

Testing hierarchical pathway kinetics with residue data on cyantraniliprole

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Introduction

The purpose of this document is to test demonstrate how nonlinear hierarchical models (NLHM) based on the parent degradation models SFO, FOMC, DFOP and HS, with serial formation of two or more metabolites can be fitted with the mkin package.

It was assembled in the course of work package 1.2 of Project Number 173340 (Application of nonlinear hierarchical models to the kinetic evaluation of chemical degradation data) of the German Environment Agency carried out in 2022 and 2023.

The mkin package is used in version 1.2.9 which is currently under development. The newly introduced functionality that is used here is a simplification of excluding random effects for a set of fits based on a related set of fits with a reduced model, and the documentation of the starting parameters of the fit, so that all starting parameters of saem fits are now listed in the summary. The saemix package is used as a backend for fitting the NLHM, but is also loaded to make the convergence plot function available.

This document is processed with the knitr package, which also provides the kable function that is used to improve the display of tabular data in R markdown documents. For parallel processing, the parallel package is used.

```
library(mkin)
library(knitr)
library(saemix)
library(parallel)
n_cores <- detectCores()

# We need to start a new cluster after defining a compiled model that is
# saved as a DLL to the user directory, therefore we define a function
# This is used again after defining the pathway model
start_cluster <- function(n_cores) {
  if (Sys.info()["sysname"] == "Windows") {
    ret <- makePSOCKcluster(n_cores)
  } else {
    ret <- makeForkCluster(n_cores)
  }
  return(ret)
}
cl <- start_cluster(n_cores)
```

Test data

The example data are taken from the final addendum to the DAR from 2014 and are distributed with the `mkim` package. Residue data and time step normalisation factors are read in using the function `read_spreadsheet` from the `mkim` package. This function also performs the time step normalisation.

```
data_file <- system.file(  
  "testdata", "cyantraniliprole_soil_efsa_2014.xlsx",  
  package = "mkim")  
cyan_ds <- read_spreadsheet(data_file, parent_only = FALSE)
```

The following tables show the covariate data and the 5 datasets that were read in from the spreadsheet file.

```
pH <- attr(cyan_ds, "covariates")  
kable(pH, caption = "Covariate data")
```

Table 1: Covariate data

	pH
Nambsheim	7.90
Tama	6.20
Gross-Umstadt	7.04
Sassafras	4.62
Lleida	8.05

```

for (ds_name in names(cyan_ds)) {
  print(
    kable(mkin_long_to_wide(cyan_ds[[ds_name]]),
          caption = paste("Dataset", ds_name),
          booktabs = TRUE, row.names = FALSE))
  cat("\n\\clearpage\n")
}

```

Table 2: Dataset Nambsheim

time	cyan	JCZ38	J9C38	JSE76	J9Z38
0.000000	105.79	NA	NA	NA	NA
3.210424	77.26	7.92	11.94	5.58	9.12
7.490988	57.13	15.46	16.58	12.59	11.74
17.122259	37.74	15.98	13.36	26.05	10.77
23.543105	31.47	6.05	14.49	34.71	4.96
43.875788	16.74	6.07	7.57	40.38	6.52
67.418893	8.85	10.34	6.39	30.71	8.90
107.014116	5.19	9.61	1.95	20.41	12.93
129.487080	3.45	6.18	1.36	21.78	6.99
195.835832	2.15	9.13	0.95	16.29	7.69
254.693596	1.92	6.92	0.20	13.57	7.16
321.042348	2.26	7.02	NA	11.12	8.66
383.110535	NA	5.05	NA	10.64	5.56
0.000000	105.57	NA	NA	NA	NA
3.210424	78.88	12.77	11.94	5.47	9.12
7.490988	59.94	15.27	16.58	13.60	11.74
17.122259	39.67	14.26	13.36	29.44	10.77
23.543105	30.21	16.07	14.49	35.90	4.96
43.875788	18.06	9.44	7.57	42.30	6.52
67.418893	8.54	5.78	6.39	34.70	8.90
107.014116	7.26	4.54	1.95	23.33	12.93
129.487080	3.60	4.22	1.36	23.56	6.99
195.835832	2.84	3.05	0.95	16.21	7.69
254.693596	2.00	2.90	0.20	15.53	7.16
321.042348	1.79	0.94	NA	9.80	8.66
383.110535	NA	1.82	NA	9.49	5.56

Table 3: Dataset Tama

time	cyan	JCZ38	J9Z38	JSE76
0.000000	106.14	NA	NA	NA
2.400833	93.47	6.46	2.85	NA
5.601943	88.39	10.86	4.65	3.85
12.804442	72.29	11.97	4.91	11.24
17.606108	65.79	13.11	6.63	13.79
32.811382	53.16	11.24	8.90	23.40
50.417490	44.01	11.34	9.98	29.56
80.027761	33.23	8.82	11.31	35.63
96.833591	40.68	5.94	8.32	29.09
146.450803	20.65	4.49	8.72	36.88
190.466072	17.71	4.66	11.10	40.97
240.083284	14.86	2.27	11.62	40.11
286.499386	12.02	NA	10.73	42.58
0.000000	109.11	NA	NA	NA
2.400833	96.84	5.52	2.04	2.02
5.601943	85.29	9.65	2.99	4.39
12.804442	73.68	12.48	5.05	11.47
17.606108	64.89	12.44	6.29	15.00
32.811382	52.27	10.86	7.65	23.30
50.417490	42.61	10.54	9.37	31.06
80.027761	34.29	10.02	9.04	37.87
96.833591	30.50	6.34	8.14	33.97
146.450803	19.21	6.29	8.52	26.15
190.466072	17.55	5.81	9.89	32.08
240.083284	13.22	5.99	10.79	40.66
286.499386	11.09	6.05	8.82	42.90

Table 4: Dataset Gross-Umstadt

time	cyan	JCZ38	J9Z38	JSE76
0.0000000	103.03	NA	NA	NA
2.1014681	87.85	4.79	3.26	0.62
4.9034255	77.35	8.05	9.89	1.32
10.5073404	69.33	9.74	12.32	4.74
21.0146807	55.65	14.57	13.59	9.84
31.5220211	49.03	14.66	16.71	12.32
42.0293615	41.86	15.97	13.64	15.53
63.0440422	34.88	18.20	14.12	22.02
84.0587230	28.26	15.64	14.06	25.60
0.0000000	104.05	NA	NA	NA
2.1014681	85.25	2.68	7.32	0.69
4.9034255	77.22	7.28	8.37	1.45
10.5073404	65.23	10.73	10.93	4.74
21.0146807	57.78	12.29	14.80	9.05
31.5220211	54.83	14.05	12.01	11.05
42.0293615	45.17	12.12	17.89	15.71
63.0440422	34.83	12.90	15.86	22.52
84.0587230	26.59	14.28	14.91	28.48
0.0000000	104.62	NA	NA	NA
0.8145225	97.21	NA	4.00	NA
1.9005525	89.64	3.59	5.24	NA
4.0726125	87.90	4.10	9.58	NA
8.1452251	86.90	5.96	9.45	NA
12.2178376	74.74	7.83	15.03	5.33
16.2904502	74.13	8.84	14.41	5.10
24.4356753	65.26	11.84	18.33	6.71
32.5809004	57.70	12.74	19.93	9.74
0.0000000	101.94	NA	NA	NA
0.8145225	99.94	NA	NA	NA
1.9005525	94.87	NA	4.56	NA
4.0726125	86.96	6.75	6.90	NA
8.1452251	80.51	10.68	7.43	2.58
12.2178376	78.38	10.35	9.46	3.69
16.2904502	70.05	13.73	9.27	7.18
24.4356753	61.28	12.57	13.28	13.19
32.5809004	52.85	12.67	12.95	13.69

Table 5: Dataset Sassafras

time	cyan	JCZ38	J9Z38	JSE76
0.000000	102.17	NA	NA	NA
2.216719	95.49	1.11	0.10	0.83
5.172343	83.35	6.43	2.89	3.30
11.083593	78.18	10.00	5.59	0.81
22.167186	70.44	17.21	4.23	1.09
33.250779	68.00	20.45	5.86	1.17
44.334371	59.64	24.64	3.17	2.72
66.501557	50.73	27.50	6.19	1.27
88.668742	45.65	32.77	5.69	4.54
0.000000	100.43	NA	NA	NA
2.216719	95.34	3.21	0.14	0.46
5.172343	84.38	5.73	4.75	0.62
11.083593	78.50	11.89	3.99	0.73
22.167186	71.17	17.28	4.39	0.66
33.250779	59.41	18.73	11.85	2.65
44.334371	64.57	22.93	5.13	2.01
66.501557	49.08	33.39	5.67	3.63
88.668742	40.41	39.60	5.93	6.17

Table 6: Dataset Lleida

time	cyan	JCZ38	J9Z38	JSE76
0.000000	102.71	NA	NA	NA
2.821051	79.11	5.70	8.07	0.97
6.582451	70.03	7.17	11.31	4.72
14.105253	50.93	10.25	14.84	9.95
28.210505	33.43	10.40	14.82	24.06
42.315758	24.69	9.75	16.38	29.38
56.421010	22.99	10.06	15.51	29.25
84.631516	14.63	5.63	14.74	31.04
112.842021	12.43	4.17	13.53	33.28
0.000000	99.31	NA	NA	NA
2.821051	82.07	6.55	5.60	1.12
6.582451	70.65	7.61	8.01	3.21
14.105253	53.52	11.48	10.82	12.24
28.210505	35.60	11.19	15.43	23.53
42.315758	34.26	11.09	13.26	27.42
56.421010	21.79	4.80	18.30	30.20
84.631516	14.06	6.30	16.35	32.32
112.842021	11.51	5.57	12.64	32.51

Parent only evaluations

As the pathway fits have very long run times, evaluations of the parent data are performed first, in order to determine for each hierarchical parent degradation model which random effects on the degradation model parameters are ill-defined.

```
cyan_sep_const <- mmkin(c("SFO", "FOMC", "DFOP", "SFORB", "HS"),
  cyan_ds, quiet = TRUE, cores = n_cores)
cyan_sep_tc <- update(cyan_sep_const, error_model = "tc")
cyan_saem_full <- mhmkin(list(cyan_sep_const, cyan_sep_tc))
status(cyan_saem_full) |> kable()
```

	const	tc
SFO	OK	OK
FOMC	OK	OK
DFOP	OK	OK
SFORB	OK	OK
HS	OK	OK

All fits converged successfully.

```
illparms(cyan_saem_full) |> kable()
```

	const	tc
SFO	sd(cyan_0)	sd(cyan_0)
FOMC	sd(log_beta)	sd(cyan_0)
DFOP	sd(cyan_0)	sd(cyan_0), sd(log_k1)
SFORB	sd(cyan_free_0)	sd(cyan_free_0), sd(log_k_cyan_free_bound)
HS	sd(cyan_0)	sd(cyan_0)

In almost all models, the random effect for the initial concentration of the parent compound is ill-defined. For the biexponential models DFOP and SFORB, the random effect of one additional parameter is ill-defined when the two-component error model is used.

```
anova(cyan_saem_full) |> kable(digits = 1)
```

	npar	AIC	BIC	Lik
SFO const	5	833.9	832.0	-412.0
SFO tc	6	831.6	829.3	-409.8
FOMC const	7	709.1	706.4	-347.6
FOMC tc	8	689.2	686.1	-336.6
DFOP const	9	703.0	699.5	-342.5
SFORB const	9	701.3	697.8	-341.7
HS const	9	718.6	715.1	-350.3
DFOP tc	10	703.1	699.2	-341.6
SFORB tc	10	700.0	696.1	-340.0
HS tc	10	716.7	712.8	-348.3

Model comparison based on AIC and BIC indicates that the two-component error model is preferable for all parent models with the exception of DFOP. The lowest AIC and BIC values are obtained with the FOMC model, followed by SFORB and DFOP.

```
stopCluster(c1)
```

Pathway fits

Evaluations with pathway established previously

To test the technical feasibility of coupling the relevant parent degradation models with different transformation pathway models, a list of mkinmod models is set up below. As in the EU evaluation, parallel formation of metabolites JCZ38 and J9Z38 and secondary formation of metabolite JSE76 from JCZ38 is used.

```
if (!dir.exists("cyan_dlls")) dir.create("cyan_dlls")
cyan_path_1 <- list(
  sfo_path_1 = mkinmod(
    cyan = mkinsub("SF0", c("JCZ38", "J9Z38")),
    JCZ38 = mkinsub("SF0", "JSE76"),
    J9Z38 = mkinsub("SF0"),
    JSE76 = mkinsub("SF0"), quiet = TRUE,
    name = "sfo_path_1", dll_dir = "cyan_dlls", overwrite = TRUE),
  fomc_path_1 = mkinmod(
    cyan = mkinsub("FOMC", c("JCZ38", "J9Z38")),
    JCZ38 = mkinsub("SF0", "JSE76"),
    J9Z38 = mkinsub("SF0"),
    JSE76 = mkinsub("SF0"), quiet = TRUE,
    name = "fomc_path_1", dll_dir = "cyan_dlls", overwrite = TRUE),
  dfop_path_1 = mkinmod(
    cyan = mkinsub("DFOP", c("JCZ38", "J9Z38")),
    JCZ38 = mkinsub("SF0", "JSE76"),
    J9Z38 = mkinsub("SF0"),
    JSE76 = mkinsub("SF0"), quiet = TRUE,
    name = "dfop_path_1", dll_dir = "cyan_dlls", overwrite = TRUE),
  sforb_path_1 = mkinmod(
    cyan = mkinsub("SFORB", c("JCZ38", "J9Z38")),
    JCZ38 = mkinsub("SF0", "JSE76"),
    J9Z38 = mkinsub("SF0"),
    JSE76 = mkinsub("SF0"), quiet = TRUE,
    name = "sforb_path_1", dll_dir = "cyan_dlls", overwrite = TRUE),
  hs_path_1 = mkinmod(
    cyan = mkinsub("HS", c("JCZ38", "J9Z38")),
    JCZ38 = mkinsub("SF0", "JSE76"),
    J9Z38 = mkinsub("SF0"),
    JSE76 = mkinsub("SF0"), quiet = TRUE,
    name = "hs_path_1", dll_dir = "cyan_dlls", overwrite = TRUE)
)
cl_path_1 <- start_cluster(n_cores)
```

To obtain suitable starting values for the NLHM fits, separate pathway fits are performed for all datasets.

```
f_sep_1_const <- mmkin(
  cyan_path_1,
  cyan_ds,
  error_model = "const",
  cluster = cl_path_1,
  quiet = TRUE)
status(f_sep_1_const) |> kable()
```

	Nambsheim	Tama	Gross-Umstadt	Sassafras	Lleida
sfo_path_1	OK	OK	OK	C	OK
fomc_path_1	OK	OK	OK	OK	OK
dfop_path_1	OK	OK	OK	OK	OK

	Nambsheim	Tama	Gross-Umstadt	Sassafras	Lleida
sforb_path_1	OK	OK	OK	OK	OK
hs_path_1	C	C	C	C	C

```
f_sep_1_tc <- update(f_sep_1_const, error_model = "tc")
status(f_sep_1_tc) |> kable()
```

	Nambsheim	Tama	Gross-Umstadt	Sassafras	Lleida
sfo_path_1	OK	OK	OK	OK	OK
fomc_path_1	OK	OK	OK	OK	OK
dfop_path_1	OK	OK	OK	OK	OK
sforb_path_1	OK	OK	OK	OK	OK
hs_path_1	C	OK	C	OK	C

Most separate fits converged successfully. The biggest convergence problems are seen when using the HS model with constant variance.

For the hierarchical pathway fits, those random effects that could not be quantified in the corresponding parent data analyses are excluded.

In the code below, the output of the `illparms` function for the parent only fits is used as an argument `no_random_effect` to the `mhmkin` function. The possibility to do so was introduced in `mkim` version 1.2.2 which is currently under development.

```
f_saem_1 <- mhmkin(list(f_sep_1_const, f_sep_1_tc),
  no_random_effect = illparms(cyan_saem_full),
  cluster = cl_path_1)
```

```
status(f_saem_1) |> kable()
```

	const	tc
sfo_path_1	FO	Fth, FO
fomc_path_1	OK	Fth, FO
dfop_path_1	Fth, FO	Fth, FO
sforb_path_1	Fth, FO	Fth, FO
hs_path_1	FO	E

The status information from the individual fits shows that all fits completed successfully. The matrix entries Fth and FO indicate that the Fisher Information Matrix could not be inverted for the fixed effects (θ) and the random effects (Ω), respectively. For the affected fits, ill-defined parameters cannot be determined using the `illparms` function, because it relies on the Fisher Information Matrix.

```
illparms(f_saem_1) |> kable()
```

	const	tc
sfo_path_1	NA	NA
fomc_path_1	sd(log_k_J9Z38), sd(f_cyan_ilr_2), sd(f_JCZ38_qlogis)	NA
dfop_path_1	NA	NA
sforb_path_1	NA	NA
hs_path_1	NA	E

The model comparisons below suggest that the pathway fits using DFOP or SFORB for the parent compound provide the best fit.

```
anova(f_saem_1[, "const"]) |> kable(digits = 1)
```

	npar	AIC	BIC	Lik
sfo_path_1 const	16	2693.0	2686.8	-1330.5
fomc_path_1 const	18	2427.9	2420.9	-1196.0
dfop_path_1 const	20	2403.2	2395.4	-1181.6
sforb_path_1 const	20	2401.4	2393.6	-1180.7
hs_path_1 const	20	2427.2	2419.4	-1193.6

```
anova(f_saem_1[1:4, ]) |> kable(digits = 1)
```

	npar	AIC	BIC	Lik
sfo_path_1 const	16	2693.0	2686.8	-1330.5
sfo_path_1 tc	17	2657.6	2651.0	-1311.8
fomc_path_1 const	18	2427.9	2420.9	-1196.0
fomc_path_1 tc	19	2423.6	2416.2	-1192.8
dfop_path_1 const	20	2403.2	2395.4	-1181.6
sforb_path_1 const	20	2401.4	2393.6	-1180.7
dfop_path_1 tc	20	2398.0	2390.1	-1179.0
sforb_path_1 tc	20	2399.9	2392.1	-1180.0

For these two parent model, successful fits are shown below. Plots of the fits with the other parent models are shown in the Appendix.

```
plot(f_saem_1[["dfop_path_1", "tc"]])
```

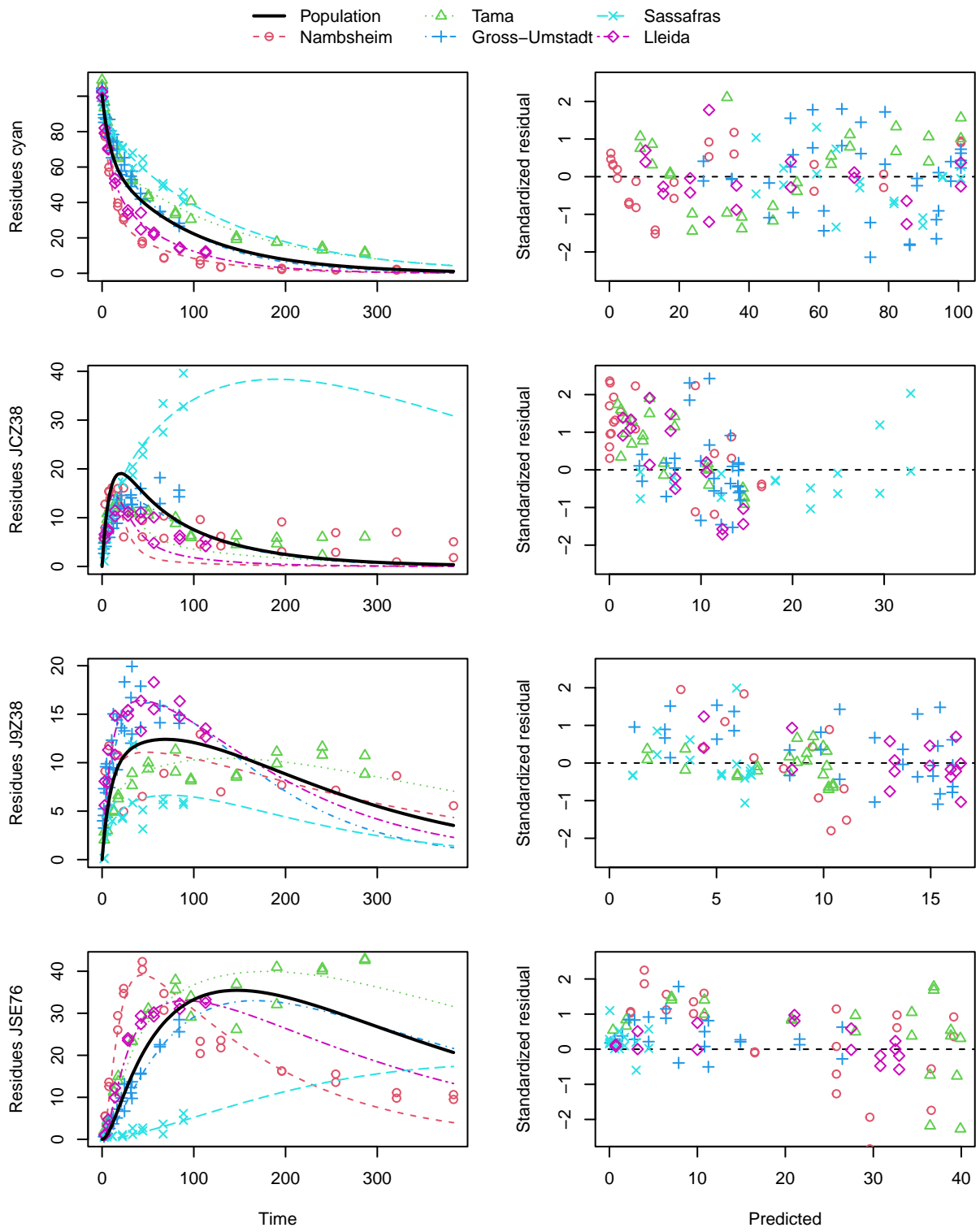


Figure 1: DFOP pathway fit with two-component error

```
plot(f_saem_1[["sforb_path_1", "tc"]])
```

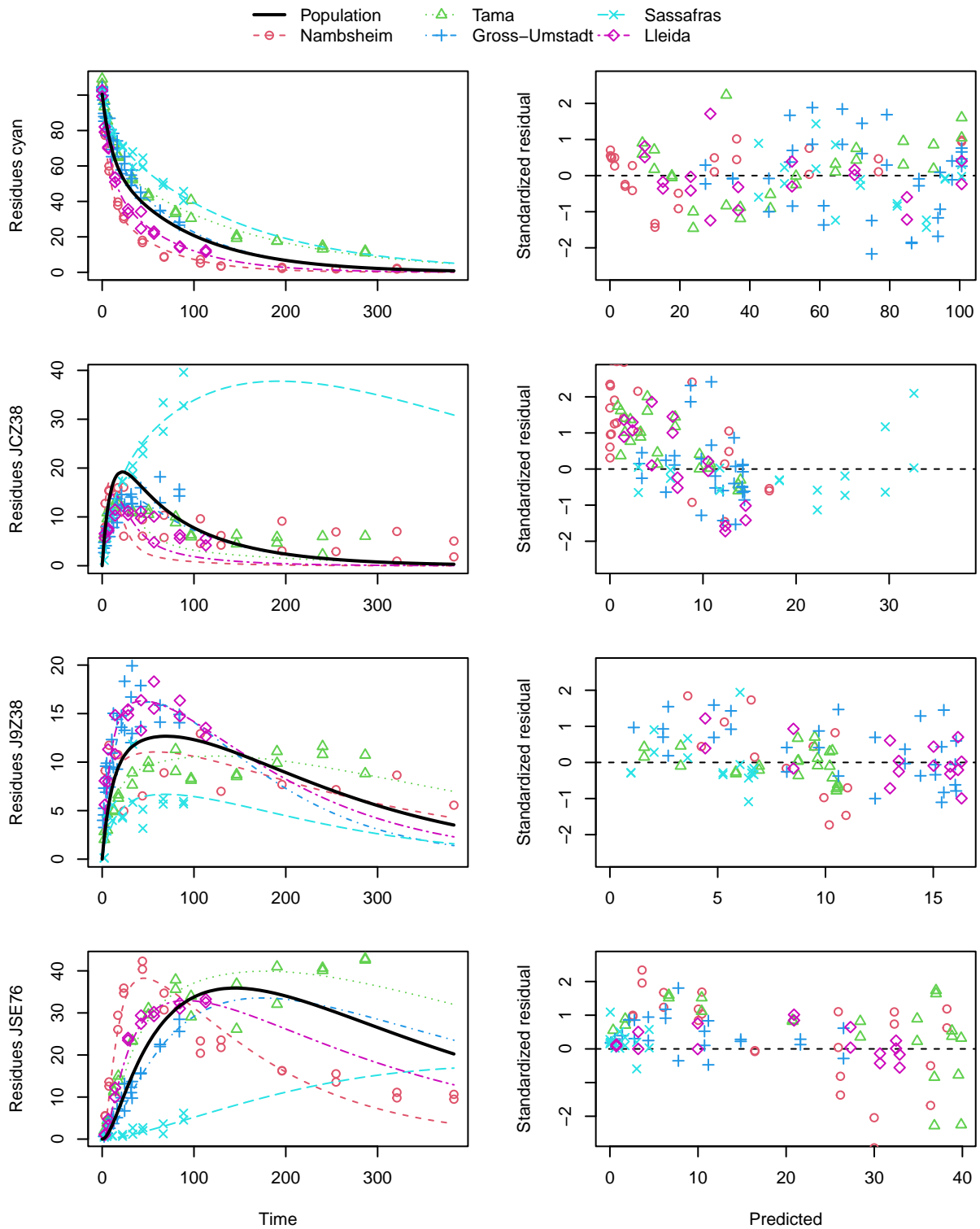


Figure 2: SFORB pathway fit with two-component error

A closer graphical analysis of these Figures shows that the residues of transformation product JCZ38 in the soils Tama and Nambshiem observed at later time points are strongly and systematically underestimated.

```
stopCluster(cl_path_1)
```

