SIV** has the highest total order sensitivity.

Un-influential variables in arithmetic mean model:

max.temp.ad.juv.fry.SIV
max.temp.emb.SIV
min.DO.growing.season.SIV
avg.thalweg.d.SIV
avg.vel.spwn.SIV
instream.cov.pct.juv.SIV
instream.cov.pct.adult.SIV
avg.size.subs.SIV
subs.size.class.winter.SIV
dominant.subs.rffl.run.SIV
pls.late.growing.season.SIV
veg.pct.SIV
rooted.veg.SIV
max.min.pH.SIV
base.flow.late.summer.SIV
pl.aug.to.oct.SIV
fines.spwn.SIV
fines.rffl.run.SIV
strm.area.shaded.SIV

Geometric mean model In the **geometric mean brooktroutRivAllLtoe15CMt5mEC** model, **11 of 19** variables are influential and **max.temp.emb.SIV** has the highest first order sensitivity. In addition, **max.temp.emb.SIV** has the highest total order sensitivity.

Un-influential variables in geometric mean model:

instream.cov.pct.juv.SIV
instream.cov.pct.adult.SIV
dominant.subs.rffl.run.SIV
pls.late.growing.season.SIV

rooted.veg.SIV
pl.aug.to.oct.SIV
fines.rffl.run.SIV
strm.area.shaded.SIV

Limiting factor model In the **limiting factor brooktroutRivAllLtoe15CMt5mEC** model, **11 of 19** variables are influential and **max.temp.emb.SIV** has the highest first order sensitivity. In addition, **fines.spwn.SIV** has the highest total order sensitivity.

Un-influential variables in limiting factor mean model:

instream.cov.pct.juv.SIV
instream.cov.pct.adult.SIV
dominant.subs.rffl.run.SIV
pls.late.growing.season.SIV
rooted.veg.SIV
pl.aug.to.oct.SIV
fines.rffl.run.SIV
strm.area.shaded.SIV

Multiplicative model In the **multiplicative mean brooktroutRivAllLtoe15CMt5mEC** model, **9 of 19** variables are influential and **dominant.subs.rffl.run.SIV** has the highest first order sensitivity. In addition, **fines.spwn.SIV** has the highest total order sensitivity.

Un-influential variables in multiplicative model:

min.DO.growing.season.SIV
instream.cov.pct.juv.SIV
instream.cov.pct.adult.SIV
avg.size.subs.SIV
subs.size.class.winter.SIV
pls.late.growing.season.SIV
max.min.pH.SIV
base.flow.late.summer.SIV
fines.spwn.SIV
strm.area.shaded.SIV

References

1. McKay S, D Hernandez-Abrams, and K Cushway. 2024. ecorest: conducts analyses informing ecosystem restoration decisions. R package version 2.0.0, <https://CRAN.R-project.org/package=ecorest>.
2. Puy, A, S Lo Piano, A Saltelli, and SA Levin. 2022. sensobol: an R package to compute variance based sensitivity indices. *Journal of Statistical Software* 102(5):1-37. doi: 10.18637/jss.v102.i05
3. Raleigh, RF. 1982. Habitat suitability index models: Brook trout. U.S. Dept. Int., Fish Wildl. Serv. FWS/OBS-82/10.24. 42 pp.