Alternative pathway fits

To improve the fit for JCZ38, a back-reaction from JSE76 to JCZ38 was introduced in an alternative version of the transformation pathway, in analogy to the back-reaction from K5A78 to K5A77. Both pairs of transformation products are pairs of an organic acid with its corresponding amide (Addendum 2014, p. 109). As FOMC provided the best fit for the parent, and the biexponential models DFOP and SFORB provided the best initial pathway fits, these three parent models are used in the alternative pathway fits.

```
cyan_path_2 <- list(  
  fomc_path_2 = mkinmod(  
    cyan = mkinsub("FOMC", c("JCZ38", "J9Z38")),  
    JCZ38 = mkinsub("SF0", "JSE76"),  
    J9Z38 = mkinsub("SF0"),  
    JSE76 = mkinsub("SF0", "JCZ38"),  
    name = "fomc_path_2", quiet = TRUE,  
    dll_dir = "cyan_dlls",  
    overwrite = TRUE  
  ),  
  dfop_path_2 = mkinmod(  
    cyan = mkinsub("DFOP", c("JCZ38", "J9Z38")),  
    JCZ38 = mkinsub("SF0", "JSE76"),  
    J9Z38 = mkinsub("SF0"),  
    JSE76 = mkinsub("SF0", "JCZ38"),  
    name = "dfop_path_2", quiet = TRUE,  
    dll_dir = "cyan_dlls",  
    overwrite = TRUE  
  ),  
  sforb_path_2 = mkinmod(  
    cyan = mkinsub("SFORB", c("JCZ38", "J9Z38")),  
    JCZ38 = mkinsub("SF0", "JSE76"),  
    J9Z38 = mkinsub("SF0"),  
    JSE76 = mkinsub("SF0", "JCZ38"),  
    name = "sforb_path_2", quiet = TRUE,  
    dll_dir = "cyan_dlls",  
    overwrite = TRUE  
  )  
)  
  
cl_path_2 <- start_cluster(n_cores)  
f_sep_2_const <- mmkin(  
  cyan_path_2,  
  cyan_ds,  
  error_model = "const",  
  cluster = cl_path_2,  
  quiet = TRUE)  
  
status(f_sep_2_const) |> kable()
```

	Nambsheim	Tama	Gross-Umstadt	Sassafras	Lleida
fomc_path_2	OK	OK	OK	C	OK
dfop_path_2	OK	OK	OK	C	OK
sforb_path_2	OK	OK	OK	OK	OK

Using constant variance, separate fits converge with the exception of the fits to the Sassafras soil data.

```
f_sep_2_tc <- update(f_sep_2_const, error_model = "tc")
status(f_sep_2_tc) |> kable()
```

	Nambsheim	Tama	Gross-Umstadt	Sassafras	Lleida
fomc_path_2	OK	OK	OK	C	OK
dfop_path_2	OK	C	OK	C	OK
sforb_path_2	OK	OK	OK	C	OK

Using the two-component error model, all separate fits converge with the exception of the alternative pathway fit with DFOP used for the parent and the Sassafras dataset.

```
f_saem_2 <- mhmkin(list(f_sep_2_const, f_sep_2_tc),
  no_random_effect = illparms(cyan_saem_full[2:4, ]),
  cluster = cl_path_2)
```

```
status(f_saem_2) |> kable()
```

	const	tc
fomc_path_2	E	OK
dfop_path_2	OK	OK
sforb_path_2	OK	OK

The hierarchical fits for the alternative pathway completed successfully, with the exception of the model using FOMC for the parent compound and constant variance as the error model.

```
illparms(f_saem_2) |> kable()
```

	const	tc
fomc_path_2	E	sd(f_JSE76_qlogis)
dfop_path_2	sd(f_JCZ38_qlogis), sd(f_JSE76_qlogis)	sd(f_JCZ38_qlogis), sd(f_JSE76_qlogis)
sforb_path_2	sd(f_JCZ38_qlogis), sd(f_JSE76_qlogis)	sd(f_JCZ38_qlogis), sd(f_JSE76_qlogis)

In all biphasic fits (DFOP or SFORB for the parent compound), the random effects for the formation fractions for the pathways from JCZ38 to JSE76, and for the reverse pathway from JSE76 to JCZ38 are ill-defined.

```
anova(f_saem_2[, "tc"]) |> kable(digits = 1)
```

	npar	AIC	BIC	Lik
fomc_path_2 tc	21	2249.0	2240.8	-1103.5
dfop_path_2 tc	22	2234.4	2225.8	-1095.2
sforb_path_2 tc	22	2239.7	2231.1	-1097.9

```
anova(f_saem_2[2:3,]) |> kable(digits = 1)
```

	npar	AIC	BIC	Lik
dfop_path_2 const	22	2288.4	2279.8	-1122.2
sforb_path_2 const	22	2283.3	2274.7	-1119.7
dfop_path_2 tc	22	2234.4	2225.8	-1095.2
sforb_path_2 tc	22	2239.7	2231.1	-1097.9

The variants using the biexponential models DFOP and SFORB for the parent compound and the two-component error model give the lowest AIC and BIC values and are plotted below. Compared with the original pathway, the AIC and BIC values indicate a large improvement. This is confirmed by the plots, which show that the metabolite JCZ38 is fitted much better with this model.

```
plot(f_saem_2[["fomc_path_2", "tc"]])
```

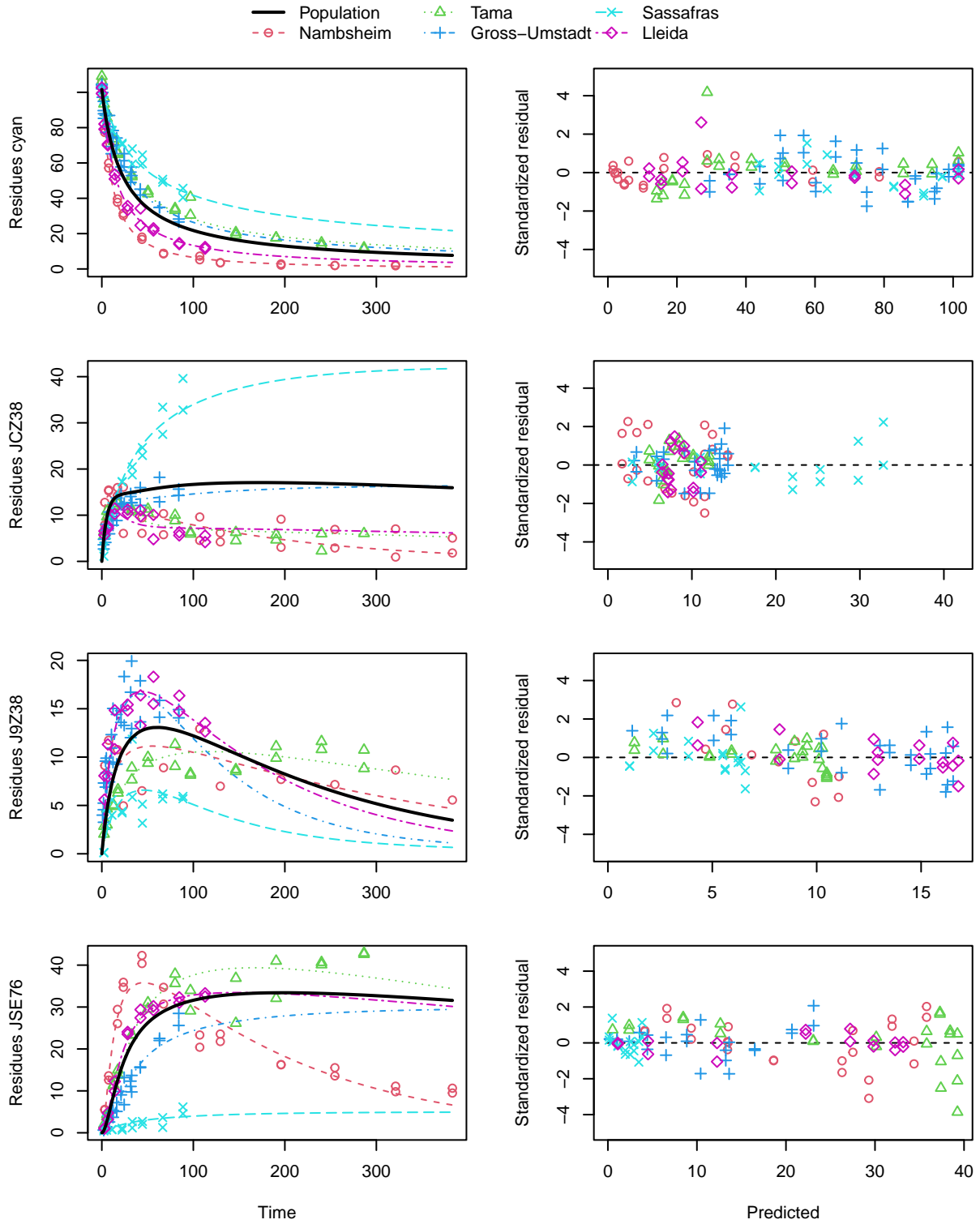


Figure 3: FOMC pathway fit with two-component error, alternative pathway

```
plot(f_saem_2[["dfop_path_2", "tc"]])
```

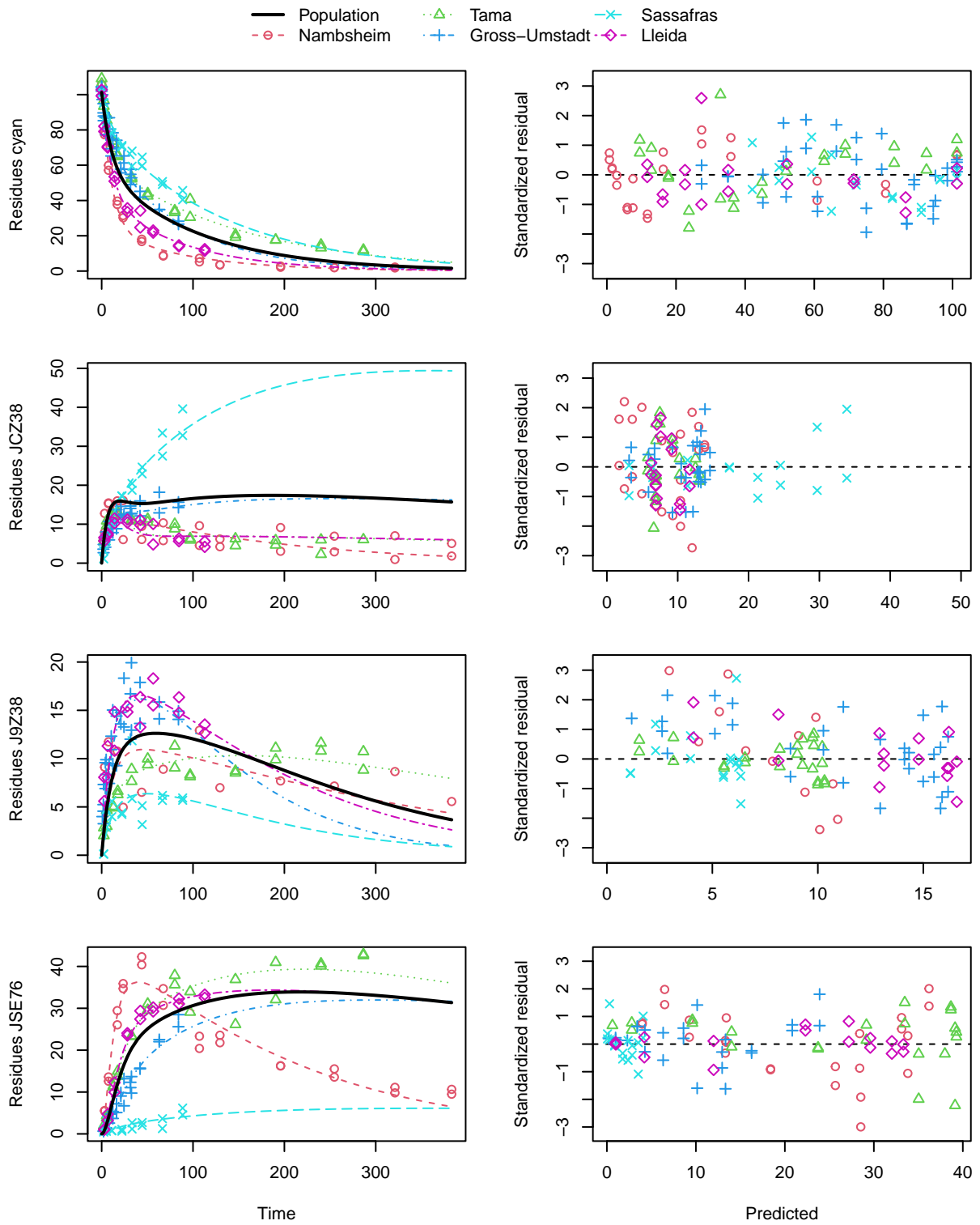


Figure 4: DFOP pathway fit with two-component error, alternative pathway

```
plot(f_saem_2[["sforb_path_2", "tc"]])
```

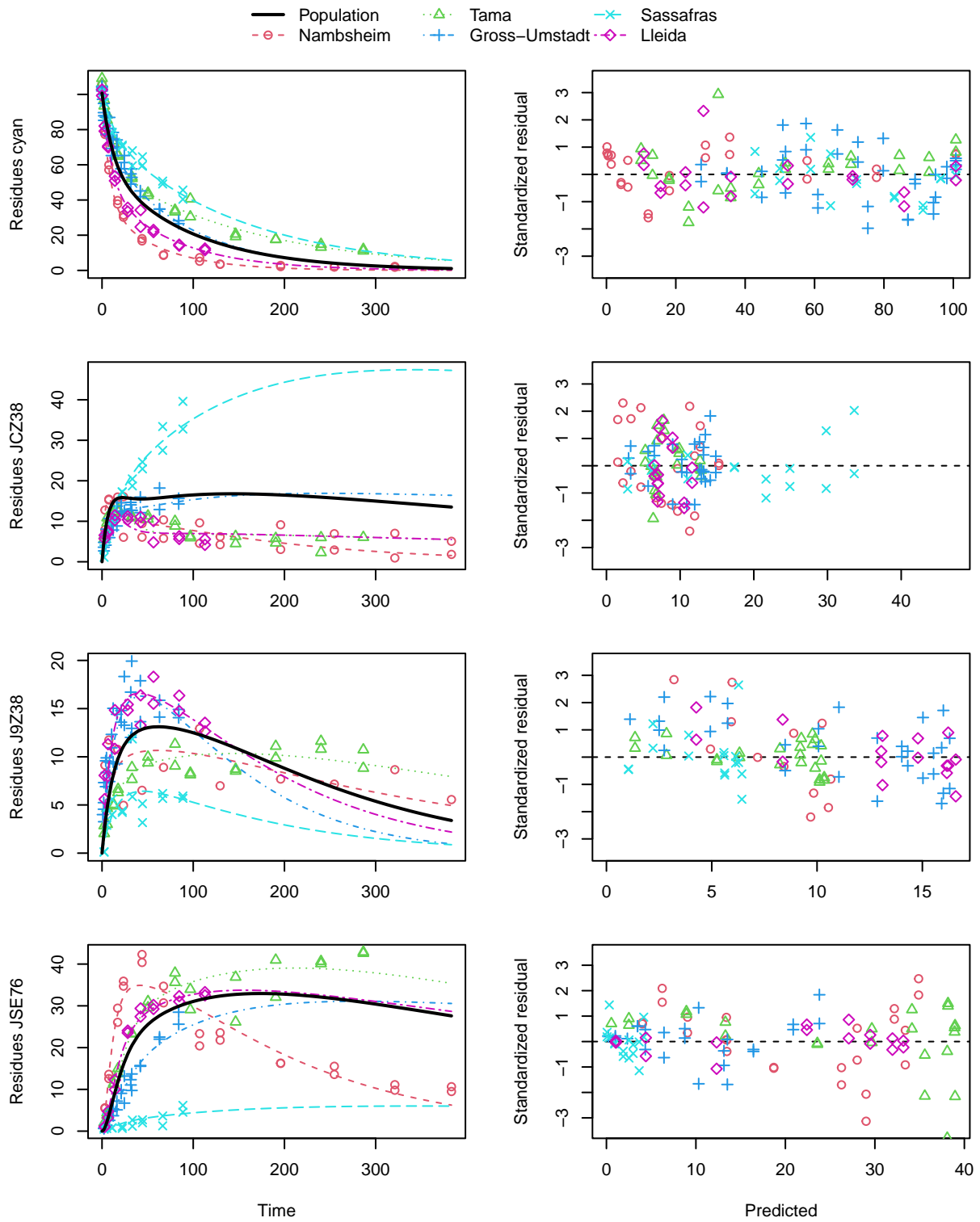


Figure 5: SFORB pathway fit with two-component error, alternative pathway

Refinement of alternative pathway fits

All ill-defined random effects that were identified in the parent only fits and in the above pathway fits, are excluded for the final evaluations below. For this purpose, a list of character vectors is created below that can be indexed by row and column indices, and which contains the degradation parameter names for which random effects should be excluded for each of the hierarchical fits contained in `f_saem_2`.

```
no_ranef <- matrix(list(), nrow = 3, ncol = 2, dimnames = dimnames(f_saem_2))
no_ranef[["fomc_path_2", "const"]] <- c("log_beta", "f_JCZ38_qlogis", "f_JSE76_qlogis")
no_ranef[["fomc_path_2", "tc"]] <- c("cyan_0", "f_JCZ38_qlogis", "f_JSE76_qlogis")
no_ranef[["dfop_path_2", "const"]] <- c("cyan_0", "f_JCZ38_qlogis", "f_JSE76_qlogis")
no_ranef[["dfop_path_2", "tc"]] <- c("cyan_0", "log_k1", "f_JCZ38_qlogis", "f_JSE76_qlogis")
no_ranef[["sforb_path_2", "const"]] <- c("cyan_free_0",
    "f_JCZ38_qlogis", "f_JSE76_qlogis")
no_ranef[["sforb_path_2", "tc"]] <- c("cyan_free_0", "log_k_cyan_free_bound",
    "f_JCZ38_qlogis", "f_JSE76_qlogis")
clusterExport(cl_path_2, "no_ranef")

f_saem_3 <- update(f_saem_2,
  no_random_effect = no_ranef,
  cluster = cl_path_2)
```

```
status(f_saem_3) |> kable()
```

	const	tc
fomc_path_2	E	Fth
dfop_path_2	Fth	Fth
sforb_path_2	Fth	Fth

With the exception of the FOMC pathway fit with constant variance, all updated fits completed successfully. However, the Fisher Information Matrix for the fixed effects (Fth) could not be inverted, so no confidence intervals for the optimised parameters are available.

```
illparms(f_saem_3) |> kable()
```

	const	tc
fomc_path_2	E	
dfop_path_2		
sforb_path_2		

```
anova(f_saem_3[, "tc"]) |> kable(digits = 1)
```

	npar	AIC	BIC	Lik
fomc_path_2 tc	19	2249.1	2241.6	-1105.5
dfop_path_2 tc	20	2237.3	2229.5	-1098.6
sforb_path_2 tc	20	2241.3	2233.5	-1100.7

```
anova(f_saem_3[2:3,]) |> kable(digits = 1)
```

	npar	AIC	BIC	Lik
dfop_path_2 const	20	2282.2	2274.4	-1121.1
sforb_path_2 const	20	2279.7	2271.9	-1119.9

	npar	AIC	BIC	Lik
dfop_path_2 tc	20	2237.3	2229.5	-1098.6
sforb_path_2 tc	20	2241.3	2233.5	-1100.7

While the AIC and BIC values of the best fit (DFOP pathway fit with two-component error) are lower than in the previous fits with the alternative pathway, the practical value of these refined evaluations is limited as no confidence intervals are obtained.

```
stopCluster(cl_path_2)
```

Conclusion

It was demonstrated that a relatively complex transformation pathway with parallel formation of two primary metabolites and one secondary metabolite can be fitted even if the data in the individual datasets are quite different and partly only cover the formation phase.

The run times of the pathway fits were several hours, limiting the practical feasibility of iterative refinements based on ill-defined parameters and of alternative checks of parameter identifiability based on multistart runs.

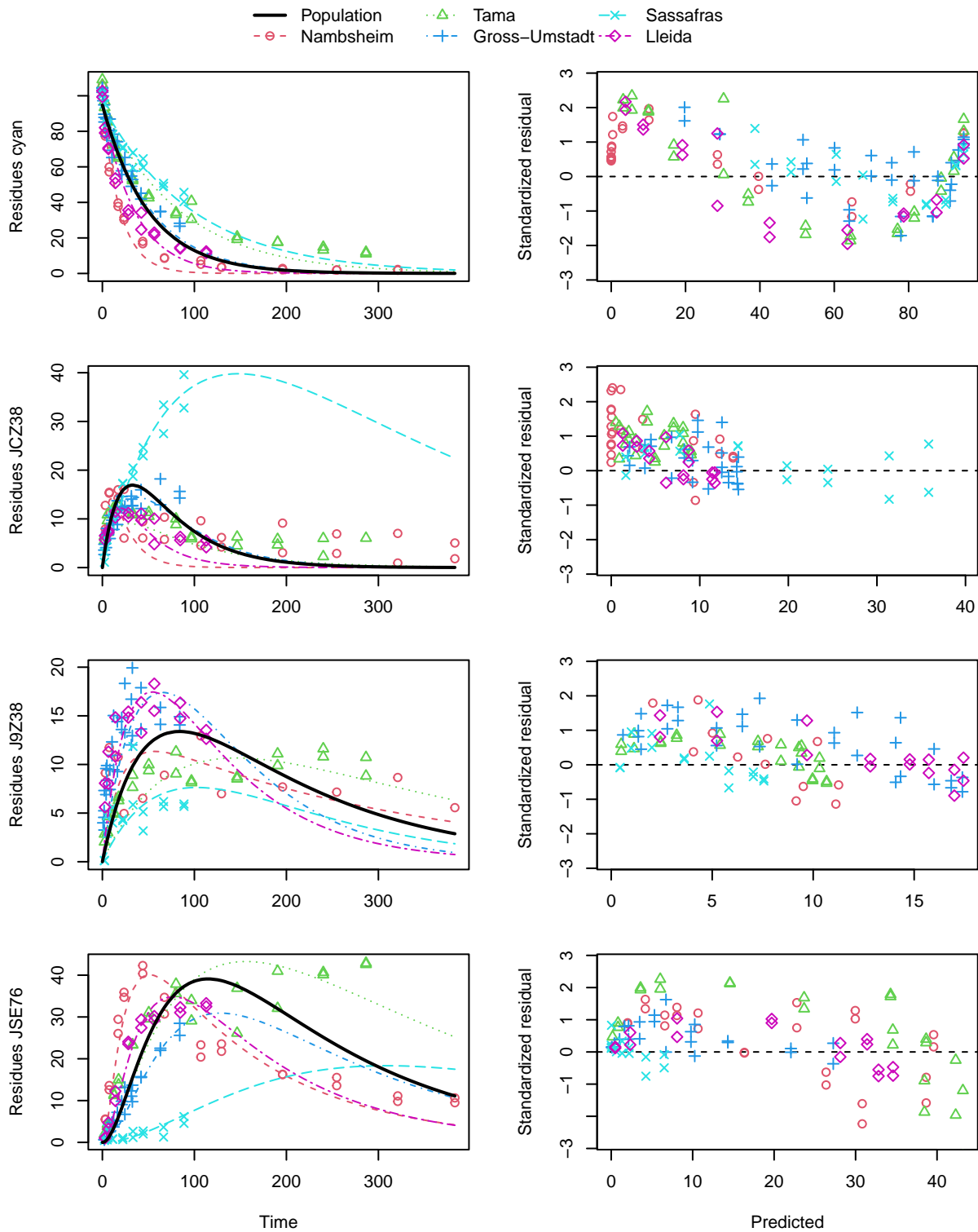
Acknowledgements

The helpful comments by Janina Wöltjen of the German Environment Agency are gratefully acknowledged.

Appendix

Plots of fits that were not refined further

```
plot(f_saem_1[["sfo_path_1", "tc"]])
```




```
plot(f_saem_1[["fomc_path_1", "tc"]])
```

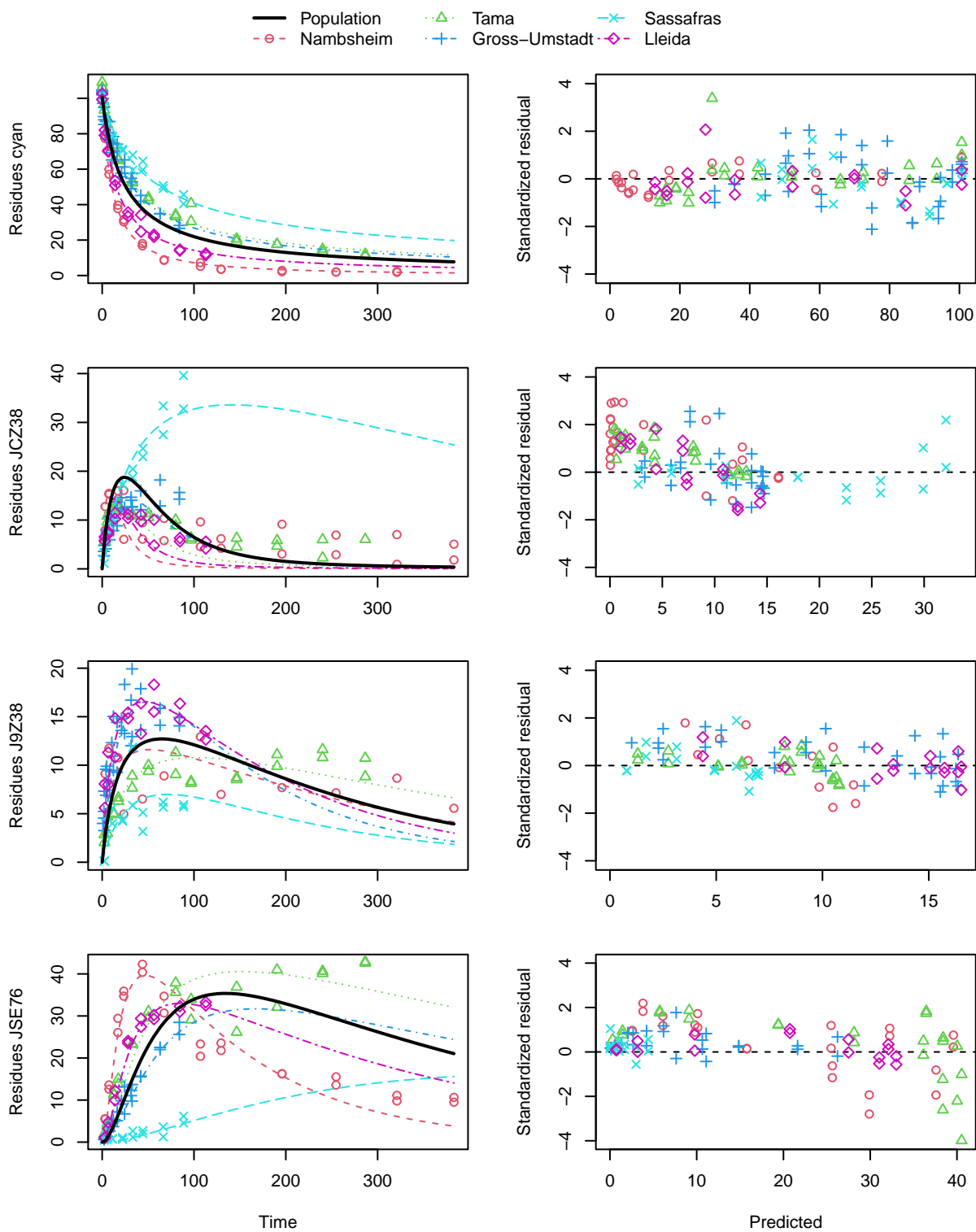


Figure 7: FOMC pathway fit with two-component error

```
plot(f_saem_1[["sforb_path_1", "tc"]])
```

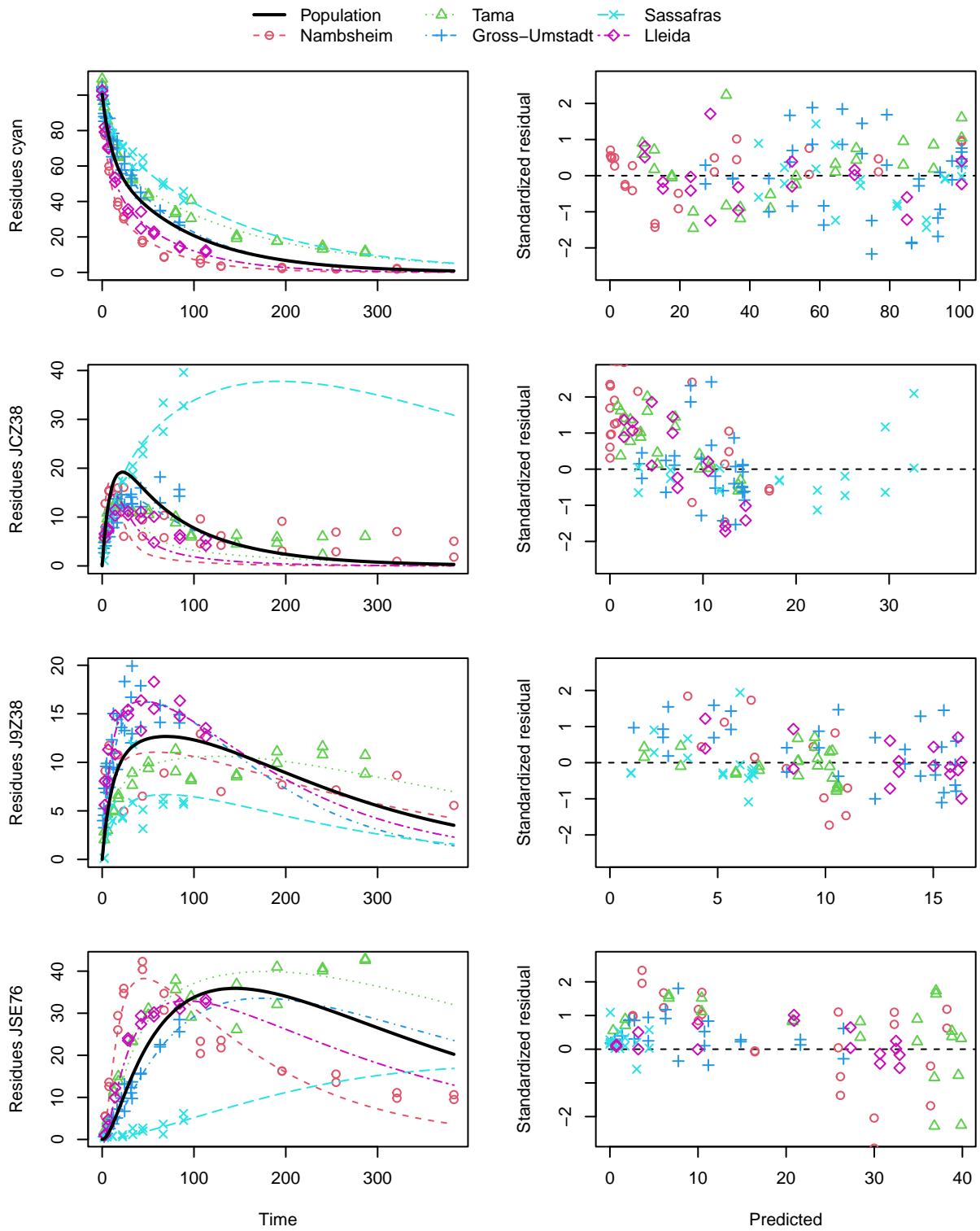


Figure 8: HS pathway fit with two-component error

Hierarchical fit listings

Pathway 1

Listing 1: Hierarchical SFO path 1 fit with constant variance

```
saemix version used for fitting: 3.3
mkin version used for pre-fitting: 1.2.9
R version used for fitting: 4.4.2
Date of fit: Thu Feb 13 18:32:35 2025
Date of summary: Thu Feb 13 19:05:54 2025

Equations:
d_cyan/dt = - k_cyan * cyan
d_JCZ38/dt = + f_cyan_to_JCZ38 * k_cyan * cyan - k_JCZ38 * JCZ38
d_J9Z38/dt = + f_cyan_to_J9Z38 * k_cyan * cyan - k_J9Z38 * J9Z38
d_JSE76/dt = + f_JCZ38_to_JSE76 * k_JCZ38 * JCZ38 - k_JSE76 * JSE76

Data:
433 observations of 4 variable(s) grouped in 5 datasets

Model predictions using solution type deSolve

Fitted in 530.472 s
Using 300, 100 iterations and 10 chains

Variance model: Constant variance

Starting values for degradation parameters:
cyan_0 log_k_cyan log_k_JCZ38 log_k_J9Z38 log_k_JSE76
95.3304 -3.8459 -3.1305 -5.0678 -5.3196
f_cyan_ilr_1 f_cyan_ilr_2 f_JCZ38_qlogis
0.8158 23.5335 11.8774

Fixed degradation parameter values:
None

Starting values for random effects (square root of initial entries in omega):
cyan_0 log_k_cyan log_k_JCZ38 log_k_J9Z38 log_k_JSE76
4.797 0.0000 0.000 0.000 0.000 0.0000
log_k_cyan 0.000 0.9619 0.000 0.000 0.000 0.0000
log_k_JCZ38 0.000 0.0000 2.139 0.000 0.000 0.0000
log_k_J9Z38 0.000 0.0000 0.000 0.000 1.639 0.0000
log_k_JSE76 0.000 0.0000 0.000 0.000 0.000 0.7894
f_cyan_ilr_1 0.000 0.0000 0.000 0.000 0.000 0.0000
f_cyan_ilr_2 0.000 0.0000 0.000 0.000 0.000 0.0000
f_JCZ38_qlogis 0.000 0.0000 0.000 0.000 0.000 0.0000
f_cyan_ilr_1 f_cyan_ilr_2 f_JCZ38_qlogis
cyan_0 0.0000 0.000 0.00 0.00
log_k_cyan 0.0000 0.000 0.00
log_k_JCZ38 0.0000 0.000 0.00
log_k_J9Z38 0.0000 0.000 0.00
log_k_JSE76 0.0000 0.000 0.00
f_cyan_ilr_1 0.7714 0.000 0.00
f_cyan_ilr_2 0.0000 9.247 0.00
f_JCZ38_qlogis 0.0000 0.000 16.61

Starting values for error model parameters:
a.1
1

Results:

Likelihood computed by importance sampling
AIC BIC logLik
2693 2687 -1331

Optimised parameters:
est. lower upper
cyan_0 95.1279 9.354e+01 9.671e+01
log_k_cyan -3.8527 -4.367e+00 -3.338e+00
log_k_JCZ38 -3.0381 -4.187e+00 -1.889e+00
log_k_J9Z38 -5.0095 -5.623e+00 -4.396e+00
log_k_JSE76 -5.3357 -6.025e+00 -4.646e+00
f_cyan_ilr_1 0.8050 5.174e-01 1.093e+00
f_cyan_ilr_2 12.4820 -1.050e+06 1.051e+06
f_JCZ38_qlogis 1.2912 3.561e-01 2.226e+00
a.1 4.8393 NA NA
SD.log_k_cyan 0.5840 NA NA
SD.log_k_JCZ38 1.2740 NA NA
SD.log_k_J9Z38 0.3172 NA NA
SD.log_k_JSE76 0.5677 NA NA
SD.f_cyan_ilr_1 0.2623 NA NA
```

SD.f_cyan_ilr_2	1.3724	NA	NA
SD.f_JCZ38_qlogis	0.1464	NA	NA

Correlation is not available

Random effects:

	est.	lower	upper
SD.log_k_cyan	0.5840	NA	NA
SD.log_k_JCZ38	1.2740	NA	NA
SD.log_k_J9Z38	0.3172	NA	NA
SD.log_k_JSE76	0.5677	NA	NA
SD.f_cyan_ilr_1	0.2623	NA	NA
SD.f_cyan_ilr_2	1.3724	NA	NA
SD.f_JCZ38_qlogis	0.1464	NA	NA

Variance model:

	est.	lower	upper
a.1	4.839	NA	NA

Backtransformed parameters:

	est.	lower	upper
cyan_0	95.127935	93.542456	96.713413
k_cyan	0.021221	0.012687	0.035497
k_JCZ38	0.047924	0.015189	0.151213
k_J9Z38	0.006674	0.003612	0.012332
k_JSE76	0.004817	0.002417	0.009601
f_cyan_to_JCZ38	0.757402	NA	NA
f_cyan_to_J9Z38	0.242597	NA	NA
f_JCZ38_to_JSE76	0.784347	0.588098	0.902582

Resulting formation fractions:

	ff
cyan_JCZ38	7.574e-01
cyan_J9Z38	2.426e-01
cyan_sink	9.839e-08
JCZ38_JSE76	7.843e-01
JCZ38_sink	2.157e-01

Estimated disappearance times:

	DT50	DT90
cyan	32.66	108.50
JCZ38	14.46	48.05
J9Z38	103.86	345.00
JSE76	143.91	478.04

Listing 2: Hierarchical SFO path 1 fit with two-component error

```

saemix version used for fitting:      3.3
mkin version used for pre-fitting:    1.2.9
R version used for fitting:           4.4.2
Date of fit:                          Thu Feb 13 18:31:56 2025
Date of summary:                      Thu Feb 13 19:05:54 2025

Equations:
d_cyan/dt = - k_cyan * cyan
d_JCZ38/dt = + f_cyan_to_JCZ38 * k_cyan * cyan - k_JCZ38 * JCZ38
d_J9Z38/dt = + f_cyan_to_J9Z38 * k_cyan * cyan - k_J9Z38 * J9Z38
d_JSE76/dt = + f_JCZ38_to_JSE76 * k_JCZ38 * JCZ38 - k_JSE76 * JSE76

Data:
433 observations of 4 variable(s) grouped in 5 datasets

Model predictions using solution type deSolve

Fitted in 491.09 s
Using 300, 100 iterations and 10 chains

Variance model: Two-component variance function

Starting values for degradation parameters:
      cyan_0   log_k_cyan   log_k_JCZ38   log_k_J9Z38   log_k_JSE76
      96.0039   -3.8907    -3.1276     -5.0069     -4.9367
  f_cyan_ilr_1 f_cyan_ilr_2 f_JCZ38_qlogis
      0.7937    22.3422    17.8932

Fixed degradation parameter values:
None

Starting values for random effects (square root of initial entries in omega):
      cyan_0   log_k_cyan   log_k_JCZ38   log_k_J9Z38   log_k_JSE76
cyan_0      4.859    0.000    0.00    0.00    0.00    0.0000
log_k_cyan  0.000    0.962    0.00    0.00    0.00    0.0000
log_k_JCZ38 0.000    0.000    2.04    0.00    0.00    0.0000
log_k_J9Z38 0.000    0.000    0.00    1.72    0.00    0.0000
log_k_JSE76 0.000    0.000    0.00    0.00    0.00    0.9076
f_cyan_ilr_1 0.000    0.000    0.00    0.00    0.00    0.0000
f_cyan_ilr_2 0.000    0.000    0.00    0.00    0.00    0.0000
f_JCZ38_qlogis 0.000    0.000    0.00    0.00    0.00    0.0000
  f_cyan_ilr_1 f_cyan_ilr_2 f_JCZ38_qlogis
cyan_0      0.0000    0.000    0.00
log_k_cyan  0.0000    0.000    0.00
log_k_JCZ38 0.0000    0.000    0.00
log_k_J9Z38 0.0000    0.000    0.00
log_k_JSE76 0.0000    0.000    0.00
f_cyan_ilr_1 0.7598    0.000    0.00
f_cyan_ilr_2 0.0000    8.939    0.00
f_JCZ38_qlogis 0.0000    0.000    14.49

Starting values for error model parameters:
a.1 b.1
  1  1

Results:

Likelihood computed by importance sampling
  AIC BIC logLik
 2658 2651 -1312

Optimised parameters:
      est. lower upper
cyan_0      94.81681   NA   NA
log_k_cyan  -3.91558   NA   NA
log_k_JCZ38 -3.12715   NA   NA
log_k_J9Z38 -5.04840   NA   NA
log_k_JSE76 -5.10443   NA   NA
f_cyan_ilr_1  0.80760   NA   NA
f_cyan_ilr_2 48.66960   NA   NA
f_JCZ38_qlogis 3.03397   NA   NA
a.1          3.93879   NA   NA
b.1          0.08057   NA   NA
SD.log_k_cyan 0.58921   NA   NA
SD.log_k_JCZ38 1.29813   NA   NA
SD.log_k_J9Z38 0.68372   NA   NA
SD.log_k_JSE76 0.35128   NA   NA
SD.f_cyan_ilr_1 0.38352   NA   NA
SD.f_cyan_ilr_2 4.98884   NA   NA
SD.f_JCZ38_qlogis 1.75636   NA   NA

Correlation is not available

```

```

Random effects:
      est. lower upper
SD.log_k_cyan    0.5892   NA   NA
SD.log_k_JCZ38   1.2981   NA   NA
SD.log_k_J9Z38   0.6837   NA   NA
SD.log_k_JSE76    0.3513   NA   NA
SD.f_cyan_ilr_1  0.3835   NA   NA
SD.f_cyan_ilr_2  4.9888   NA   NA
SD.f_JCZ38_qlogis 1.7564   NA   NA

Variance model:
      est. lower upper
a.1 3.93879   NA   NA
b.1 0.08057   NA   NA

Backtransformed parameters:
      est. lower upper
cyan_0    94.81681   NA   NA
k_cyan     0.01993   NA   NA
k_JCZ38    0.04384   NA   NA
k_J9Z38    0.00642   NA   NA
k_JSE76    0.00607   NA   NA
f_cyan_to_JCZ38 0.75807   NA   NA
f_cyan_to_J9Z38 0.24193   NA   NA
f_JCZ38_to_JSE76 0.95409   NA   NA

Resulting formation fractions:
      ff
cyan_JCZ38 0.75807
cyan_J9Z38 0.24193
cyan_sink  0.00000
JCZ38_JSE76 0.95409
JCZ38_sink 0.04591

Estimated disappearance times:
      DT50  DT90
cyan    34.78 115.54
JCZ38   15.81  52.52
J9Z38  107.97 358.68
JSE76  114.20 379.35

```

Listing 3: Hierarchical FOMC path 1 fit with constant variance

```

saemix version used for fitting:      3.3
mkin version used for pre-fitting:    1.2.9
R version used for fitting:           4.4.2
Date of fit:                          Thu Feb 13 18:34:08 2025
Date of summary:                      Thu Feb 13 19:05:54 2025

Equations:
d_cyan/dt = - (alpha/beta) * 1/((time/beta) + 1) * cyan
d_JCZ38/dt = + f_cyan_to_JCZ38 * (alpha/beta) * 1/((time/beta) + 1) *
cyan - k_JCZ38 * JCZ38
d_J9Z38/dt = + f_cyan_to_J9Z38 * (alpha/beta) * 1/((time/beta) + 1) *
cyan - k_J9Z38 * J9Z38
d_JSE76/dt = + f_JCZ38_to_JSE76 * k_JCZ38 * JCZ38 - k_JSE76 * JSE76

Data:
433 observations of 4 variable(s) grouped in 5 datasets

Model predictions using solution type deSolve

Fitted in 623.314 s
Using 300, 100 iterations and 10 chains

Variance model: Constant variance

Starting values for degradation parameters:
cyan_0      log_k_JCZ38      log_k_J9Z38      log_k_JSE76      f_cyan_ilr_1
101.2314    -3.3680              -5.1108          -5.9416          0.7144
f_cyan_ilr_2 f_JCZ38_qlogis      log_alpha      log_beta
7.0229      14.9234              -0.1791         2.9811

Fixed degradation parameter values:
None

Starting values for random effects (square root of initial entries in omega):
cyan_0      cyan_0      log_k_JCZ38      log_k_J9Z38      log_k_JSE76      f_cyan_ilr_1
5.416       0.000       0.000           0.0             0.000           0.0000
log_k_JCZ38 0.000       2.439           0.0             0.000           0.0000
log_k_J9Z38 0.000       0.000           1.7             0.000           0.0000
log_k_JSE76 0.000       0.000           0.0             1.856           0.0000
f_cyan_ilr_1 0.000       0.000           0.0             0.000           0.7164
f_cyan_ilr_2 0.000       0.000           0.0             0.000           0.0000
f_JCZ38_qlogis 0.000       0.000           0.0             0.000           0.0000
log_alpha    0.000       0.000           0.0             0.000           0.0000
log_beta     0.000       0.000           0.0             0.000           0.0000
f_cyan_ilr_2 f_JCZ38_qlogis      log_alpha      log_beta
cyan_0      0.00       0.00       0.0000       0.0000
log_k_JCZ38 0.00       0.00       0.0000       0.0000
log_k_J9Z38 0.00       0.00       0.0000       0.0000
log_k_JSE76 0.00       0.00       0.0000       0.0000
f_cyan_ilr_1 0.00       0.00       0.0000       0.0000
f_cyan_ilr_2 11.57      0.00       0.0000       0.0000
f_JCZ38_qlogis 0.00      18.81      0.0000       0.0000
log_alpha    0.00       0.00       0.4144       0.0000
log_beta     0.00       0.00       0.0000       0.5077

Starting values for error model parameters:
a.1
1

Results:

Likelihood computed by importance sampling
AIC  BIC  logLik
2428 2421 -1196

Optimised parameters:
      est.      lower      upper
cyan_0      101.1664  98.51265  103.8202
log_k_JCZ38   -3.3883 -4.78250  -1.9941
log_k_J9Z38   -5.3087 -5.91564  -4.7017
log_k_JSE76   -6.1313 -7.30061  -4.9619
f_cyan_ilr_1    0.7456  0.43782   1.0534
f_cyan_ilr_2    0.8181  0.24956   1.3866
f_JCZ38_qlogis  2.0467  0.61165   3.4817
log_alpha     -0.2391 -0.62806   0.1499
log_beta       2.8739  2.67664   3.0711
a.1            3.4160  3.17960   3.6525
SD.cyan_0      2.4355  0.40399   4.4671
SD.log_k_JCZ38  1.5654  0.57311   2.5576
SD.log_k_J9Z38  0.4645 -0.06533   0.9943
SD.log_k_JSE76  0.9841  0.10738   1.8609
SD.f_cyan_ilr_1 0.3285  0.10546   0.5515

```

```

SD.f_cyan_ilr_2    0.2276 -0.38711  0.8424
SD.f_JCZ38_qlogis 0.8340 -0.20970  1.8777
SD.log_alpha       0.4250  0.16017  0.6898

```

Correlation:

```

cyan_0  l__JCZ3  l__J9Z3  l__JSE7  f_cy__1  f_cy__2  f_JCZ38  log_lph
log_k_JCZ38  -0.0159
log_k_J9Z38  -0.0546  0.0080
log_k_JSE76  -0.0337  0.0016  0.0074
f_cyan_ilr_1 -0.0095  0.0194 -0.1573  0.0003
f_cyan_ilr_2 -0.2733  0.0799  0.3059  0.0263  0.0125
f_JCZ38_qlogis 0.0755 -0.0783 -0.0516  0.1222 -0.1155 -0.5231
log_alpha    -0.0567  0.0120  0.0351  0.0189  0.0040  0.0829 -0.0502
log_beta     -0.2980  0.0461  0.1382  0.0758  0.0209  0.4079 -0.2053  0.2759

```

Random effects:

```

est. lower upper
SD.cyan_0      2.4355  0.40399  4.4671
SD.log_k_JCZ38 1.5654  0.57311  2.5576
SD.log_k_J9Z38 0.4645 -0.06533  0.9943
SD.log_k_JSE76 0.9841  0.10738  1.8609
SD.f_cyan_ilr_1 0.3285  0.10546  0.5515
SD.f_cyan_ilr_2 0.2276 -0.38711  0.8424
SD.f_JCZ38_qlogis 0.8340 -0.20970  1.8777
SD.log_alpha    0.4250  0.16017  0.6898

```

Variance model:

```

est. lower upper
a.1 3.416  3.18 3.652

```

Backtransformed parameters:

```

est. lower upper
cyan_0      1.012e+02 9.851e+01 103.82023
k_JCZ38     3.377e-02 8.375e-03  0.13614
k_J9Z38     4.948e-03 2.697e-03  0.00908
k_JSE76     2.174e-03 6.751e-04  0.00700
f_cyan_to_JCZ38 6.389e-01      NA      NA
f_cyan_to_J9Z38 2.226e-01      NA      NA
f_JCZ38_to_JSE76 8.856e-01 6.483e-01  0.97016
alpha       7.873e-01 5.336e-01  1.16166
beta        1.771e+01 1.454e+01 21.56509

```

Resulting formation fractions:

```

ff
cyan_JCZ38  0.6389
cyan_J9Z38  0.2226
cyan_sink   0.1385
JCZ38_JSE76 0.8856
JCZ38_sink  0.1144

```

Estimated disappearance times:

```

DT50 DT90 DT50back
cyan  25.00 312.06  93.94
JCZ38 20.53  68.19   NA
J9Z38 140.07 465.32  NA
JSE76 318.86 1059.22 NA

```


Listing 4: Hierarchical FOMC path 1 fit with two-component error

```

saemix version used for fitting:      3.3
mkin version used for pre-fitting:    1.2.9
R version used for fitting:           4.4.2
Date of fit:                          Thu Feb 13 18:32:56 2025
Date of summary:                      Thu Feb 13 19:05:54 2025

Equations:
d_cyan/dt = - (alpha/beta) * 1/((time/beta) + 1) * cyan
d_JCZ38/dt = + f_cyan_to_JCZ38 * (alpha/beta) * 1/((time/beta) + 1) *
             cyan - k_JCZ38 * JCZ38
d_J9Z38/dt = + f_cyan_to_J9Z38 * (alpha/beta) * 1/((time/beta) + 1) *
             cyan - k_J9Z38 * J9Z38
d_JSE76/dt = + f_JCZ38_to_JSE76 * k_JCZ38 * JCZ38 - k_JSE76 * JSE76

Data:
433 observations of 4 variable(s) grouped in 5 datasets

Model predictions using solution type deSolve

Fitted in 550.58 s
Using 300, 100 iterations and 10 chains

Variance model: Two-component variance function

Starting values for degradation parameters:
      cyan_0  log_k_JCZ38  log_k_J9Z38  log_k_JSE76  f_cyan_ilr_1
101.13294   -3.32499   -5.09097   -5.93566   0.71359
  f_cyan_ilr_2 f_JCZ38_qlogis  log_alpha  log_beta
10.30315     14.62272    -0.09633    3.10634

Fixed degradation parameter values:
None

Starting values for random effects (square root of initial entries in omega):
      cyan_0  log_k_JCZ38  log_k_J9Z38  log_k_JSE76  f_cyan_ilr_1
5.649      0.000      0.000      0.000      0.000      0.0000
log_k_JCZ38 0.000      2.319      0.000      0.000      0.000      0.0000
log_k_J9Z38 0.000      0.000      1.73      0.000      0.000      0.0000
log_k_JSE76 0.000      0.000      0.000      1.86      0.000      0.0000
f_cyan_ilr_1 0.000      0.000      0.000      0.000      0.7183
f_cyan_ilr_2 0.000      0.000      0.000      0.000      0.000      0.0000
f_JCZ38_qlogis 0.000      0.000      0.000      0.000      0.000      0.0000
log_alpha     0.000      0.000      0.000      0.000      0.000      0.0000
log_beta      0.000      0.000      0.000      0.000      0.000      0.0000
      f_cyan_ilr_2 f_JCZ38_qlogis  log_alpha  log_beta
cyan_0      0.00      0.00      0.0000      0.0000
log_k_JCZ38 0.00      0.00      0.0000      0.0000
log_k_J9Z38 0.00      0.00      0.0000      0.0000
log_k_JSE76 0.00      0.00      0.0000      0.0000
f_cyan_ilr_1 0.00      0.00      0.0000      0.0000
f_cyan_ilr_2 0.00      12.85      0.00      0.0000      0.0000
f_JCZ38_qlogis 0.00      18.54      0.0000      0.0000
log_alpha     0.00      0.00      0.3142      0.0000
log_beta      0.00      0.00      0.0000      0.7333

Starting values for error model parameters:
a.1 b.1
1 1

Results:

Likelihood computed by importance sampling
  AIC  BIC  logLik
2424 2416 -1193

Optimised parameters:
      est.  lower  upper
cyan_0    100.65667  NA    NA
log_k_JCZ38 -3.45782  NA    NA
log_k_J9Z38 -5.23476  NA    NA
log_k_JSE76 -5.71827  NA    NA
f_cyan_ilr_1 0.68389  NA    NA
f_cyan_ilr_2 0.61027  NA    NA
f_JCZ38_qlogis 116.27482  NA    NA
log_alpha  -0.14484  NA    NA
log_beta    3.03220  NA    NA
a.1         3.11051  NA    NA
b.1         0.04508  NA    NA
SD.log_k_JCZ38 1.39961  NA    NA
SD.log_k_J9Z38 0.57920  NA    NA
SD.log_k_JSE76 0.68364  NA    NA
SD.f_cyan_ilr_1 0.31477  NA    NA

```

SD.f_cyan_ilr_2	0.37716	NA	NA
SD.f_JCZ38_qlogis	5.52695	NA	NA
SD.log_alpha	0.22823	NA	NA
SD.log_beta	0.39161	NA	NA

Correlation is not available

Random effects:

	est.	lower	upper
SD.log_k_JCZ38	1.3996	NA	NA
SD.log_k_J9Z38	0.5792	NA	NA
SD.log_k_JSE76	0.6836	NA	NA
SD.f_cyan_ilr_1	0.3148	NA	NA
SD.f_cyan_ilr_2	0.3772	NA	NA
SD.f_JCZ38_qlogis	5.5270	NA	NA
SD.log_alpha	0.2282	NA	NA
SD.log_beta	0.3916	NA	NA

Variance model:

	est.	lower	upper
a.1	3.11051	NA	NA
b.1	0.04508	NA	NA

Backtransformed parameters:

	est.	lower	upper
cyan_0	1.007e+02	NA	NA
k_JCZ38	3.150e-02	NA	NA
k_J9Z38	5.328e-03	NA	NA
k_JSE76	3.285e-03	NA	NA
f_cyan_to_JCZ38	5.980e-01	NA	NA
f_cyan_to_J9Z38	2.273e-01	NA	NA
f_JCZ38_to_JSE76	1.000e+00	NA	NA
alpha	8.652e-01	NA	NA
beta	2.074e+01	NA	NA

Resulting formation fractions:

	ff
cyan_JCZ38	0.5980
cyan_J9Z38	0.2273
cyan_sink	0.1746
JCZ38_JSE76	1.0000
JCZ38_sink	0.0000

Estimated disappearance times:

	DT50	DT90	DT50back
cyan	25.48	276.2	83.15
JCZ38	22.01	73.1	NA
J9Z38	130.09	432.2	NA
JSE76	210.98	700.9	NA

Listing 5: Hierarchical DFOP path 1 fit with constant variance

```

saemix version used for fitting:      3.3
mkin version used for pre-fitting:    1.2.9
R version used for fitting:           4.4.2
Date of fit:                          Thu Feb 13 18:33:28 2025
Date of summary:                      Thu Feb 13 19:05:54 2025

Equations:
d_cyan/dt = - ((k1 * g * exp(-k1 * time) + k2 * (1 - g) * exp(-k2 *
time)) / (g * exp(-k1 * time) + (1 - g) * exp(-k2 * time)))
* cyan
d_JCZ38/dt = + f_cyan_to_JCZ38 * ((k1 * g * exp(-k1 * time) + k2 * (1 -
g) * exp(-k2 * time)) / (g * exp(-k1 * time) + (1 - g) *
exp(-k2 * time))) * cyan - k_JCZ38 * JCZ38
d_J9Z38/dt = + f_cyan_to_J9Z38 * ((k1 * g * exp(-k1 * time) + k2 * (1 -
g) * exp(-k2 * time)) / (g * exp(-k1 * time) + (1 - g) *
exp(-k2 * time))) * cyan - k_J9Z38 * J9Z38
d_JSE76/dt = + f_JCZ38_to_JSE76 * k_JCZ38 * JCZ38 - k_JSE76 * JSE76

Data:
433 observations of 4 variable(s) grouped in 5 datasets

Model predictions using solution type deSolve

Fitted in 583.053 s
Using 300, 100 iterations and 10 chains

Variance model: Constant variance

Starting values for degradation parameters:
      cyan_0  log_k_JCZ38  log_k_J9Z38  log_k_JSE76  f_cyan_ilr_1
102.0643    -3.4008      -5.0024      -5.8612      0.6855
f_cyan_ilr_2 f_JCZ38_qlogis  log_k1      log_k2      g_qlogis
1.2366      13.6901      -1.8641      -4.5063      -0.6468

Fixed degradation parameter values:
None

Starting values for random effects (square root of initial entries in omega):
      cyan_0  log_k_JCZ38  log_k_J9Z38  log_k_JSE76  f_cyan_ilr_1
cyan_0      4.466      0.000      0.000      0.000      0.0000
log_k_JCZ38  0.000      2.382      0.000      0.000      0.0000
log_k_J9Z38  0.000      0.000      1.595      0.000      0.0000
log_k_JSE76  0.000      0.000      0.000      1.245      0.0000
f_cyan_ilr_1 0.000      0.000      0.000      0.000      0.6852
f_cyan_ilr_2 0.000      0.000      0.000      0.000      0.0000
f_JCZ38_qlogis 0.000      0.000      0.000      0.000      0.0000
log_k1      0.000      0.000      0.000      0.000      0.0000
log_k2      0.000      0.000      0.000      0.000      0.0000
g_qlogis    0.000      0.000      0.000      0.000      0.0000
      f_cyan_ilr_2  f_JCZ38_qlogis  log_k1  log_k2  g_qlogis
cyan_0      0.00      0.00  0.00  0.0000  0.0000  0.000
log_k_JCZ38  0.00      0.00  0.00  0.0000  0.0000  0.000
log_k_J9Z38  0.00      0.00  0.00  0.0000  0.0000  0.000
log_k_JSE76  0.00      0.00  0.00  0.0000  0.0000  0.000
f_cyan_ilr_1 0.00      0.00  0.00  0.0000  0.0000  0.000
f_cyan_ilr_2 0.00      1.28  0.00  0.0000  0.0000  0.000
f_JCZ38_qlogis 0.00      16.08  0.0000  0.0000  0.000
log_k1      0.00      0.00  0.9866  0.0000  0.000
log_k2      0.00      0.00  0.0000  0.5953  0.000
g_qlogis    0.00      0.00  0.0000  0.0000  1.583

Starting values for error model parameters:
a.1
1

Results:

Likelihood computed by importance sampling
      AIC  BIC  logLik
2403 2395 -1182

Optimised parameters:
      est.  lower  upper
cyan_0      102.5565  NA  NA
log_k_JCZ38  -3.4729  NA  NA
log_k_J9Z38  -5.1533  NA  NA
log_k_JSE76  -5.6669  NA  NA
f_cyan_ilr_1  0.6665  NA  NA
f_cyan_ilr_2  0.5191  NA  NA
f_JCZ38_qlogis 37.0113  NA  NA
log_k1      -1.8497  NA  NA
log_k2      -4.4931  NA  NA

```

g_qlogis	-0.6383	NA	NA
a.1	3.2397	NA	NA
SD.log_k_JCZ38	1.4286	NA	NA
SD.log_k_J9Z38	0.5312	NA	NA
SD.log_k_JSE76	0.6627	NA	NA
SD.f_cyan_ilr_1	0.3013	NA	NA
SD.f_cyan_ilr_2	0.2980	NA	NA
SD.f_JCZ38_qlogis	0.1637	NA	NA
SD.log_k1	0.5069	NA	NA
SD.log_k2	0.3828	NA	NA
SD.g_qlogis	0.8641	NA	NA

Correlation is not available

Random effects:

	est.	lower	upper
SD.log_k_JCZ38	1.4286	NA	NA
SD.log_k_J9Z38	0.5312	NA	NA
SD.log_k_JSE76	0.6627	NA	NA
SD.f_cyan_ilr_1	0.3013	NA	NA
SD.f_cyan_ilr_2	0.2980	NA	NA
SD.f_JCZ38_qlogis	0.1637	NA	NA
SD.log_k1	0.5069	NA	NA
SD.log_k2	0.3828	NA	NA
SD.g_qlogis	0.8641	NA	NA

Variance model:

	est.	lower	upper
a.1	3.24	NA	NA

Backtransformed parameters:

	est.	lower	upper
cyan_0	1.026e+02	NA	NA
k_JCZ38	3.103e-02	NA	NA
k_J9Z38	5.780e-03	NA	NA
k_JSE76	3.459e-03	NA	NA
f_cyan_to_JCZ38	5.813e-01	NA	NA
f_cyan_to_J9Z38	2.265e-01	NA	NA
f_JCZ38_to_JSE76	1.000e+00	NA	NA
k1	1.573e-01	NA	NA
k2	1.119e-02	NA	NA
g	3.456e-01	NA	NA

Resulting formation fractions:

	ff
cyan_JCZ38	0.5813
cyan_J9Z38	0.2265
cyan_sink	0.1922
JCZ38_JSE76	1.0000
JCZ38_sink	0.0000

Estimated disappearance times:

	DT50	DT90	DT50back	DT50_k1	DT50_k2
cyan	25.23	167.94	50.55	4.407	61.97
JCZ38	22.34	74.22	NA	NA	NA
J9Z38	119.92	398.36	NA	NA	NA
JSE76	200.41	665.76	NA	NA	NA

Listing 6: Hierarchical DFOP path 1 fit with two-component error

```

saemix version used for fitting:      3.3
mkin version used for pre-fitting:    1.2.9
R version used for fitting:           4.4.2
Date of fit:                          Thu Feb 13 18:37:24 2025
Date of summary:                      Thu Feb 13 19:05:54 2025

Equations:
d_cyan/dt = - ((k1 * g * exp(-k1 * time) + k2 * (1 - g) * exp(-k2 *
time)) / (g * exp(-k1 * time) + (1 - g) * exp(-k2 * time)))
* cyan
d_JCZ38/dt = + f_cyan_to_JCZ38 * ((k1 * g * exp(-k1 * time) + k2 * (1 -
g) * exp(-k2 * time)) / (g * exp(-k1 * time) + (1 - g) *
exp(-k2 * time))) * cyan - k_JCZ38 * JCZ38
d_J9Z38/dt = + f_cyan_to_J9Z38 * ((k1 * g * exp(-k1 * time) + k2 * (1 -
g) * exp(-k2 * time)) / (g * exp(-k1 * time) + (1 - g) *
exp(-k2 * time))) * cyan - k_J9Z38 * J9Z38
d_JSE76/dt = + f_JCZ38_to_JSE76 * k_JCZ38 * JCZ38 - k_JSE76 * JSE76

Data:
433 observations of 4 variable(s) grouped in 5 datasets

Model predictions using solution type deSolve

Fitted in 818.805 s
Using 300, 100 iterations and 10 chains

Variance model: Two-component variance function

Starting values for degradation parameters:
      cyan_0  log_k_JCZ38  log_k_J9Z38  log_k_JSE76  f_cyan_ilr_1
101.3964    -3.3626    -4.9792    -5.8727    0.6814
f_cyan_ilr_2 f_JCZ38_qlogis  log_k1  log_k2  g_qlogis
 6.8713    13.6901    -1.9222    -4.5035    -0.7172

Fixed degradation parameter values:
None

Starting values for random effects (square root of initial entries in omega):
cyan_0  log_k_JCZ38  log_k_J9Z38  log_k_JSE76  f_cyan_ilr_1
cyan_0  5.317  0.000  0.000  0.000  0.000  0.0000
log_k_JCZ38  0.000  2.272  0.000  0.000  0.000  0.0000
log_k_J9Z38  0.000  0.000  1.633  0.000  0.000  0.0000
log_k_JSE76  0.000  0.000  0.000  1.271  0.000  0.0000
f_cyan_ilr_1  0.000  0.000  0.000  0.000  0.000  0.6839
f_cyan_ilr_2  0.000  0.000  0.000  0.000  0.000  0.0000
f_JCZ38_qlogis  0.000  0.000  0.000  0.000  0.000  0.0000
log_k1  0.000  0.000  0.000  0.000  0.000  0.0000
log_k2  0.000  0.000  0.000  0.000  0.000  0.0000
g_qlogis  0.000  0.000  0.000  0.000  0.000  0.0000
      f_cyan_ilr_2  f_JCZ38_qlogis  log_k1  log_k2  g_qlogis
cyan_0  0.00  0.00  0.00  0.0000  0.0000  0.0000
log_k_JCZ38  0.00  0.00  0.00  0.0000  0.0000  0.0000
log_k_J9Z38  0.00  0.00  0.00  0.0000  0.0000  0.0000
log_k_JSE76  0.00  0.00  0.00  0.0000  0.0000  0.0000
f_cyan_ilr_1  0.00  0.00  0.00  0.0000  0.0000  0.0000
f_cyan_ilr_2  11.95  0.00  0.00  0.0000  0.0000  0.0000
f_JCZ38_qlogis  0.00  16.08  0.0000  0.0000  0.0000
log_k1  0.00  0.00  0.9496  0.0000  0.0000
log_k2  0.00  0.00  0.00  0.5846  0.0000
g_qlogis  0.00  0.00  0.00  0.0000  0.0000  1.719

Starting values for error model parameters:
a.1 b.1
 1  1

Results:

Likelihood computed by importance sampling
      AIC  BIC  logLik
2398 2390 -1179

Optimised parameters:
      est.  lower  upper
cyan_0  100.69709  NA  NA
log_k_JCZ38  -3.46669  NA  NA
log_k_J9Z38  -5.05076  NA  NA
log_k_JSE76  -5.55558  NA  NA
f_cyan_ilr_1  0.66045  NA  NA
f_cyan_ilr_2  0.84275  NA  NA
f_JCZ38_qlogis  64.22404  NA  NA
log_k1  -2.17715  NA  NA
log_k2  -4.55002  NA  NA

```

g_qlogis	-0.55920	NA	NA
a.1	2.95785	NA	NA
b.1	0.04456	NA	NA
SD.log_k_JCZ38	1.39881	NA	NA
SD.log_k_J9Z38	0.67788	NA	NA
SD.log_k_JSE76	0.52603	NA	NA
SD.f_cyan_ilr_1	0.32490	NA	NA
SD.f_cyan_ilr_2	0.53923	NA	NA
SD.f_JCZ38_qlogis	2.75576	NA	NA
SD.log_k2	0.30694	NA	NA
SD.g_qlogis	0.83619	NA	NA

Correlation is not available

Random effects:

	est.	lower	upper
SD.log_k_JCZ38	1.3988	NA	NA
SD.log_k_J9Z38	0.6779	NA	NA
SD.log_k_JSE76	0.5260	NA	NA
SD.f_cyan_ilr_1	0.3249	NA	NA
SD.f_cyan_ilr_2	0.5392	NA	NA
SD.f_JCZ38_qlogis	2.7558	NA	NA
SD.log_k2	0.3069	NA	NA
SD.g_qlogis	0.8362	NA	NA

Variance model:

	est.	lower	upper
a.1	2.95785	NA	NA
b.1	0.04456	NA	NA

Backtransformed parameters:

	est.	lower	upper
cyan_0	1.007e+02	NA	NA
k_JCZ38	3.122e-02	NA	NA
k_J9Z38	6.404e-03	NA	NA
k_JSE76	3.866e-03	NA	NA
f_cyan_to_JCZ38	6.187e-01	NA	NA
f_cyan_to_J9Z38	2.431e-01	NA	NA
f_JCZ38_to_JSE76	1.000e+00	NA	NA
k1	1.134e-01	NA	NA
k2	1.057e-02	NA	NA
g	3.637e-01	NA	NA

Resulting formation fractions:

	ff
cyan_JCZ38	0.6187
cyan_J9Z38	0.2431
cyan_sink	0.1382
JCZ38_JSE76	1.0000
JCZ38_sink	0.0000

Estimated disappearance times:

	DT50	DT90	DT50back	DT50_k1	DT50_k2
cyan	26.35	175.12	52.72	6.114	65.6
JCZ38	22.20	73.75	NA	NA	NA
J9Z38	108.23	359.53	NA	NA	NA
JSE76	179.30	595.62	NA	NA	NA

Listing 7: Hierarchical SFORB path 1 fit with constant variance

```

saemix version used for fitting:      3.3
mkin version used for pre-fitting:    1.2.9
R version used for fitting:          4.4.2
Date of fit:      Thu Feb 13 18:32:56 2025
Date of summary:  Thu Feb 13 19:05:54 2025

Equations:
d_cyan_free/dt = - k_cyan_free * cyan_free - k_cyan_free_bound *
                cyan_free + k_cyan_bound_free * cyan_bound
d_cyan_bound/dt = + k_cyan_free_bound * cyan_free - k_cyan_bound_free *
                cyan_bound
d_JCZ38/dt = + f_cyan_free_to_JCZ38 * k_cyan_free * cyan_free - k_JCZ38
                * JCZ38
d_J9Z38/dt = + f_cyan_free_to_J9Z38 * k_cyan_free * cyan_free - k_J9Z38
                * J9Z38
d_JSE76/dt = + f_JCZ38_to_JSE76 * k_JCZ38 * JCZ38 - k_JSE76 * JSE76

Data:
433 observations of 4 variable(s) grouped in 5 datasets

Model predictions using solution type deSolve

Fitted in 551.176 s
Using 300, 100 iterations and 10 chains

Variance model: Constant variance

Starting values for degradation parameters:
cyan_free_0      log_k_cyan_free log_k_cyan_free_bound
102.0643         -2.8987         -2.7077
log_k_cyan_bound_free      log_k_JCZ38      log_k_J9Z38
-3.4717          -3.4008          -5.0024
log_k_JSE76      f_cyan_ilr_1      f_cyan_ilr_2
-5.8613         0.6855         1.2366
f_JCZ38_qlogis
13.7395

Fixed degradation parameter values:
None

Starting values for random effects (square root of initial entries in omega):
cyan_free_0      log_k_cyan_free log_k_cyan_free_bound
4.466            0.0000            0.000
log_k_cyan_free  0.000            0.6158            0.000
log_k_cyan_bound_free      0.000            0.0000            1.463
log_k_cyan_bound_free      0.000            0.0000            0.000
log_k_JCZ38      0.000            0.0000            0.000
log_k_J9Z38      0.000            0.0000            0.000
log_k_JSE76      0.000            0.0000            0.000
f_cyan_ilr_1     0.000            0.0000            0.000
f_cyan_ilr_2     0.000            0.0000            0.000
f_JCZ38_qlogis  0.000            0.0000            0.000
log_k_cyan_bound_free      log_k_JCZ38 log_k_J9Z38 log_k_JSE76
cyan_free_0      0.000            0.000            0.000            0.000
log_k_cyan_free  0.000            0.000            0.000            0.000
log_k_cyan_bound_free      0.000            0.000            0.000            0.000
log_k_cyan_bound_free      1.058            0.000            0.000            0.000
log_k_JCZ38      0.000            2.382            0.000            0.000
log_k_J9Z38      0.000            0.000            1.595            0.000
log_k_JSE76      0.000            0.000            0.000            1.245
f_cyan_ilr_1     0.000            0.000            0.000            0.000
f_cyan_ilr_2     0.000            0.000            0.000            0.000
f_JCZ38_qlogis  0.000            0.000            0.000            0.000
f_cyan_ilr_1     f_cyan_ilr_2 f_JCZ38_qlogis
cyan_free_0      0.0000            0.00            0.00
log_k_cyan_free  0.0000            0.00            0.00
log_k_cyan_bound_free      0.0000            0.00            0.00
log_k_cyan_bound_free      0.0000            0.00            0.00
log_k_JCZ38      0.0000            0.00            0.00
log_k_J9Z38      0.0000            0.00            0.00
log_k_JSE76      0.0000            0.00            0.00
f_cyan_ilr_1     0.6852            0.00            0.00
f_cyan_ilr_2     0.0000            1.28            0.00
f_JCZ38_qlogis  0.0000            0.00            16.13

Starting values for error model parameters:
a.1
1

Results:
Likelihood computed by importance sampling

```

AIC BIC logLik
2401 2394 -1181

Optimised parameters:

	est.	lower	upper
cyan_free_0	102.8136	NA	NA
log_k_cyan_free	-2.7935	NA	NA
log_k_cyan_free_bound	-2.5440	NA	NA
log_k_cyan_bound_free	-3.4303	NA	NA
log_k_JCZ38	-3.5010	NA	NA
log_k_J9Z38	-5.1226	NA	NA
log_k_JSE76	-5.6314	NA	NA
f_cyan_ilr_1	0.6609	NA	NA
f_cyan_ilr_2	0.5085	NA	NA
f_JCZ38_qlogis	44.0153	NA	NA
a.1	3.2318	NA	NA
SD.log_k_cyan_free	0.3211	NA	NA
SD.log_k_cyan_free_bound	0.8408	NA	NA
SD.log_k_cyan_bound_free	0.5724	NA	NA
SD.log_k_JCZ38	1.4925	NA	NA
SD.log_k_J9Z38	0.5816	NA	NA
SD.log_k_JSE76	0.6037	NA	NA
SD.f_cyan_ilr_1	0.3115	NA	NA
SD.f_cyan_ilr_2	0.3436	NA	NA
SD.f_JCZ38_qlogis	4.8937	NA	NA

Correlation is not available

Random effects:

	est.	lower	upper
SD.log_k_cyan_free	0.3211	NA	NA
SD.log_k_cyan_free_bound	0.8408	NA	NA
SD.log_k_cyan_bound_free	0.5724	NA	NA
SD.log_k_JCZ38	1.4925	NA	NA
SD.log_k_J9Z38	0.5816	NA	NA
SD.log_k_JSE76	0.6037	NA	NA
SD.f_cyan_ilr_1	0.3115	NA	NA
SD.f_cyan_ilr_2	0.3436	NA	NA
SD.f_JCZ38_qlogis	4.8937	NA	NA

Variance model:

	est.	lower	upper
a.1	3.232	NA	NA

Backtransformed parameters:

	est.	lower	upper
cyan_free_0	1.028e+02	NA	NA
k_cyan_free	6.120e-02	NA	NA
k_cyan_free_bound	7.855e-02	NA	NA
k_cyan_bound_free	3.238e-02	NA	NA
k_JCZ38	3.017e-02	NA	NA
k_J9Z38	5.961e-03	NA	NA
k_JSE76	3.584e-03	NA	NA
f_cyan_free_to_JCZ38	5.784e-01	NA	NA
f_cyan_free_to_J9Z38	2.271e-01	NA	NA
f_JCZ38_to_JSE76	1.000e+00	NA	NA

Estimated Eigenvalues of SFORB model(s):

	cyan_b1	cyan_b2	cyan_g
	0.15973	0.01241	0.33124

Resulting formation fractions:

	ff
cyan_free_JCZ38	0.5784
cyan_free_J9Z38	0.2271
cyan_free_sink	0.1945
cyan_free	1.0000
JCZ38_JSE76	1.0000
JCZ38_sink	0.0000

Estimated disappearance times:

	DT50	DT90	DT50back	DT50_cyan_b1	DT50_cyan_b2
cyan	24.51	153.18	46.11	4.34	55.87
JCZ38	22.98	76.33	NA	NA	NA
J9Z38	116.28	386.29	NA	NA	NA
JSE76	193.42	642.53	NA	NA	NA

Listing 8: Hierarchical SFORB path 1 fit with two-component error

```

saemix version used for fitting:      3.3
mkin version used for pre-fitting:    1.2.9
R version used for fitting:           4.4.2
Date of fit:                          Thu Feb 13 18:36:44 2025
Date of summary:                      Thu Feb 13 19:05:54 2025

Equations:
d_cyan_free/dt = - k_cyan_free * cyan_free - k_cyan_free_bound *
                cyan_free + k_cyan_bound_free * cyan_bound
d_cyan_bound/dt = + k_cyan_free_bound * cyan_free - k_cyan_bound_free *
                cyan_bound
d_JCZ38/dt = + f_cyan_free_to_JCZ38 * k_cyan_free * cyan_free - k_JCZ38
                * JCZ38
d_J9Z38/dt = + f_cyan_free_to_J9Z38 * k_cyan_free * cyan_free - k_J9Z38
                * J9Z38
d_JSE76/dt = + f_JCZ38_to_JSE76 * k_JCZ38 * JCZ38 - k_JSE76 * JSE76

Data:
433 observations of 4 variable(s) grouped in 5 datasets

Model predictions using solution type deSolve

Fitted in 778.828 s
Using 300, 100 iterations and 10 chains

Variance model: Two-component variance function

Starting values for degradation parameters:
cyan_free_0      log_k_cyan_free log_k_cyan_free_bound
101.3964         -2.9881         -2.7949
log_k_cyan_bound_free  log_k_JCZ38      log_k_J9Z38
-3.4376         -3.3626         -4.9792
log_k_JSE76      f_cyan_ilr_1    f_cyan_ilr_2
-5.8727         0.6814         6.7399
f_JCZ38_qlogis
13.7395

Fixed degradation parameter values:
None

Starting values for random effects (square root of initial entries in omega):
cyan_free_0      log_k_cyan_free log_k_cyan_free_bound
5.317            0.000          0.000
log_k_cyan_free  0.000          0.7301         0.000
log_k_cyan_bound_free  0.000          0.0000         1.384
log_k_cyan_bound_free  0.000          0.0000         0.000
log_k_JCZ38      0.000          0.0000         0.000
log_k_J9Z38      0.000          0.0000         0.000
log_k_JSE76      0.000          0.0000         0.000
f_cyan_ilr_1     0.000          0.0000         0.000
f_cyan_ilr_2     0.000          0.0000         0.000
f_JCZ38_qlogis   0.000          0.0000         0.000
log_k_cyan_bound_free  log_k_JCZ38 log_k_J9Z38 log_k_JSE76
cyan_free_0      0.000          0.000          0.000          0.000
log_k_cyan_free  0.000          0.000          0.000          0.000
log_k_cyan_bound_free  0.000          0.000          0.000          0.000
log_k_cyan_bound_free  1.109          0.000          0.000          0.000
log_k_JCZ38      0.000          2.272          0.000          0.000
log_k_J9Z38      0.000          0.000          1.633          0.000
log_k_JSE76      0.000          0.000          0.000          1.271
f_cyan_ilr_1     0.000          0.000          0.000          0.000
f_cyan_ilr_2     0.000          0.000          0.000          0.000
f_JCZ38_qlogis   0.000          0.000          0.000          0.000
f_cyan_ilr_1     f_cyan_ilr_2 f_JCZ38_qlogis
cyan_free_0      0.0000          0.00          0.00
log_k_cyan_free  0.0000          0.00          0.00
log_k_cyan_bound_free  0.0000          0.00          0.00
log_k_cyan_bound_free  0.0000          0.00          0.00
log_k_JCZ38      0.0000          0.00          0.00
log_k_J9Z38      0.0000          0.00          0.00
log_k_JSE76      0.0000          0.00          0.00
f_cyan_ilr_1     0.6838          0.00          0.00
f_cyan_ilr_2     0.0000          11.69         0.00
f_JCZ38_qlogis   0.0000          0.00          16.13

Starting values for error model parameters:
a.1 b.1
1 1

Results:

Likelihood computed by importance sampling

```

AIC BIC logLik
 2400 2392 -1180

Optimised parameters:

	est.	lower	upper
cyan_free_0	100.56004	NA	NA
log_k_cyan_free	-3.12657	NA	NA
log_k_cyan_free_bound	-3.16825	NA	NA
log_k_cyan_bound_free	-3.66003	NA	NA
log_k_JCZ38	-3.47278	NA	NA
log_k_J9Z38	-5.06823	NA	NA
log_k_JSE76	-5.54327	NA	NA
f_cyan_ilr_1	0.66631	NA	NA
f_cyan_ilr_2	0.82898	NA	NA
f_JCZ38_qlogis	38.31115	NA	NA
a.1	2.98352	NA	NA
b.1	0.04388	NA	NA
SD.log_k_cyan_free	0.49145	NA	NA
SD.log_k_cyan_bound_free	0.27347	NA	NA
SD.log_k_JCZ38	1.41193	NA	NA
SD.log_k_J9Z38	0.66073	NA	NA
SD.log_k_JSE76	0.55885	NA	NA
SD.f_cyan_ilr_1	0.33020	NA	NA
SD.f_cyan_ilr_2	0.51367	NA	NA
SD.f_JCZ38_qlogis	5.52122	NA	NA

Correlation is not available

Random effects:

	est.	lower	upper
SD.log_k_cyan_free	0.4914	NA	NA
SD.log_k_cyan_bound_free	0.2735	NA	NA
SD.log_k_JCZ38	1.4119	NA	NA
SD.log_k_J9Z38	0.6607	NA	NA
SD.log_k_JSE76	0.5589	NA	NA
SD.f_cyan_ilr_1	0.3302	NA	NA
SD.f_cyan_ilr_2	0.5137	NA	NA
SD.f_JCZ38_qlogis	5.5212	NA	NA

Variance model:

	est.	lower	upper
a.1	2.98352	NA	NA
b.1	0.04388	NA	NA

Backtransformed parameters:

	est.	lower	upper
cyan_free_0	1.006e+02	NA	NA
k_cyan_free	4.387e-02	NA	NA
k_cyan_free_bound	4.208e-02	NA	NA
k_cyan_bound_free	2.573e-02	NA	NA
k_JCZ38	3.103e-02	NA	NA
k_J9Z38	6.294e-03	NA	NA
k_JSE76	3.914e-03	NA	NA
f_cyan_free_to_JCZ38	6.188e-01	NA	NA
f_cyan_free_to_J9Z38	2.412e-01	NA	NA
f_JCZ38_to_JSE76	1.000e+00	NA	NA

Estimated Eigenvalues of SFORB model(s):

cyan_b1	cyan_b2	cyan_g
0.10044	0.01124	0.36580

Resulting formation fractions:

	ff
cyan_free_JCZ38	0.6188
cyan_free_J9Z38	0.2412
cyan_free_sink	0.1400
cyan_free	1.0000
JCZ38_JSE76	1.0000
JCZ38_sink	0.0000

Estimated disappearance times:

	DT50	DT90	DT50back	DT50_cyan_b1	DT50_cyan_b2
cyan	26.05	164.4	49.48	6.901	61.67
JCZ38	22.34	74.2	NA	NA	NA
J9Z38	110.14	365.9	NA	NA	NA
JSE76	177.11	588.3	NA	NA	NA

Listing 9: Hierarchical HS path 1 fit with constant variance

```

saemix version used for fitting:      3.3
mkin version used for pre-fitting:    1.2.9
R version used for fitting:           4.4.2
Date of fit:                          Thu Feb 13 18:33:28 2025
Date of summary:                      Thu Feb 13 19:05:54 2025

Equations:
d_cyan/dt = - ifelse(time <= tb, k1, k2) * cyan
d_JCZ38/dt = + f_cyan_to_JCZ38 * ifelse(time <= tb, k1, k2) * cyan -
             k_JCZ38 * JCZ38
d_J9Z38/dt = + f_cyan_to_J9Z38 * ifelse(time <= tb, k1, k2) * cyan -
             k_J9Z38 * J9Z38
d_JSE76/dt = + f_JCZ38_to_JSE76 * k_JCZ38 * JCZ38 - k_JSE76 * JSE76

Data:
433 observations of 4 variable(s) grouped in 5 datasets

Model predictions using solution type deSolve

Fitted in 583.355 s
Using 300, 100 iterations and 10 chains

Variance model: Constant variance

Starting values for degradation parameters:
      cyan_0  log_k_JCZ38  log_k_J9Z38  log_k_JSE76  f_cyan_ilr_1
102.8845    -3.4495    -4.9355    -5.6040    0.6468
  f_cyan_ilr_2 f_JCZ38_qlogis      log_k1      log_k2      log_tb
  1.2396      9.7220    -2.9079    -4.1810    1.7813

Fixed degradation parameter values:
None

Starting values for random effects (square root of initial entries in omega):
      cyan_0  log_k_JCZ38  log_k_J9Z38  log_k_JSE76  f_cyan_ilr_1
5.406      0.00      0.00      0.00      0.000      0.0000
log_k_JCZ38 0.000      2.33      0.00      0.00      0.000      0.0000
log_k_J9Z38 0.000      0.00      1.59      0.00      0.000      0.0000
log_k_JSE76 0.000      0.00      0.00      1.013     0.000      0.0000
f_cyan_ilr_1 0.000      0.00      0.00      0.00      0.000      0.6367
f_cyan_ilr_2 0.000      0.00      0.00      0.00      0.000      0.0000
f_JCZ38_qlogis 0.000      0.00      0.00      0.00      0.000      0.0000
log_k1      0.000      0.00      0.00      0.00      0.000      0.0000
log_k2      0.000      0.00      0.00      0.00      0.000      0.0000
log_tb      0.000      0.00      0.00      0.00      0.000      0.0000
      f_cyan_ilr_2 f_JCZ38_qlogis log_k1 log_k2 log_tb
cyan_0      0.000      0.00 0.0000 0.0000 0.0000
log_k_JCZ38 0.000      0.00 0.0000 0.0000 0.0000
log_k_J9Z38 0.000      0.00 0.0000 0.0000 0.0000
log_k_JSE76 0.000      0.00 0.0000 0.0000 0.0000
f_cyan_ilr_1 0.000      0.00 0.0000 0.0000 0.0000
f_cyan_ilr_2 2.038      0.00 0.0000 0.0000 0.0000
f_JCZ38_qlogis 0.000      10.33 0.0000 0.0000 0.0000
log_k1      0.000      0.00 0.7006 0.0000 0.0000
log_k2      0.000      0.00 0.0000 0.8928 0.0000
log_tb      0.000      0.00 0.0000 0.0000 0.6773

Starting values for error model parameters:
a.1
1

Results:

Likelihood computed by importance sampling
  AIC  BIC  logLik
2427 2419 -1194

Optimised parameters:
      est.      lower      upper
cyan_0      101.9660  1.005e+02  1.035e+02
log_k_JCZ38  -3.4698  -4.716e+00  -2.224e+00
log_k_J9Z38  -5.0947  -5.740e+00  -4.450e+00
log_k_JSE76  -5.5977  -6.321e+00  -4.875e+00
f_cyan_ilr_1  0.6595  3.734e-01  9.456e-01
f_cyan_ilr_2  0.5905  1.664e-01  1.015e+00
f_JCZ38_qlogis 25.8627  -4.224e+05  4.225e+05
log_k1      -3.0884  -3.453e+00  -2.723e+00
log_k2      -4.3877  -4.778e+00  -3.998e+00
log_tb      2.3057  1.715e+00  2.896e+00
a.1         3.3228      NA      NA
SD.log_k_JCZ38 1.4071      NA      NA
SD.log_k_J9Z38 0.5774      NA      NA

```

SD.log_k_JSE76	0.6214	NA	NA
SD.f_cyan_ilr_1	0.3058	NA	NA
SD.f_cyan_ilr_2	0.3470	NA	NA
SD.f_JCZ38_qlogis	0.0644	NA	NA
SD.log_k1	0.3994	NA	NA
SD.log_k2	0.4373	NA	NA
SD.log_tb	0.6419	NA	NA

Correlation is not available

Random effects:

	est.	lower	upper
SD.log_k_JCZ38	1.4071	NA	NA
SD.log_k_J9Z38	0.5774	NA	NA
SD.log_k_JSE76	0.6214	NA	NA
SD.f_cyan_ilr_1	0.3058	NA	NA
SD.f_cyan_ilr_2	0.3470	NA	NA
SD.f_JCZ38_qlogis	0.0644	NA	NA
SD.log_k1	0.3994	NA	NA
SD.log_k2	0.4373	NA	NA
SD.log_tb	0.6419	NA	NA

Variance model:

	est.	lower	upper
a.1	3.323	NA	NA

Backtransformed parameters:

	est.	lower	upper
cyan_0	1.020e+02	1.005e+02	1.035e+02
k_JCZ38	3.112e-02	8.951e-03	1.082e-01
k_J9Z38	6.129e-03	3.216e-03	1.168e-02
k_JSE76	3.706e-03	1.798e-03	7.639e-03
f_cyan_to_JCZ38	5.890e-01	NA	NA
f_cyan_to_J9Z38	2.318e-01	NA	NA
f_JCZ38_to_JSE76	1.000e+00	0.000e+00	1.000e+00
k1	4.558e-02	3.164e-02	6.565e-02
k2	1.243e-02	8.417e-03	1.835e-02
tb	1.003e+01	5.557e+00	1.811e+01

Resulting formation fractions:

	ff
cyan_JCZ38	5.890e-01
cyan_J9Z38	2.318e-01
cyan_sink	1.793e-01
JCZ38_JSE76	1.000e+00
JCZ38_sink	5.861e-12

Estimated disappearance times:

	DT50	DT90	DT50back	DT50_k1	DT50_k2
cyan	29.02	158.51	47.72	15.21	55.77
JCZ38	22.27	73.98	NA	NA	NA
J9Z38	113.09	375.69	NA	NA	NA
JSE76	187.01	621.23	NA	NA	NA

Pathway 2

Listing 10: Hierarchical FOMC path 2 fit with two-component error

```

saemix version used for fitting: 3.3
mkin version used for pre-fitting: 1.2.9
R version used for fitting: 4.4.2
Date of fit: Thu Feb 13 18:46:09 2025
Date of summary: Thu Feb 13 19:05:54 2025

Equations:
d_cyan/dt = - (alpha/beta) * 1/((time/beta) + 1) * cyan
d_JCZ38/dt = + f_cyan_to_JCZ38 * (alpha/beta) * 1/((time/beta) + 1) *
cyan - k_JCZ38 * JCZ38 + f_JSE76_to_JCZ38 * k_JSE76 * JSE76
d_J9Z38/dt = + f_cyan_to_J9Z38 * (alpha/beta) * 1/((time/beta) + 1) *
cyan - k_J9Z38 * J9Z38
d_JSE76/dt = + f_JCZ38_to_JSE76 * k_JCZ38 * JCZ38 - k_JSE76 * JSE76

Data:
433 observations of 4 variable(s) grouped in 5 datasets

Model predictions using solution type deSolve

Fitted in 513.642 s
Using 300, 100 iterations and 10 chains

Variance model: Two-component variance function

Starting values for degradation parameters:
cyan_0 log_k_JCZ38 log_k_J9Z38 log_k_JSE76 f_cyan_ilr_1
102.4477 -1.8631 -5.1087 -2.5114 0.6826
f_cyan_ilr_2 f_JCZ38_qlogis f_JSE76_qlogis log_alpha log_beta
4.7944 15.9616 13.1566 -0.1564 2.9781

Fixed degradation parameter values:
None

Starting values for random effects (square root of initial entries in omega):
cyan_0 log_k_JCZ38 log_k_J9Z38 log_k_JSE76 f_cyan_ilr_1
cyan_0 7.701 0.000 0.000 0.000 0.000 0.0000
log_k_JCZ38 0.000 1.448 0.000 0.000 0.000 0.0000
log_k_J9Z38 0.000 0.000 1.724 0.000 0.000 0.0000
log_k_JSE76 0.000 0.000 0.000 3.659 0.000 0.0000
f_cyan_ilr_1 0.000 0.000 0.000 0.000 0.000 0.6356
f_cyan_ilr_2 0.000 0.000 0.000 0.000 0.000 0.0000
f_JCZ38_qlogis 0.000 0.000 0.000 0.000 0.000 0.0000
f_JSE76_qlogis 0.000 0.000 0.000 0.000 0.000 0.0000
log_alpha 0.000 0.000 0.000 0.000 0.000 0.0000
log_beta 0.000 0.000 0.000 0.000 0.000 0.0000
f_cyan_ilr_2 f_JCZ38_qlogis f_JSE76_qlogis log_alpha log_beta
cyan_0 0.00 0.00 0.00 0.00 0.0000 0.0000
log_k_JCZ38 0.00 0.00 0.00 0.00 0.0000 0.0000
log_k_J9Z38 0.00 0.00 0.00 0.00 0.0000 0.0000
log_k_JSE76 0.00 0.00 0.00 0.00 0.0000 0.0000
f_cyan_ilr_1 0.00 0.00 0.00 0.00 0.0000 0.0000
f_cyan_ilr_2 10.32 0.00 0.00 0.00 0.0000 0.0000
f_JCZ38_qlogis 0.00 12.23 0.00 0.00 0.0000 0.0000
f_JSE76_qlogis 0.00 0.00 14.99 0.0000 0.0000
log_alpha 0.00 0.00 0.00 0.3924 0.0000
log_beta 0.00 0.00 0.00 0.0000 0.5639

Starting values for error model parameters:
a.1 b.1
1 1

Results:

Likelihood computed by importance sampling
AIC BIC logLik
2249 2241 -1104

Optimised parameters:
est. lower upper
cyan_0 101.55265 9.920e+01 103.9059
log_k_JCZ38 -2.32302 -2.832e+00 -1.8142
log_k_J9Z38 -5.13082 -5.942e+00 -4.3199
log_k_JSE76 -3.01756 -4.262e+00 -1.7736
f_cyan_ilr_1 0.70850 3.657e-01 1.0513
f_cyan_ilr_2 0.95775 2.612e-01 1.6543
f_JCZ38_qlogis 3.86105 9.248e-01 6.7973
f_JSE76_qlogis 7.51583 -1.120e+02 127.0392
log_alpha -0.15308 -4.508e-01 0.1446
log_beta 2.99165 2.711e+00 3.2720
a.1 2.04034 1.843e+00 2.2382

```

b.1	0.06924	5.749e-02	0.0810
SD.log_k_JCZ38	0.50818	1.390e-01	0.8774
SD.log_k_J9Z38	0.86597	2.652e-01	1.4667
SD.log_k_JSE76	1.38092	4.864e-01	2.2754
SD.f_cyan_ilr_1	0.38204	1.354e-01	0.6286
SD.f_cyan_ilr_2	0.55129	7.198e-02	1.0306
SD.f_JCZ38_qlogis	1.88457	1.711e-02	3.7520
SD.f_JSE76_qlogis	2.64018	-2.450e+03	2454.9447
SD.log_alpha	0.31860	1.047e-01	0.5325
SD.log_beta	0.24195	1.273e-02	0.4712

Correlation:

	cyan_0	1__JCZ3	1__J9Z3	1__JSE7	f_cy__1	f_cy__2	f_JCZ38	f_JSE76
log_k_JCZ38	-0.0235							
log_k_J9Z38	-0.0442	0.0047						
log_k_JSE76	-0.0023	0.0966	0.0006					
f_cyan_ilr_1	-0.0032	0.0070	-0.0536	-0.0001				
f_cyan_ilr_2	-0.5189	0.0452	0.1152	0.0013	-0.0304			
f_JCZ38_qlogis	0.1088	-0.0848	-0.0240	0.0040	-0.0384	-0.2303		
f_JSE76_qlogis	-0.0545	0.1315	0.0195	0.0020	0.0252	0.1737	-0.5939	
log_alpha	-0.0445	0.0056	0.0261	0.0019	-0.0055	0.0586	-0.0239	-0.0284
log_beta	-0.2388	0.0163	0.0566	0.0040	-0.0078	0.2183	-0.0714	-0.0332
	log_lph							

log_k_JCZ38	
log_k_J9Z38	
log_k_JSE76	
f_cyan_ilr_1	
f_cyan_ilr_2	
f_JCZ38_qlogis	
f_JSE76_qlogis	
log_alpha	
log_beta	0.2135

Random effects:

	est.	lower	upper
SD.log_k_JCZ38	0.5082	1.390e-01	0.8774
SD.log_k_J9Z38	0.8660	2.652e-01	1.4667
SD.log_k_JSE76	1.3809	4.864e-01	2.2754
SD.f_cyan_ilr_1	0.3820	1.354e-01	0.6286
SD.f_cyan_ilr_2	0.5513	7.198e-02	1.0306
SD.f_JCZ38_qlogis	1.8846	1.711e-02	3.7520
SD.f_JSE76_qlogis	2.6402	-2.450e+03	2454.9447
SD.log_alpha	0.3186	1.047e-01	0.5325
SD.log_beta	0.2420	1.273e-02	0.4712

Variance model:

	est.	lower	upper
a.1	2.04034	1.84252	2.238
b.1	0.06924	0.05749	0.081

Backtransformed parameters:

	est.	lower	upper
cyan_0	1.016e+02	9.920e+01	103.9059
k_JCZ38	9.798e-02	5.890e-02	0.1630
k_J9Z38	5.912e-03	2.627e-03	0.0133
k_JSE76	4.892e-02	1.410e-02	0.1697
f_cyan_to_JCZ38	6.432e-01	NA	NA
f_cyan_to_J9Z38	2.362e-01	NA	NA
f_JCZ38_to_JSE76	9.794e-01	7.160e-01	0.9989
f_JSE76_to_JCZ38	9.995e-01	2.268e-49	1.0000
alpha	8.581e-01	6.371e-01	1.1556
beta	1.992e+01	1.505e+01	26.3646

Resulting formation fractions:

	ff
cyan_JCZ38	0.6432301
cyan_J9Z38	0.2361657
cyan_sink	0.1206042
JCZ38_JSE76	0.9793879
JCZ38_sink	0.0206121
JSE76_JCZ38	0.9994559
JSE76_sink	0.0005441

Estimated disappearance times:

	DT50	DT90	DT50back
cyan	24.759	271.61	81.76
JCZ38	7.075	23.50	NA
J9Z38	117.249	389.49	NA
JSE76	14.169	47.07	NA

Listing 11: Hierarchical DFOP path 2 fit with constant variance

```

saemix version used for fitting:      3.3
mkin version used for pre-fitting:    1.2.9
R version used for fitting:           4.4.2
Date of fit:                          Thu Feb 13 18:47:03 2025
Date of summary:                      Thu Feb 13 19:05:54 2025

Equations:
d_cyan/dt = - ((k1 * g * exp(-k1 * time) + k2 * (1 - g) * exp(-k2 *
time)) / (g * exp(-k1 * time) + (1 - g) * exp(-k2 * time)))
* cyan
d_JCZ38/dt = + f_cyan_to_JCZ38 * ((k1 * g * exp(-k1 * time) + k2 * (1 -
g) * exp(-k2 * time)) / (g * exp(-k1 * time) + (1 - g) *
exp(-k2 * time))) * cyan - k_JCZ38 * JCZ38 +
f_JSE76_to_JCZ38 * k_JSE76 * JSE76
d_J9Z38/dt = + f_cyan_to_J9Z38 * ((k1 * g * exp(-k1 * time) + k2 * (1 -
g) * exp(-k2 * time)) / (g * exp(-k1 * time) + (1 - g) *
exp(-k2 * time))) * cyan - k_J9Z38 * J9Z38
d_JSE76/dt = + f_JCZ38_to_JSE76 * k_JCZ38 * JCZ38 - k_JSE76 * JSE76

Data:
433 observations of 4 variable(s) grouped in 5 datasets

Model predictions using solution type deSolve

Fitted in 567.679 s
Using 300, 100 iterations and 10 chains

Variance model: Constant variance

Starting values for degradation parameters:
cyan_0      log_k_JCZ38      log_k_J9Z38      log_k_JSE76      f_cyan_ilr_1
102.4380    -2.3107                -5.3123                -3.7120                0.6757
f_cyan_ilr_2 f_JCZ38_qlogis f_JSE76_qlogis      log_k1            log_k2
1.1439      13.1194                12.3492                -1.9317                -4.4557
g_qlogis
-0.5644

Fixed degradation parameter values:
None

Starting values for random effects (square root of initial entries in omega):
cyan_0      log_k_JCZ38      log_k_J9Z38      log_k_JSE76      f_cyan_ilr_1
4.591       0.0000           0.000           0.0              0.0000
log_k_JCZ38 0.000           0.7966           0.000           0.0              0.0000
log_k_J9Z38 0.000           0.0000           1.561           0.0              0.0000
log_k_JSE76 0.000           0.0000           0.000           0.8              0.0000
f_cyan_ilr_1 0.000           0.0000           0.000           0.0              0.6349
f_cyan_ilr_2 0.000           0.0000           0.000           0.0              0.0000
f_JCZ38_qlogis 0.000           0.0000           0.000           0.0              0.0000
f_JSE76_qlogis 0.000           0.0000           0.000           0.0              0.0000
log_k1       0.000           0.0000           0.000           0.0              0.0000
log_k2       0.000           0.0000           0.000           0.0              0.0000
g_qlogis     0.000           0.0000           0.000           0.0              0.0000
f_cyan_ilr_2 f_JCZ38_qlogis f_JSE76_qlogis      log_k1      log_k2
cyan_0       0.000           0.00           0.00           0.00           0.0000 0.0000
log_k_JCZ38 0.000           0.00           0.00           0.00           0.0000 0.0000
log_k_J9Z38 0.000           0.00           0.00           0.00           0.0000 0.0000
log_k_JSE76 0.000           0.00           0.00           0.00           0.0000 0.0000
f_cyan_ilr_1 0.000           0.00           0.00           0.00           0.0000 0.0000
f_cyan_ilr_2 0.000           1.797           0.00           0.00           0.0000 0.0000
f_JCZ38_qlogis 0.000           13.86           0.00           0.00           0.0000 0.0000
f_JSE76_qlogis 0.000           0.00           13.91           0.00           0.0000 0.0000
log_k1       0.000           0.00           0.00           1.106           0.0000 0.0000
log_k2       0.000           0.00           0.00           0.00           0.6141 0.0000
g_qlogis     0.000           0.00           0.00           0.00           0.0000 0.0000
g_qlogis     g_qlogis
cyan_0       0.000
log_k_JCZ38 0.000
log_k_J9Z38 0.000
log_k_JSE76 0.000
f_cyan_ilr_1 0.000
f_cyan_ilr_2 0.000
f_JCZ38_qlogis 0.000
f_JSE76_qlogis 0.000
log_k1       0.000
log_k2       0.000
g_qlogis     1.595

Starting values for error model parameters:
a.1
1

```

Results:

Likelihood computed by importance sampling

AIC BIC logLik
2288 2280 -1122

Optimised parameters:

	est.	lower	upper
cyan_0	102.7204	1.014e+02	1.040e+02
log_k_JCZ38	-2.8925	-4.044e+00	-1.741e+00
log_k_J9Z38	-5.1430	-5.828e+00	-4.457e+00
log_k_JSE76	-3.5577	-4.174e+00	-2.941e+00
f_cyan_ilr_1	0.6929	3.788e-01	1.007e+00
f_cyan_ilr_2	0.6066	5.342e-02	1.160e+00
f_JCZ38_qlogis	9.8071	-2.819e+03	2.838e+03
f_JSE76_qlogis	2.2229	5.684e-01	3.877e+00
log_k1	-1.9339	-2.609e+00	-1.258e+00
log_k2	-4.4709	-4.935e+00	-4.007e+00
g_qlogis	-0.4987	-1.373e+00	3.757e-01
a.1	2.7368	2.545e+00	2.928e+00
SD.log_k_JCZ38	1.2747	4.577e-01	2.092e+00
SD.log_k_J9Z38	0.6758	1.418e-01	1.210e+00
SD.log_k_JSE76	0.5869	1.169e-01	1.057e+00
SD.f_cyan_ilr_1	0.3392	1.161e-01	5.622e-01
SD.f_cyan_ilr_2	0.4200	8.501e-02	7.550e-01
SD.f_JCZ38_qlogis	0.8511	-1.137e+06	1.137e+06
SD.f_JSE76_qlogis	0.3767	-5.238e-01	1.277e+00
SD.log_k1	0.7475	2.601e-01	1.235e+00
SD.log_k2	0.5179	1.837e-01	8.521e-01
SD.g_qlogis	0.9817	3.553e-01	1.608e+00

Correlation:

	cyan_0	l__JCZ3	l__J9Z3	l__JSE7	f_cy__1	f_cy__2	f_JCZ38	f_JSE76
log_k_JCZ38	-0.0351							
log_k_J9Z38	-0.0541	0.0043						
log_k_JSE76	-0.0078	0.0900	-0.0014					
f_cyan_ilr_1	-0.0249	0.0268	-0.0962	0.0000				
f_cyan_ilr_2	-0.3560	0.0848	0.1545	-0.0022	0.0463			
f_JCZ38_qlogis	0.2005	-0.1226	-0.0347	0.0514	-0.1840	-0.5906		
f_JSE76_qlogis	-0.1638	0.1307	0.0266	0.0001	0.1645	0.5181	-0.9297	
log_k1	0.0881	-0.0071	0.0005	-0.0070	-0.0064	-0.0346	0.0316	-0.0341
log_k2	0.0238	-0.0003	0.0082	-0.0022	-0.0017	-0.0017	-0.0002	-0.0076
g_qlogis	0.0198	-0.0002	-0.0109	0.0034	0.0017	-0.0176	0.0044	0.0051
		log_k1	log_k2					
log_k_JCZ38								
log_k_J9Z38								
log_k_JSE76								
f_cyan_ilr_1								
f_cyan_ilr_2								
f_JCZ38_qlogis								
f_JSE76_qlogis								
log_k1								
log_k2	0.0276							
g_qlogis	-0.0283	-0.0309						

Random effects:

	est.	lower	upper
SD.log_k_JCZ38	1.2747	4.577e-01	2.092e+00
SD.log_k_J9Z38	0.6758	1.418e-01	1.210e+00
SD.log_k_JSE76	0.5869	1.169e-01	1.057e+00
SD.f_cyan_ilr_1	0.3392	1.161e-01	5.622e-01
SD.f_cyan_ilr_2	0.4200	8.501e-02	7.550e-01
SD.f_JCZ38_qlogis	0.8511	-1.137e+06	1.137e+06
SD.f_JSE76_qlogis	0.3767	-5.238e-01	1.277e+00
SD.log_k1	0.7475	2.601e-01	1.235e+00
SD.log_k2	0.5179	1.837e-01	8.521e-01
SD.g_qlogis	0.9817	3.553e-01	1.608e+00

Variance model:

est. lower upper
a.1 2.737 2.545 2.928

Backtransformed parameters:

	est.	lower	upper
cyan_0	102.72037	1.014e+02	104.00464
k_JCZ38	0.05544	1.752e-02	0.17539
k_J9Z38	0.00584	2.942e-03	0.01159
k_JSE76	0.02850	1.539e-02	0.05279
f_cyan_to_JCZ38	0.59995	NA	NA
f_cyan_to_J9Z38	0.22519	NA	NA
f_JCZ38_to_JSE76	0.99994	0.000e+00	1.00000
f_JSE76_to_JCZ38	0.90229	6.384e-01	0.97971
k1	0.14459	7.357e-02	0.28414
k2	0.01144	7.192e-03	0.01819

g 0.37784 2.021e-01 0.59284

Resulting formation fractions:

ff
cyan_JCZ38 5.999e-01
cyan_J9Z38 2.252e-01
cyan_sink 1.749e-01
JCZ38_JSE76 9.999e-01
JCZ38_sink 5.506e-05
JSE76_JCZ38 9.023e-01
JSE76_sink 9.771e-02

Estimated disappearance times:

	DT50	DT90	DT50back	DT50_k1	DT50_k2
cyan	21.93	159.83	48.11	4.794	60.6
JCZ38	12.50	41.53	NA	NA	NA
J9Z38	118.69	394.27	NA	NA	NA
JSE76	24.32	80.78	NA	NA	NA

Listing 12: Hierarchical DFOP path 2 fit with two-component error

```

saemix version used for fitting:      3.3
mkin version used for pre-fitting:    1.2.9
R version used for fitting:           4.4.2
Date of fit:                          Thu Feb 13 18:49:50 2025
Date of summary:                      Thu Feb 13 19:05:54 2025

Equations:
d_cyan/dt = - ((k1 * g * exp(-k1 * time) + k2 * (1 - g) * exp(-k2 *
time)) / (g * exp(-k1 * time) + (1 - g) * exp(-k2 * time)))
* cyan
d_JCZ38/dt = + f_cyan_to_JCZ38 * ((k1 * g * exp(-k1 * time) + k2 * (1 -
g) * exp(-k2 * time)) / (g * exp(-k1 * time) + (1 - g) *
exp(-k2 * time))) * cyan - k_JCZ38 * JCZ38 +
f_JSE76_to_JCZ38 * k_JSE76 * JSE76
d_J9Z38/dt = + f_cyan_to_J9Z38 * ((k1 * g * exp(-k1 * time) + k2 * (1 -
g) * exp(-k2 * time)) / (g * exp(-k1 * time) + (1 - g) *
exp(-k2 * time))) * cyan - k_J9Z38 * J9Z38
d_JSE76/dt = + f_JCZ38_to_JSE76 * k_JCZ38 * JCZ38 - k_JSE76 * JSE76

Data:
433 observations of 4 variable(s) grouped in 5 datasets

Model predictions using solution type deSolve

Fitted in 734.852 s
Using 300, 100 iterations and 10 chains

Variance model: Two-component variance function

Starting values for degradation parameters:
      cyan_0  log_k_JCZ38  log_k_J9Z38  log_k_JSE76  f_cyan_ilr_1
      101.7393      -1.4493      -5.0118      -2.1269      0.6720
f_cyan_ilr_2 f_JCZ38_qlogis f_JSE76_qlogis  log_k1      log_k2
      7.3362      13.4423      13.2659      -2.0061      -4.5527
g_qlogis
      -0.5806

Fixed degradation parameter values:
None

Starting values for random effects (square root of initial entries in omega):
      cyan_0  log_k_JCZ38  log_k_J9Z38  log_k_JSE76  f_cyan_ilr_1
cyan_0      5.604      0.00      0.000      0.000      0.0000
log_k_JCZ38  0.000      2.77      0.000      0.000      0.0000
log_k_J9Z38  0.000      0.00      1.662      0.000      0.0000
log_k_JSE76  0.000      0.00      0.000      5.021      0.0000
f_cyan_ilr_1 0.000      0.00      0.000      0.000      0.6519
f_cyan_ilr_2 0.000      0.00      0.000      0.000      0.0000
f_JCZ38_qlogis 0.000      0.00      0.000      0.000      0.0000
f_JSE76_qlogis 0.000      0.00      0.000      0.000      0.0000
log_k1      0.000      0.00      0.000      0.000      0.0000
log_k2      0.000      0.00      0.000      0.000      0.0000
g_qlogis     0.000      0.00      0.000      0.000      0.0000
      f_cyan_ilr_2 f_JCZ38_qlogis f_JSE76_qlogis log_k1 log_k2
cyan_0      0.00      0.00      0.00      0.00 0.0000 0.0000
log_k_JCZ38 0.00      0.00      0.00      0.00 0.0000 0.0000
log_k_J9Z38 0.00      0.00      0.00      0.00 0.0000 0.0000
log_k_JSE76 0.00      0.00      0.00      0.00 0.0000 0.0000
f_cyan_ilr_1 0.00      0.00      0.00      0.00 0.0000 0.0000
f_cyan_ilr_2 13.37      0.00      0.00      0.00 0.0000 0.0000
f_JCZ38_qlogis 0.00      14.21      0.00      0.00 0.0000 0.0000
f_JSE76_qlogis 0.00      0.00      14.58 0.0000 0.0000
log_k1      0.00      0.00      0.00      0.00 0.8453 0.0000
log_k2      0.00      0.00      0.00      0.00 0.0000 0.5969
g_qlogis     0.00      0.00      0.00      0.00 0.0000 0.0000
      g_qlogis
cyan_0      0.00
log_k_JCZ38 0.00
log_k_J9Z38 0.00
log_k_JSE76 0.00
f_cyan_ilr_1 0.00
f_cyan_ilr_2 0.00
f_JCZ38_qlogis 0.00
f_JSE76_qlogis 0.00
log_k1      0.00
log_k2      0.00
g_qlogis     1.69

Starting values for error model parameters:
a.1 b.1
1 1

```

Results:

Likelihood computed by importance sampling

AIC BIC logLik
2234 2226 -1095

Optimised parameters:

	est.	lower	upper
cyan_0	101.25496	99.14662	103.36331
log_k_JCZ38	-2.55593	-3.32972	-1.78215
log_k_J9Z38	-5.07103	-5.85423	-4.28783
log_k_JSE76	-3.25468	-4.17577	-2.33360
f_cyan_ilr_1	0.70139	0.35924	1.04355
f_cyan_ilr_2	1.07712	0.17789	1.97636
f_JCZ38_qlogis	3.57483	0.05990	7.08976
f_JSE76_qlogis	4.54884	-7.25628	16.35395
log_k1	-2.38201	-2.51639	-2.24763
log_k2	-4.66741	-4.91865	-4.41617
g_qlogis	-0.28446	-1.14192	0.57300
a.1	2.05925	1.86481	2.25369
b.1	0.06172	0.05062	0.07282
SD.log_k_JCZ38	0.81137	0.25296	1.36977
SD.log_k_J9Z38	0.83542	0.25395	1.41689
SD.log_k_JSE76	0.97903	0.30100	1.65707
SD.f_cyan_ilr_1	0.37878	0.13374	0.62382
SD.f_cyan_ilr_2	0.67274	0.10102	1.24446
SD.f_JCZ38_qlogis	1.35327	-0.42359	3.13012
SD.f_JSE76_qlogis	1.43956	-19.14972	22.02884
SD.log_k2	0.25329	0.07521	0.43138
SD.g_qlogis	0.95167	0.35149	1.55184

Correlation:

	cyan_0	l__JCZ3	l__J9Z3	l__JSE7	f_cy__1	f_cy__2	f_JCZ38	f_JSE76
log_k_JCZ38	-0.0265							
log_k_J9Z38	-0.0392	0.0024						
log_k_JSE76	0.0011	0.1220	-0.0016					
f_cyan_ilr_1	-0.0161	0.0217	-0.0552	0.0034				
f_cyan_ilr_2	-0.4718	0.0829	0.1102	0.0042	0.0095			
f_JCZ38_qlogis	0.1609	-0.1318	-0.0277	0.0081	-0.1040	-0.4559		
f_JSE76_qlogis	-0.1289	0.1494	0.0219	0.0012	0.1004	0.4309	-0.8543	
log_k1	0.2618	-0.0739	-0.0167	-0.0148	-0.0444	-0.2768	0.3518	-0.3818
log_k2	0.0603	-0.0217	0.0174	-0.0058	-0.0197	-0.0533	0.0923	-0.1281
g_qlogis	0.0362	0.0115	-0.0111	0.0040	0.0095	-0.0116	-0.0439	0.0651
		log_k1	log_k2					
log_k_JCZ38								
log_k_J9Z38								
log_k_JSE76								
f_cyan_ilr_1								
f_cyan_ilr_2								
f_JCZ38_qlogis								
f_JSE76_qlogis								
log_k1								
log_k2	0.3269							
g_qlogis	-0.1656	-0.0928						

Random effects:

	est.	lower	upper
SD.log_k_JCZ38	0.8114	0.25296	1.3698
SD.log_k_J9Z38	0.8354	0.25395	1.4169
SD.log_k_JSE76	0.9790	0.30100	1.6571
SD.f_cyan_ilr_1	0.3788	0.13374	0.6238
SD.f_cyan_ilr_2	0.6727	0.10102	1.2445
SD.f_JCZ38_qlogis	1.3533	-0.42359	3.1301
SD.f_JSE76_qlogis	1.4396	-19.14972	22.0288
SD.log_k2	0.2533	0.07521	0.4314
SD.g_qlogis	0.9517	0.35149	1.5518

Variance model:

	est.	lower	upper
a.1	2.05925	1.86481	2.25369
b.1	0.06172	0.05062	0.07282

Backtransformed parameters:

	est.	lower	upper
cyan_0	1.013e+02	9.915e+01	103.36331
k_JCZ38	7.762e-02	3.580e-02	0.16828
k_J9Z38	6.276e-03	2.868e-03	0.01373
k_JSE76	3.859e-02	1.536e-02	0.09695
f_cyan_to_JCZ38	6.520e-01	NA	NA
f_cyan_to_J9Z38	2.418e-01	NA	NA
f_JCZ38_to_JSE76	9.727e-01	5.150e-01	0.99917
f_JSE76_to_JCZ38	9.895e-01	7.052e-04	1.00000
k1	9.236e-02	8.075e-02	0.10565
k2	9.397e-03	7.309e-03	0.01208

g 4.294e-01 2.420e-01 0.63945

Resulting formation fractions:

ff
cyan_JCZ38 0.65203
cyan_J9Z38 0.24181
cyan_sink 0.10616
JCZ38_JSE76 0.97274
JCZ38_sink 0.02726
JSE76_JCZ38 0.98953
JSE76_sink 0.01047

Estimated disappearance times:

	DT50	DT90	DT50back	DT50_k1	DT50_k2
cyan	24.26	185.34	55.79	7.504	73.77
JCZ38	8.93	29.66	NA	NA	NA
J9Z38	110.45	366.89	NA	NA	NA
JSE76	17.96	59.66	NA	NA	NA

Listing 13: Hierarchical SFORB path 2 fit with constant variance

```

saemix version used for fitting:      3.3
mkin version used for pre-fitting:    1.2.9
R version used for fitting:           4.4.2
Date of fit:                          Thu Feb 13 18:47:00 2025
Date of summary:                      Thu Feb 13 19:05:54 2025

Equations:
d_cyan_free/dt = - k_cyan_free * cyan_free - k_cyan_free_bound *
                cyan_free + k_cyan_bound_free * cyan_bound
d_cyan_bound/dt = + k_cyan_free_bound * cyan_free - k_cyan_bound_free *
                cyan_bound
d_JCZ38/dt = + f_cyan_free_to_JCZ38 * k_cyan_free * cyan_free - k_JCZ38
                * JCZ38 + f_JSE76_to_JCZ38 * k_JSE76 * JSE76
d_J9Z38/dt = + f_cyan_free_to_J9Z38 * k_cyan_free * cyan_free - k_J9Z38
                * J9Z38
d_JSE76/dt = + f_JCZ38_to_JSE76 * k_JCZ38 * JCZ38 - k_JSE76 * JSE76

Data:
433 observations of 4 variable(s) grouped in 5 datasets

Model predictions using solution type deSolve

Fitted in 564.736 s
Using 300, 100 iterations and 10 chains

Variance model: Constant variance

Starting values for degradation parameters:
cyan_free_0      log_k_cyan_free  log_k_cyan_free_bound
102.4395         -2.7673                -2.8942
log_k_cyan_bound_free  log_k_JCZ38          log_k_J9Z38
-3.6201         -2.3107                -5.3123
log_k_JSE76      f_cyan_ilr_1          f_cyan_ilr_2
-3.7120         0.6754                1.1448
f_JCZ38_qlogis   f_JSE76_qlogis
14.8408         15.4734

Fixed degradation parameter values:
None

Starting values for random effects (square root of initial entries in omega):
cyan_free_0      log_k_cyan_free  log_k_cyan_free_bound
4.589           0.0000          0.0000
log_k_cyan_free  0.000           0.4849          0.0000
log_k_cyan_bound_free  0.000           0.0000          0.0000
log_k_cyan_bound_free  0.000           0.0000          0.0000
log_k_JCZ38      0.000           0.0000          0.0000
log_k_J9Z38      0.000           0.0000          0.0000
log_k_JSE76      0.000           0.0000          0.0000
f_cyan_ilr_1     0.000           0.0000          0.0000
f_cyan_ilr_2     0.000           0.0000          0.0000
f_JCZ38_qlogis   0.000           0.0000          0.0000
f_JSE76_qlogis   0.000           0.0000          0.0000
cyan_free_0      log_k_cyan_bound_free  log_k_JCZ38  log_k_J9Z38  log_k_JSE76
0.000           0.0000          0.0000      0.0000      0.0000
log_k_cyan_free  0.000           0.0000          0.0000      0.0000      0.0000
log_k_cyan_bound_free  0.000           0.0000          0.0000      0.0000      0.0000
log_k_cyan_bound_free  1.197           0.0000          0.0000      0.0000      0.0000
log_k_JCZ38      0.000           0.7966          0.0000      0.0000      0.0000
log_k_J9Z38      0.000           0.0000          1.5610      0.0000      0.0000
log_k_JSE76      0.000           0.0000          0.0000      0.0000      0.8000
f_cyan_ilr_1     0.000           0.0000          0.0000      0.0000      0.0000
f_cyan_ilr_2     0.000           0.0000          0.0000      0.0000      0.0000
f_JCZ38_qlogis   0.000           0.0000          0.0000      0.0000      0.0000
f_JSE76_qlogis   0.000           0.0000          0.0000      0.0000      0.0000
cyan_free_0      f_cyan_ilr_1  f_cyan_ilr_2  f_JCZ38_qlogis  f_JSE76_qlogis
0.0000          0.0000        0.0000        0.0000          0.0000
log_k_cyan_free  0.0000          0.0000        0.0000          0.0000
log_k_cyan_bound_free  0.0000          0.0000        0.0000          0.0000
log_k_cyan_bound_free  0.0000          0.0000        0.0000          0.0000
log_k_JCZ38      0.0000          0.0000        0.0000          0.0000
log_k_J9Z38      0.0000          0.0000        0.0000          0.0000
log_k_JSE76      0.0000          0.0000        0.0000          0.0000
f_cyan_ilr_1     0.6349          0.0000        0.0000          0.0000
f_cyan_ilr_2     0.0000          1.7970        0.0000          0.0000
f_JCZ38_qlogis   0.0000          0.0000        15.6000         0.0000
f_JSE76_qlogis   0.0000          0.0000        0.0000          17.5200

Starting values for error model parameters:
a.1
1

```

Results:

Likelihood computed by importance sampling

AIC BIC logLik
2283 2275 -1120

Optimised parameters:

	est.	lower	upper
cyan_free_0	102.6517	101.40815	103.8952
log_k_cyan_free	-2.8729	-3.18649	-2.5593
log_k_cyan_free_bound	-2.7803	-3.60525	-1.9552
log_k_cyan_bound_free	-3.5845	-4.16644	-3.0026
log_k_JCZ38	-2.3411	-2.89698	-1.7852
log_k_J9Z38	-5.2487	-6.01271	-4.4847
log_k_JSE76	-3.0259	-4.28274	-1.7690
f_cyan_ilr_1	0.7289	0.38214	1.0756
f_cyan_ilr_2	0.6891	0.18277	1.1954
f_JCZ38_qlogis	4.2162	0.47015	7.9622
f_JSE76_qlogis	5.8911	-20.19088	31.9730
a.1	2.7159	2.52587	2.9060
SD.log_k_cyan_free	0.3354	0.10979	0.5610
SD.log_k_cyan_free_bound	0.9061	0.30969	1.5025
SD.log_k_cyan_bound_free	0.6376	0.21229	1.0628
SD.log_k_JCZ38	0.5499	0.14533	0.9545
SD.log_k_J9Z38	0.7457	0.15106	1.3404
SD.log_k_JSE76	1.3822	0.47329	2.2912
SD.f_cyan_ilr_1	0.3820	0.13280	0.6313
SD.f_cyan_ilr_2	0.4317	0.06803	0.7953
SD.f_JCZ38_qlogis	1.8258	-0.25423	3.9059
SD.f_JSE76_qlogis	2.2348	-83.33679	87.8065

Correlation:

	cyn_f_0	lg_k_c_	lg_k_cyn_f_	lg_k_cyn_b_	l__JCZ3	l__J9Z3
log_k_cyan_free	0.1944					
log_k_cyan_free_bound	0.0815	0.0814				
log_k_cyan_bound_free	0.0106	0.0426	0.0585			
log_k_JCZ38	-0.0231	-0.0106	-0.0089	-0.0051		
log_k_J9Z38	-0.0457	-0.0108	0.0019	0.0129	0.0032	
log_k_JSE76	-0.0054	-0.0024	-0.0017	-0.0005	0.1108	0.0009
f_cyan_ilr_1	0.0051	-0.0005	-0.0035	-0.0056	0.0131	-0.0967
f_cyan_ilr_2	-0.3182	-0.0771	-0.0309	-0.0038	0.0680	0.1643
f_JCZ38_qlogis	0.0834	0.0369	0.0302	0.0172	-0.1145	-0.0204
f_JSE76_qlogis	-0.0553	-0.0365	-0.0441	-0.0414	0.1579	0.0175
	l__JSE7	f_cy__1	f_cy__2	f_JCZ38		
log_k_cyan_free						
log_k_cyan_free_bound						
log_k_cyan_bound_free						
log_k_JCZ38						
log_k_J9Z38						
log_k_JSE76						
f_cyan_ilr_1	-0.0002					
f_cyan_ilr_2	0.0020	-0.0415				
f_JCZ38_qlogis	0.0052	-0.0665	-0.3437			
f_JSE76_qlogis	0.0066	0.0635	0.3491	-0.7487		

Random effects:

	est.	lower	upper
SD.log_k_cyan_free	0.3354	0.10979	0.5610
SD.log_k_cyan_free_bound	0.9061	0.30969	1.5025
SD.log_k_cyan_bound_free	0.6376	0.21229	1.0628
SD.log_k_JCZ38	0.5499	0.14533	0.9545
SD.log_k_J9Z38	0.7457	0.15106	1.3404
SD.log_k_JSE76	1.3822	0.47329	2.2912
SD.f_cyan_ilr_1	0.3820	0.13280	0.6313
SD.f_cyan_ilr_2	0.4317	0.06803	0.7953
SD.f_JCZ38_qlogis	1.8258	-0.25423	3.9059
SD.f_JSE76_qlogis	2.2348	-83.33679	87.8065

Variance model:

est. lower upper
a.1 2.716 2.526 2.906

Backtransformed parameters:

	est.	lower	upper
cyan_free_0	1.027e+02	1.014e+02	103.89517
k_cyan_free	5.654e-02	4.132e-02	0.07736
k_cyan_free_bound	6.202e-02	2.718e-02	0.14153
k_cyan_bound_free	2.775e-02	1.551e-02	0.04966
k_JCZ38	9.622e-02	5.519e-02	0.16777
k_J9Z38	5.254e-03	2.447e-03	0.01128
k_JSE76	4.852e-02	1.380e-02	0.17051
f_cyan_free_to_JCZ38	6.197e-01	5.643e-01	0.84429
f_cyan_free_to_J9Z38	2.211e-01	5.643e-01	0.84429
f_JCZ38_to_JSE76	9.855e-01	6.154e-01	0.99965

f_JSE76_to_JCZ38 9.972e-01 1.703e-09 1.00000

Estimated Eigenvalues of SFORB model(s):

cyan_b1 cyan_b2 cyan_g
0.13466 0.01165 0.36490

Resulting formation fractions:

ff
cyan_free_JCZ38 0.619745
cyan_free_J9Z38 0.221083
cyan_free_sink 0.159172
cyan_free 1.000000
JCZ38_JSE76 0.985460
JCZ38_sink 0.014540
JSE76_JCZ38 0.997244
JSE76_sink 0.002756

Estimated disappearance times:

	DT50	DT90	DT50back	DT50_cyan_b1	DT50_cyan_b2
cyan	23.293	158.67	47.77	5.147	59.5
JCZ38	7.203	23.93	NA	NA	NA
J9Z38	131.918	438.22	NA	NA	NA
JSE76	14.287	47.46	NA	NA	NA

Listing 14: Hierarchical SFORB path 2 fit with two-component error

```

saemix version used for fitting:      3.3
mkin version used for pre-fitting:    1.2.9
R version used for fitting:          4.4.2
Date of fit:      Thu Feb 13 18:49:47 2025
Date of summary:  Thu Feb 13 19:05:54 2025

Equations:
d_cyan_free/dt = - k_cyan_free * cyan_free - k_cyan_free_bound *
                cyan_free + k_cyan_bound_free * cyan_bound
d_cyan_bound/dt = + k_cyan_free_bound * cyan_free - k_cyan_bound_free *
                cyan_bound
d_JCZ38/dt = + f_cyan_free_to_JCZ38 * k_cyan_free * cyan_free - k_JCZ38
            * JCZ38 + f_JSE76_to_JCZ38 * k_JSE76 * JSE76
d_J9Z38/dt = + f_cyan_free_to_J9Z38 * k_cyan_free * cyan_free - k_J9Z38
            * J9Z38
d_JSE76/dt = + f_JCZ38_to_JSE76 * k_JCZ38 * JCZ38 - k_JSE76 * JSE76

Data:
433 observations of 4 variable(s) grouped in 5 datasets

Model predictions using solution type deSolve

Fitted in 731.571 s
Using 300, 100 iterations and 10 chains

Variance model: Two-component variance function

Starting values for degradation parameters:
cyan_free_0      log_k_cyan_free  log_k_cyan_free_bound
101.7511        -2.8370          -3.0162
log_k_cyan_bound_free  log_k_JCZ38      log_k_J9Z38
-3.6600         -2.2988          -5.3129
log_k_JSE76      f_cyan_ilr_1     f_cyan_ilr_2
-3.6991         0.6722          4.8596
f_JCZ38_qlogis   f_JSE76_qlogis
13.4678         14.2149

Fixed degradation parameter values:
None

Starting values for random effects (square root of initial entries in omega):
cyan_free_0      log_k_cyan_free  log_k_cyan_free_bound
5.629            0.000           0.000
log_k_cyan_free  0.000           0.446           0.000
log_k_cyan_bound_free  0.000           0.000           1.449
log_k_cyan_bound_free  0.000           0.000           0.000
log_k_JCZ38      0.000           0.000           0.000
log_k_J9Z38      0.000           0.000           0.000
log_k_JSE76      0.000           0.000           0.000
f_cyan_ilr_1     0.000           0.000           0.000
f_cyan_ilr_2     0.000           0.000           0.000
f_JCZ38_qlogis   0.000           0.000           0.000
f_JSE76_qlogis   0.000           0.000           0.000
cyan_free_0      log_k_cyan_bound_free  log_k_JCZ38  log_k_J9Z38  log_k_JSE76
0.000            0.000           0.0000      0.000       0.0000
log_k_cyan_free  0.000            0.0000      0.000       0.0000
log_k_cyan_bound_free  0.000            0.0000      0.000       0.0000
log_k_cyan_bound_free  1.213            0.0000      0.000       0.0000
log_k_JCZ38      0.000            0.7801      0.000       0.0000
log_k_J9Z38      0.000            0.0000      1.575       0.0000
log_k_JSE76      0.000            0.0000      0.000       0.8078
f_cyan_ilr_1     0.000            0.0000      0.000       0.0000
f_cyan_ilr_2     0.000            0.0000      0.000       0.0000
f_JCZ38_qlogis   0.000            0.0000      0.000       0.0000
f_JSE76_qlogis   0.000            0.0000      0.000       0.0000
cyan_free_0      f_cyan_ilr_1  f_cyan_ilr_2  f_JCZ38_qlogis  f_JSE76_qlogis
0.0000           0.000         0.000         0.00            0.00
log_k_cyan_free  0.0000           0.000         0.00            0.00
log_k_cyan_bound_free  0.0000           0.000         0.00            0.00
log_k_cyan_bound_free  0.0000           0.000         0.00            0.00
log_k_JCZ38      0.0000           0.000         0.00            0.00
log_k_J9Z38      0.0000           0.000         0.00            0.00
log_k_JSE76      0.0000           0.000         0.00            0.00
f_cyan_ilr_1     0.6518           0.000         0.00            0.00
f_cyan_ilr_2     0.0000           9.981         0.00            0.00
f_JCZ38_qlogis   0.0000           0.000         14.26           0.00
f_JSE76_qlogis   0.0000           0.000         0.00            16.17

Starting values for error model parameters:
a.1 b.1
1 1

```


Results:

Likelihood computed by importance sampling

AIC BIC logLik
2240 2231 -1098

Optimised parameters:

	est.	lower	upper
cyan_free_0	100.73014	9.873e+01	1.027e+02
log_k_cyan_free	-3.19634	-3.641e+00	-2.752e+00
log_k_cyan_free_bound	-3.43533	-3.674e+00	-3.197e+00
log_k_cyan_bound_free	-3.83282	-4.163e+00	-3.503e+00
log_k_JCZ38	-2.51065	-3.225e+00	-1.796e+00
log_k_J9Z38	-5.02539	-5.825e+00	-4.226e+00
log_k_JSE76	-3.24777	-4.163e+00	-2.333e+00
f_cyan_ilr_1	0.70640	3.562e-01	1.057e+00
f_cyan_ilr_2	1.42704	3.170e-01	2.537e+00
f_JCZ38_qlogis	2.84779	1.042e+00	4.654e+00
f_JSE76_qlogis	8.63674	-6.407e+02	6.580e+02
a.1	2.07082	1.877e+00	2.265e+00
b.1	0.06227	5.098e-02	7.355e-02
SD.log_k_cyan_free	0.49674	1.865e-01	8.069e-01
SD.log_k_cyan_bound_free	0.28537	6.809e-02	5.027e-01
SD.log_k_JCZ38	0.74846	2.305e-01	1.266e+00
SD.log_k_J9Z38	0.86077	2.713e-01	1.450e+00
SD.log_k_JSE76	0.97613	3.030e-01	1.649e+00
SD.f_cyan_ilr_1	0.38994	1.382e-01	6.417e-01
SD.f_cyan_ilr_2	0.82869	3.917e-02	1.618e+00
SD.f_JCZ38_qlogis	1.05000	-2.808e-02	2.128e+00
SD.f_JSE76_qlogis	0.44681	-3.985e+05	3.985e+05

Correlation:

	cyn_f_0	lg_k_c_	lg_k_cyn_f_	lg_k_cyn_b_	l__JCZ3	l__J9Z3
log_k_cyan_free	0.0936					
log_k_cyan_free_bound	0.1302	0.1627				
log_k_cyan_bound_free	0.0029	0.0525	0.5181			
log_k_JCZ38	-0.0116	-0.0077	-0.0430	-0.0236		
log_k_J9Z38	-0.0192	-0.0077	-0.0048	0.0229	-0.0005	
log_k_JSE76	0.0007	-0.0020	-0.0134	-0.0072	0.1225	-0.0016
f_cyan_ilr_1	-0.0118	-0.0027	-0.0132	-0.0118	0.0127	-0.0505
f_cyan_ilr_2	-0.4643	-0.0762	-0.1245	0.0137	0.0497	0.1003
f_JCZ38_qlogis	0.0710	0.0371	0.1826	0.0925	-0.0869	-0.0130
f_JSE76_qlogis	-0.0367	-0.0270	-0.2274	-0.1865	0.1244	0.0098
	l__JSE7	f_cy__1	f_cy__2	f_JCZ38		
log_k_cyan_free						
log_k_cyan_free_bound						
log_k_cyan_bound_free						
log_k_JCZ38						
log_k_J9Z38						
log_k_JSE76						
f_cyan_ilr_1	0.0036					
f_cyan_ilr_2	0.0050	-0.0201				
f_JCZ38_qlogis	0.0142	-0.0529	-0.2698			
f_JSE76_qlogis	0.0064	0.0345	0.2015	-0.7058		

Random effects:

	est.	lower	upper
SD.log_k_cyan_free	0.4967	1.865e-01	8.069e-01
SD.log_k_cyan_bound_free	0.2854	6.809e-02	5.027e-01
SD.log_k_JCZ38	0.7485	2.305e-01	1.266e+00
SD.log_k_J9Z38	0.8608	2.713e-01	1.450e+00
SD.log_k_JSE76	0.9761	3.030e-01	1.649e+00
SD.f_cyan_ilr_1	0.3899	1.382e-01	6.417e-01
SD.f_cyan_ilr_2	0.8287	3.917e-02	1.618e+00
SD.f_JCZ38_qlogis	1.0500	-2.808e-02	2.128e+00
SD.f_JSE76_qlogis	0.4468	-3.985e+05	3.985e+05

Variance model:

	est.	lower	upper
a.1	2.07082	1.87680	2.26483
b.1	0.06227	0.05098	0.07355

Backtransformed parameters:

	est.	lower	upper
cyan_free_0	1.007e+02	9.873e+01	102.72898
k_cyan_free	4.091e-02	2.623e-02	0.06382
k_cyan_free_bound	3.221e-02	2.537e-02	0.04090
k_cyan_bound_free	2.165e-02	1.557e-02	0.03011
k_JCZ38	8.122e-02	3.975e-02	0.16594
k_J9Z38	6.569e-03	2.954e-03	0.01461
k_JSE76	3.886e-02	1.556e-02	0.09703
f_cyan_free_to_JCZ38	6.785e-01	6.102e-01	0.97309
f_cyan_free_to_J9Z38	2.498e-01	6.102e-01	0.97309
f_JCZ38_to_JSE76	9.452e-01	7.392e-01	0.99056

f_JSE76_to_JCZ38 9.998e-01 5.580e-279 1.00000

Estimated Eigenvalues of SFORB model(s):

cyan_b1 cyan_b2 cyan_g
0.08426 0.01051 0.41220

Resulting formation fractions:

ff
cyan_free_JCZ38 0.6784541
cyan_free_J9Z38 0.2498405
cyan_free_sink 0.0717054
cyan_free 1.0000000
JCZ38_JSE76 0.9452043
JCZ38_sink 0.0547957
JSE76_JCZ38 0.9998226
JSE76_sink 0.0001774

Estimated disappearance times:

	DT50	DT90	DT50back	DT50_cyan_b1	DT50_cyan_b2
cyan	25.237	168.51	50.73	8.226	65.95
JCZ38	8.535	28.35	NA	NA	NA
J9Z38	105.517	350.52	NA	NA	NA
JSE76	17.837	59.25	NA	NA	NA

Pathway 2, refined fits

Listing 15: Hierarchical FOMC path 2 fit with reduced random effects, two-component error

```
saemix version used for fitting: 3.3
mkin version used for pre-fitting: 1.2.9
R version used for fitting: 4.4.2
Date of fit: Thu Feb 13 19:03:34 2025
Date of summary: Thu Feb 13 19:05:54 2025

Equations:
d_cyan/dt = - (alpha/beta) * 1/((time/beta) + 1) * cyan
d_JCZ38/dt = + f_cyan_to_JCZ38 * (alpha/beta) * 1/((time/beta) + 1) *
cyan - k_JCZ38 * JCZ38 + f_JSE76_to_JCZ38 * k_JSE76 * JSE76
d_J9Z38/dt = + f_cyan_to_J9Z38 * (alpha/beta) * 1/((time/beta) + 1) *
cyan - k_J9Z38 * J9Z38
d_JSE76/dt = + f_JCZ38_to_JSE76 * k_JCZ38 * JCZ38 - k_JSE76 * JSE76

Data:
433 observations of 4 variable(s) grouped in 5 datasets

Model predictions using solution type deSolve

Fitted in 821.812 s
Using 300, 100 iterations and 10 chains

Variance model: Two-component variance function

Starting values for degradation parameters:
cyan_0 log_k_JCZ38 log_k_J9Z38 log_k_JSE76 f_cyan_ilr_1
102.4477 -1.8631 -5.1087 -2.5114 0.6826
f_cyan_ilr_2 f_JCZ38_qlogis f_JSE76_qlogis log_alpha log_beta
4.7944 15.9616 13.1566 -0.1564 2.9781

Fixed degradation parameter values:
None

Starting values for random effects (square root of initial entries in omega):
cyan_0 log_k_JCZ38 log_k_J9Z38 log_k_JSE76 f_cyan_ilr_1
cyan_0 7.701 0.000 0.000 0.000 0.000 0.0000
log_k_JCZ38 0.000 1.448 0.000 0.000 0.000 0.0000
log_k_J9Z38 0.000 0.000 1.724 0.000 0.000 0.0000
log_k_JSE76 0.000 0.000 0.000 3.659 0.000 0.0000
f_cyan_ilr_1 0.000 0.000 0.000 0.000 0.000 0.6356
f_cyan_ilr_2 0.000 0.000 0.000 0.000 0.000 0.0000
f_JCZ38_qlogis 0.000 0.000 0.000 0.000 0.000 0.0000
f_JSE76_qlogis 0.000 0.000 0.000 0.000 0.000 0.0000
log_alpha 0.000 0.000 0.000 0.000 0.000 0.0000
log_beta 0.000 0.000 0.000 0.000 0.000 0.0000
f_cyan_ilr_2 f_JCZ38_qlogis f_JSE76_qlogis log_alpha log_beta
cyan_0 0.00 0.00 0.00 0.00 0.0000 0.0000
log_k_JCZ38 0.00 0.00 0.00 0.00 0.0000 0.0000
log_k_J9Z38 0.00 0.00 0.00 0.00 0.0000 0.0000
log_k_JSE76 0.00 0.00 0.00 0.00 0.0000 0.0000
f_cyan_ilr_1 0.00 0.00 0.00 0.00 0.0000 0.0000
f_cyan_ilr_2 10.32 0.00 0.00 0.00 0.0000 0.0000
f_JCZ38_qlogis 0.00 12.23 0.00 0.00 0.0000 0.0000
f_JSE76_qlogis 0.00 0.00 14.99 0.0000 0.0000
log_alpha 0.00 0.00 0.00 0.3924 0.0000
log_beta 0.00 0.00 0.00 0.0000 0.5639

Starting values for error model parameters:
a.1 b.1
1 1

Results:

Likelihood computed by importance sampling
AIC BIC logLik
2249 2242 -1106

Optimised parameters:
est. lower upper
cyan_0 101.24524 NA NA
log_k_JCZ38 -2.85375 NA NA
log_k_J9Z38 -5.07729 NA NA
log_k_JSE76 -3.53511 NA NA
f_cyan_ilr_1 0.67478 NA NA
f_cyan_ilr_2 0.97152 NA NA
f_JCZ38_qlogis 213.48001 NA NA
f_JSE76_qlogis 2.02040 NA NA
log_alpha -0.11041 NA NA
log_beta 3.06575 NA NA
a.1 2.05279 1.85495 2.2506
```

b.1	0.07116	0.05912	0.0832
SD.log_k_JCZ38	1.21713	0.44160	1.9927
SD.log_k_J9Z38	0.88268	0.27541	1.4900
SD.log_k_JSE76	0.59452	0.15005	1.0390
SD.f_cyan_ilr_1	0.35370	0.12409	0.5833
SD.f_cyan_ilr_2	0.78186	0.18547	1.3782
SD.log_alpha	0.27781	0.08168	0.4739
SD.log_beta	0.32608	0.06490	0.5873

Correlation is not available

Random effects:

	est.	lower	upper
SD.log_k_JCZ38	1.2171	0.44160	1.9927
SD.log_k_J9Z38	0.8827	0.27541	1.4900
SD.log_k_JSE76	0.5945	0.15005	1.0390
SD.f_cyan_ilr_1	0.3537	0.12409	0.5833
SD.f_cyan_ilr_2	0.7819	0.18547	1.3782
SD.log_alpha	0.2778	0.08168	0.4739
SD.log_beta	0.3261	0.06490	0.5873

Variance model:

	est.	lower	upper
a.1	2.05279	1.85495	2.2506
b.1	0.07116	0.05912	0.0832

Backtransformed parameters:

	est.	lower	upper
cyan_0	1.012e+02	NA	NA
k_JCZ38	5.763e-02	NA	NA
k_J9Z38	6.237e-03	NA	NA
k_JSE76	2.916e-02	NA	NA
f_cyan_to_JCZ38	6.354e-01	NA	NA
f_cyan_to_J9Z38	2.447e-01	NA	NA
f_JCZ38_to_JSE76	1.000e+00	NA	NA
f_JSE76_to_JCZ38	8.829e-01	NA	NA
alpha	8.955e-01	NA	NA
beta	2.145e+01	NA	NA

Resulting formation fractions:

	ff
cyan_JCZ38	0.6354
cyan_J9Z38	0.2447
cyan_sink	0.1200
JCZ38_JSE76	1.0000
JCZ38_sink	0.0000
JSE76_JCZ38	0.8829
JSE76_sink	0.1171

Estimated disappearance times:

	DT50	DT90	DT50back
cyan	25.07	259.21	78.03
JCZ38	12.03	39.96	NA
J9Z38	111.14	369.19	NA
JSE76	23.77	78.98	NA

Listing 16: Hierarchical DFOP path 2 fit with reduced random effects, constant variance

```

saemix version used for fitting:      3.3
mkin version used for pre-fitting:    1.2.9
R version used for fitting:           4.4.2
Date of fit:                          Thu Feb 13 19:05:19 2025
Date of summary:                      Thu Feb 13 19:05:54 2025

Equations:
d_cyan/dt = - ((k1 * g * exp(-k1 * time) + k2 * (1 - g) * exp(-k2 *
time)) / (g * exp(-k1 * time) + (1 - g) * exp(-k2 * time)))
* cyan
d_JCZ38/dt = + f_cyan_to_JCZ38 * ((k1 * g * exp(-k1 * time) + k2 * (1 -
g) * exp(-k2 * time)) / (g * exp(-k1 * time) + (1 - g) *
exp(-k2 * time))) * cyan - k_JCZ38 * JCZ38 +
f_JSE76_to_JCZ38 * k_JSE76 * JSE76
d_J9Z38/dt = + f_cyan_to_J9Z38 * ((k1 * g * exp(-k1 * time) + k2 * (1 -
g) * exp(-k2 * time)) / (g * exp(-k1 * time) + (1 - g) *
exp(-k2 * time))) * cyan - k_J9Z38 * J9Z38
d_JSE76/dt = + f_JCZ38_to_JSE76 * k_JCZ38 * JCZ38 - k_JSE76 * JSE76

Data:
433 observations of 4 variable(s) grouped in 5 datasets

Model predictions using solution type deSolve

Fitted in 926.471 s
Using 300, 100 iterations and 10 chains

Variance model: Constant variance

Starting values for degradation parameters:
cyan_0      log_k_JCZ38      log_k_J9Z38      log_k_JSE76      f_cyan_ilr_1
102.4380    -2.3107                -5.3123                -3.7120                0.6757
f_cyan_ilr_2 f_JCZ38_qlogis f_JSE76_qlogis      log_k1            log_k2
1.1439      13.1194                12.3492                -1.9317                -4.4557
g_qlogis
-0.5644

Fixed degradation parameter values:
None

Starting values for random effects (square root of initial entries in omega):
cyan_0      cyan_0      log_k_JCZ38      log_k_J9Z38      log_k_JSE76      f_cyan_ilr_1
4.591      0.0000      0.000      0.000      0.0      0.0000
log_k_JCZ38      0.000      0.7966      0.000      0.0      0.0000
log_k_J9Z38      0.000      0.0000      1.561      0.0      0.0000
log_k_JSE76      0.000      0.0000      0.000      0.8      0.0000
f_cyan_ilr_1      0.000      0.0000      0.000      0.0      0.6349
f_cyan_ilr_2      0.000      0.0000      0.000      0.0      0.0000
f_JCZ38_qlogis      0.000      0.0000      0.000      0.0      0.0000
f_JSE76_qlogis      0.000      0.0000      0.000      0.0      0.0000
log_k1      0.000      0.0000      0.000      0.0      0.0000
log_k2      0.000      0.0000      0.000      0.0      0.0000
g_qlogis      0.000      0.0000      0.000      0.0      0.0000
f_cyan_ilr_2      f_JCZ38_qlogis      f_JSE76_qlogis      log_k1      log_k2
cyan_0      0.000      0.00      0.00      0.00      0.000      0.0000
log_k_JCZ38      0.000      0.00      0.00      0.00      0.000      0.0000
log_k_J9Z38      0.000      0.00      0.00      0.00      0.000      0.0000
log_k_JSE76      0.000      0.00      0.00      0.00      0.000      0.0000
f_cyan_ilr_1      0.000      0.00      0.00      0.00      0.000      0.0000
f_cyan_ilr_2      1.797      0.00      0.00      0.00      0.000      0.0000
f_JCZ38_qlogis      0.000      13.86      0.00      0.000      0.0000
f_JSE76_qlogis      0.000      0.00      13.91      0.000      0.0000
log_k1      0.000      0.00      0.00      1.106      0.0000
log_k2      0.000      0.00      0.00      0.000      0.6141
g_qlogis      0.000      0.00      0.00      0.000      0.0000
g_qlogis
cyan_0      0.000
log_k_JCZ38      0.000
log_k_J9Z38      0.000
log_k_JSE76      0.000
f_cyan_ilr_1      0.000
f_cyan_ilr_2      0.000
f_JCZ38_qlogis      0.000
f_JSE76_qlogis      0.000
log_k1      0.000
log_k2      0.000
g_qlogis      1.595

Starting values for error model parameters:
a.1
1

```

Results:

Likelihood computed by importance sampling

AIC BIC logLik
2282 2274 -1121

Optimised parameters:

	est.	lower	upper
cyan_0	102.6036	NA	NA
log_k_JCZ38	-2.9348	NA	NA
log_k_J9Z38	-5.1617	NA	NA
log_k_JSE76	-3.6396	NA	NA
f_cyan_ilr_1	0.6991	NA	NA
f_cyan_ilr_2	0.6341	NA	NA
f_JCZ38_qlogis	4232.3011	NA	NA
f_JSE76_qlogis	1.9658	NA	NA
log_k1	-1.9503	NA	NA
log_k2	-4.4745	NA	NA
g_qlogis	-0.4967	NA	NA
a.1	2.7461	2.59274	2.8994
SD.log_k_JCZ38	1.3178	0.47602	2.1596
SD.log_k_J9Z38	0.7022	0.15061	1.2538
SD.log_k_JSE76	0.6566	0.15613	1.1570
SD.f_cyan_ilr_1	0.3409	0.11666	0.5652
SD.f_cyan_ilr_2	0.4385	0.09482	0.7821
SD.log_k1	0.7381	0.25599	1.2202
SD.log_k2	0.5133	0.18152	0.8450
SD.g_qlogis	0.9866	0.35681	1.6164

Correlation is not available

Random effects:

	est.	lower	upper
SD.log_k_JCZ38	1.3178	0.47602	2.1596
SD.log_k_J9Z38	0.7022	0.15061	1.2538
SD.log_k_JSE76	0.6566	0.15613	1.1570
SD.f_cyan_ilr_1	0.3409	0.11666	0.5652
SD.f_cyan_ilr_2	0.4385	0.09482	0.7821
SD.log_k1	0.7381	0.25599	1.2202
SD.log_k2	0.5133	0.18152	0.8450
SD.g_qlogis	0.9866	0.35681	1.6164

Variance model:

	est.	lower	upper
a.1	2.746	2.593	2.899

Backtransformed parameters:

	est.	lower	upper
cyan_0	1.026e+02	NA	NA
k_JCZ38	5.314e-02	NA	NA
k_J9Z38	5.732e-03	NA	NA
k_JSE76	2.626e-02	NA	NA
f_cyan_to_JCZ38	6.051e-01	NA	NA
f_cyan_to_J9Z38	2.251e-01	NA	NA
f_JCZ38_to_JSE76	1.000e+00	NA	NA
f_JSE76_to_JCZ38	8.772e-01	NA	NA
k1	1.422e-01	NA	NA
k2	1.140e-02	NA	NA
g	3.783e-01	NA	NA

Resulting formation fractions:

	ff
cyan_JCZ38	0.6051
cyan_J9Z38	0.2251
cyan_sink	0.1698
JCZ38_JSE76	1.0000
JCZ38_sink	0.0000
JSE76_JCZ38	0.8772
JSE76_sink	0.1228

Estimated disappearance times:

	DT50	DT90	DT50back	DT50_k1	DT50_k2
cyan	22.05	160.35	48.27	4.873	60.83
JCZ38	13.04	43.33	NA	NA	NA
J9Z38	120.93	401.73	NA	NA	NA
JSE76	26.39	87.68	NA	NA	NA

Listing 17: Hierarchical DFOP path 2 fit with reduced random effects, two-component error

```

saemix version used for fitting:      3.3
mkin version used for pre-fitting:    1.2.9
R version used for fitting:          4.4.2
Date of fit:      Thu Feb 13 19:05:53 2025
Date of summary: Thu Feb 13 19:05:54 2025

Equations:
d_cyan/dt = - ((k1 * g * exp(-k1 * time) + k2 * (1 - g) * exp(-k2 *
time)) / (g * exp(-k1 * time) + (1 - g) * exp(-k2 * time)))
* cyan
d_JCZ38/dt = + f_cyan_to_JCZ38 * ((k1 * g * exp(-k1 * time) + k2 * (1 -
g) * exp(-k2 * time)) / (g * exp(-k1 * time) + (1 - g) *
exp(-k2 * time))) * cyan - k_JCZ38 * JCZ38 +
f_JSE76_to_JCZ38 * k_JSE76 * JSE76
d_J9Z38/dt = + f_cyan_to_J9Z38 * ((k1 * g * exp(-k1 * time) + k2 * (1 -
g) * exp(-k2 * time)) / (g * exp(-k1 * time) + (1 - g) *
exp(-k2 * time))) * cyan - k_J9Z38 * J9Z38
d_JSE76/dt = + f_JCZ38_to_JSE76 * k_JCZ38 * JCZ38 - k_JSE76 * JSE76

Data:
433 observations of 4 variable(s) grouped in 5 datasets

Model predictions using solution type deSolve

Fitted in 961.025 s
Using 300, 100 iterations and 10 chains

Variance model: Two-component variance function

Starting values for degradation parameters:
      cyan_0  log_k_JCZ38  log_k_J9Z38  log_k_JSE76  f_cyan_ilr_1
101.7393      -1.4493      -5.0118      -2.1269      0.6720
f_cyan_ilr_2 f_JCZ38_qlogis f_JSE76_qlogis  log_k1      log_k2
7.3362      13.4423      13.2659      -2.0061      -4.5527
g_qlogis
-0.5806

Fixed degradation parameter values:
None

Starting values for random effects (square root of initial entries in omega):
      cyan_0  log_k_JCZ38  log_k_J9Z38  log_k_JSE76  f_cyan_ilr_1
cyan_0      5.604      0.00      0.000      0.000      0.0000
log_k_JCZ38  0.000      2.77      0.000      0.000      0.0000
log_k_J9Z38  0.000      0.00      1.662      0.000      0.0000
log_k_JSE76  0.000      0.00      0.000      5.021      0.0000
f_cyan_ilr_1 0.000      0.00      0.000      0.000      0.6519
f_cyan_ilr_2 0.000      0.00      0.000      0.000      0.0000
f_JCZ38_qlogis 0.000      0.00      0.000      0.000      0.0000
f_JSE76_qlogis 0.000      0.00      0.000      0.000      0.0000
log_k1      0.000      0.00      0.000      0.000      0.0000
log_k2      0.000      0.00      0.000      0.000      0.0000
g_qlogis     0.000      0.00      0.000      0.000      0.0000
      f_cyan_ilr_2 f_JCZ38_qlogis f_JSE76_qlogis log_k1 log_k2
cyan_0      0.00      0.00      0.00      0.00 0.0000 0.0000
log_k_JCZ38 0.00      0.00      0.00      0.00 0.0000 0.0000
log_k_J9Z38 0.00      0.00      0.00      0.00 0.0000 0.0000
log_k_JSE76 0.00      0.00      0.00      0.00 0.0000 0.0000
f_cyan_ilr_1 0.00      0.00      0.00      0.00 0.0000 0.0000
f_cyan_ilr_2 13.37      0.00      0.00      0.00 0.0000 0.0000
f_JCZ38_qlogis 0.00      14.21      0.00      0.00 0.0000 0.0000
f_JSE76_qlogis 0.00      0.00      14.58 0.0000 0.0000
log_k1      0.00      0.00      0.00      0.00 0.8453 0.0000
log_k2      0.00      0.00      0.00      0.00 0.0000 0.5969
g_qlogis     0.00      0.00      0.00      0.00 0.0000 0.0000
      g_qlogis
cyan_0      0.00
log_k_JCZ38 0.00
log_k_J9Z38 0.00
log_k_JSE76 0.00
f_cyan_ilr_1 0.00
f_cyan_ilr_2 0.00
f_JCZ38_qlogis 0.00
f_JSE76_qlogis 0.00
log_k1      0.00
log_k2      0.00
g_qlogis     1.69

Starting values for error model parameters:
a.1 b.1
1 1

```

Results:

Likelihood computed by importance sampling

AIC BIC logLik
2237 2229 -1099

Optimised parameters:

	est.	lower	upper
cyan_0	101.00243	NA	NA
log_k_JCZ38	-2.80828	NA	NA
log_k_J9Z38	-5.04449	NA	NA
log_k_JSE76	-3.66981	NA	NA
f_cyan_ilr_1	0.72564	NA	NA
f_cyan_ilr_2	1.37978	NA	NA
f_JCZ38_qlogis	1.98726	NA	NA
f_JSE76_qlogis	414.80884	NA	NA
log_k1	-2.38601	NA	NA
log_k2	-4.63632	NA	NA
g_qlogis	-0.33920	NA	NA
a.1	2.10837	1.91261	2.30413
b.1	0.06223	0.05085	0.07361
SD.log_k_JCZ38	1.30902	0.48128	2.13675
SD.log_k_J9Z38	0.83882	0.25790	1.41974
SD.log_k_JSE76	0.58104	0.14201	1.02008
SD.f_cyan_ilr_1	0.35421	0.12398	0.58443
SD.f_cyan_ilr_2	0.79373	0.12007	1.46739
SD.log_k2	0.27476	0.08557	0.46394
SD.g_qlogis	0.96170	0.35463	1.56878

Correlation is not available

Random effects:

	est.	lower	upper
SD.log_k_JCZ38	1.30902	0.48128	2.13675
SD.log_k_J9Z38	0.83882	0.25790	1.41974
SD.log_k_JSE76	0.58104	0.14201	1.02008
SD.f_cyan_ilr_1	0.35421	0.12398	0.58443
SD.f_cyan_ilr_2	0.79373	0.12007	1.46739
SD.log_k2	0.27476	0.08557	0.46394
SD.g_qlogis	0.96170	0.35463	1.56878

Variance model:

	est.	lower	upper
a.1	2.10837	1.91261	2.30413
b.1	0.06223	0.05085	0.07361

Backtransformed parameters:

	est.	lower	upper
cyan_0	1.010e+02	NA	NA
k_JCZ38	6.031e-02	NA	NA
k_J9Z38	6.445e-03	NA	NA
k_JSE76	2.548e-02	NA	NA
f_cyan_to_JCZ38	6.808e-01	NA	NA
f_cyan_to_J9Z38	2.440e-01	NA	NA
f_JCZ38_to_JSE76	8.795e-01	NA	NA
f_JSE76_to_JCZ38	1.000e+00	NA	NA
k1	9.200e-02	NA	NA
k2	9.693e-03	NA	NA
g	4.160e-01	NA	NA

Resulting formation fractions:

	ff
cyan_JCZ38	0.68081
cyan_J9Z38	0.24398
cyan_sink	0.07521
JCZ38_JSE76	0.87945
JCZ38_sink	0.12055
JSE76_JCZ38	1.00000
JSE76_sink	0.00000

Estimated disappearance times:

	DT50	DT90	DT50back	DT50_k1	DT50_k2
cyan	25.00	182.05	54.8	7.535	71.51
JCZ38	11.49	38.18	NA	NA	NA
J9Z38	107.55	357.28	NA	NA	NA
JSE76	27.20	90.36	NA	NA	NA

Listing 18: Hierarchical SFORB path 2 fit with reduced random effects, constant variance

```

saemix version used for fitting:      3.3
mkin version used for pre-fitting:    1.2.9
R version used for fitting:           4.4.2
Date of fit:                          Thu Feb 13 19:05:30 2025
Date of summary:                      Thu Feb 13 19:05:54 2025

Equations:
d_cyan_free/dt = - k_cyan_free * cyan_free - k_cyan_free_bound *
                cyan_free + k_cyan_bound_free * cyan_bound
d_cyan_bound/dt = + k_cyan_free_bound * cyan_free - k_cyan_bound_free *
                cyan_bound
d_JCZ38/dt = + f_cyan_free_to_JCZ38 * k_cyan_free * cyan_free - k_JCZ38
                * JCZ38 + f_JSE76_to_JCZ38 * k_JSE76 * JSE76
d_J9Z38/dt = + f_cyan_free_to_J9Z38 * k_cyan_free * cyan_free - k_J9Z38
                * J9Z38
d_JSE76/dt = + f_JCZ38_to_JSE76 * k_JCZ38 * JCZ38 - k_JSE76 * JSE76

Data:
433 observations of 4 variable(s) grouped in 5 datasets

Model predictions using solution type deSolve

Fitted in 937.91 s
Using 300, 100 iterations and 10 chains

Variance model: Constant variance

Starting values for degradation parameters:
cyan_free_0      log_k_cyan_free  log_k_cyan_free_bound
102.4395         -2.7673                -2.8942
log_k_cyan_bound_free  log_k_JCZ38          log_k_J9Z38
-3.6201          -2.3107                -5.3123
log_k_JSE76      f_cyan_ilr_1          f_cyan_ilr_2
-3.7120          0.6754                 1.1448
f_JCZ38_qlogis   f_JSE76_qlogis
14.8408          15.4734

Fixed degradation parameter values:
None

Starting values for random effects (square root of initial entries in omega):
cyan_free_0      log_k_cyan_free  log_k_cyan_free_bound
4.589            0.0000          0.0000
log_k_cyan_free  0.0000          0.4849          0.0000
log_k_cyan_bound_free  0.0000          0.0000          1.62
log_k_cyan_bound_free  0.0000          0.0000          0.00
log_k_JCZ38      0.0000          0.0000          0.00
log_k_J9Z38      0.0000          0.0000          0.00
log_k_JSE76      0.0000          0.0000          0.00
f_cyan_ilr_1     0.0000          0.0000          0.00
f_cyan_ilr_2     0.0000          0.0000          0.00
f_JCZ38_qlogis   0.0000          0.0000          0.00
f_JSE76_qlogis   0.0000          0.0000          0.00
cyan_free_0      log_k_cyan_bound_free  log_k_JCZ38  log_k_J9Z38  log_k_JSE76
0.0000           0.0000           0.0000      0.0000      0.00
log_k_cyan_free  0.0000           0.0000           0.0000      0.00
log_k_cyan_bound_free  0.0000           0.0000           0.0000      0.00
log_k_cyan_bound_free  1.197            0.0000           0.0000      0.00
log_k_JCZ38      0.0000           0.7966           0.0000      0.00
log_k_J9Z38      0.0000           0.0000           1.561       0.00
log_k_JSE76      0.0000           0.0000           0.0000      0.8
f_cyan_ilr_1     0.0000           0.0000           0.0000      0.00
f_cyan_ilr_2     0.0000           0.0000           0.0000      0.00
f_JCZ38_qlogis   0.0000           0.0000           0.0000      0.00
f_JSE76_qlogis   0.0000           0.0000           0.0000      0.00
cyan_free_0      f_cyan_ilr_1  f_cyan_ilr_2  f_JCZ38_qlogis  f_JSE76_qlogis
0.0000           0.0000        0.0000         0.0             0.00
log_k_cyan_free  0.0000           0.0000         0.0             0.00
log_k_cyan_bound_free  0.0000           0.0000         0.0             0.00
log_k_cyan_bound_free  0.0000           0.0000         0.0             0.00
log_k_JCZ38      0.0000           0.0000         0.0             0.00
log_k_J9Z38      0.0000           0.0000         0.0             0.00
log_k_JSE76      0.0000           0.0000         0.0             0.00
f_cyan_ilr_1     0.6349           0.0000         0.0             0.00
f_cyan_ilr_2     0.0000           1.797          0.0             0.00
f_JCZ38_qlogis   0.0000           0.0000        15.6            0.00
f_JSE76_qlogis   0.0000           0.0000         0.0             17.52

Starting values for error model parameters:
a.1
1

```

Results:

Likelihood computed by importance sampling

AIC	BIC	logLik
2280	2272	-1120

Optimised parameters:

	est.	lower	upper
cyan_free_0	102.6532	NA	NA
log_k_cyan_free	-2.8547	NA	NA
log_k_cyan_free_bound	-2.7004	NA	NA
log_k_cyan_bound_free	-3.5078	NA	NA
log_k_JCZ38	-2.9255	NA	NA
log_k_J9Z38	-5.1089	NA	NA
log_k_JSE76	-3.6263	NA	NA
f_cyan_ilr_1	0.6873	NA	NA
f_cyan_ilr_2	0.6498	NA	NA
f_JCZ38_qlogis	3624.2149	NA	NA
f_JSE76_qlogis	1.9991	NA	NA
a.1	2.7472	2.55559	2.9388
SD.log_k_cyan_free	0.3227	0.10296	0.5423
SD.log_k_cyan_free_bound	0.8757	0.29525	1.4562
SD.log_k_cyan_bound_free	0.6128	0.20220	1.0233
SD.log_k_JCZ38	1.3431	0.48474	2.2014
SD.log_k_J9Z38	0.6881	0.14714	1.2291
SD.log_k_JSE76	0.6461	0.15321	1.1390
SD.f_cyan_ilr_1	0.3361	0.11376	0.5585
SD.f_cyan_ilr_2	0.4286	0.08419	0.7730

Correlation is not available

Random effects:

	est.	lower	upper
SD.log_k_cyan_free	0.3227	0.10296	0.5423
SD.log_k_cyan_free_bound	0.8757	0.29525	1.4562
SD.log_k_cyan_bound_free	0.6128	0.20220	1.0233
SD.log_k_JCZ38	1.3431	0.48474	2.2014
SD.log_k_J9Z38	0.6881	0.14714	1.2291
SD.log_k_JSE76	0.6461	0.15321	1.1390
SD.f_cyan_ilr_1	0.3361	0.11376	0.5585
SD.f_cyan_ilr_2	0.4286	0.08419	0.7730

Variance model:

	est.	lower	upper
a.1	2.747	2.556	2.939

Backtransformed parameters:

	est.	lower	upper
cyan_free_0	1.027e+02	NA	NA
k_cyan_free	5.758e-02	NA	NA
k_cyan_free_bound	6.718e-02	NA	NA
k_cyan_bound_free	2.996e-02	NA	NA
k_JCZ38	5.364e-02	NA	NA
k_J9Z38	6.042e-03	NA	NA
k_JSE76	2.662e-02	NA	NA
f_cyan_free_to_JCZ38	6.039e-01	NA	NA
f_cyan_free_to_J9Z38	2.285e-01	NA	NA
f_JCZ38_to_JSE76	1.000e+00	NA	NA
f_JSE76_to_JCZ38	8.807e-01	NA	NA

Estimated Eigenvalues of SFORB model(s):

cyan_b1	cyan_b2	cyan_g
0.1426	0.0121	0.3484

Resulting formation fractions:

	ff
cyan_free_JCZ38	0.6039
cyan_free_J9Z38	0.2285
cyan_free_sink	0.1676
cyan_free	1.0000
JCZ38_JSE76	1.0000
JCZ38_sink	0.0000
JSE76_JCZ38	0.8807
JSE76_sink	0.1193

Estimated disappearance times:

	DT50	DT90	DT50back	DT50_cyan_b1	DT50_cyan_b2
cyan	23.84	154.95	46.65	4.86	57.31
JCZ38	12.92	42.93	NA	NA	NA
J9Z38	114.71	381.07	NA	NA	NA
JSE76	26.04	86.51	NA	NA	NA

Listing 19: Hierarchical SFORB path 2 fit with reduced random effects, two-component error

```

saemix version used for fitting:      3.3
mkin version used for pre-fitting:    1.2.9
R version used for fitting:          4.4.2
Date of fit:      Thu Feb 13 19:05:33 2025
Date of summary:  Thu Feb 13 19:05:54 2025

Equations:
d_cyan_free/dt = - k_cyan_free * cyan_free - k_cyan_free_bound *
cyan_free + k_cyan_bound_free * cyan_bound
d_cyan_bound/dt = + k_cyan_free_bound * cyan_free - k_cyan_bound_free *
cyan_bound
d_JCZ38/dt = + f_cyan_free_to_JCZ38 * k_cyan_free * cyan_free - k_JCZ38
* JCZ38 + f_JSE76_to_JCZ38 * k_JSE76 * JSE76
d_J9Z38/dt = + f_cyan_free_to_J9Z38 * k_cyan_free * cyan_free - k_J9Z38
* J9Z38
d_JSE76/dt = + f_JCZ38_to_JSE76 * k_JCZ38 * JCZ38 - k_JSE76 * JSE76

Data:
433 observations of 4 variable(s) grouped in 5 datasets

Model predictions using solution type deSolve

Fitted in 940.602 s
Using 300, 100 iterations and 10 chains

Variance model: Two-component variance function

Starting values for degradation parameters:
cyan_free_0      log_k_cyan_free  log_k_cyan_free_bound
101.7511         -2.8370          -3.0162
log_k_cyan_bound_free      log_k_JCZ38      log_k_J9Z38
-3.6600          -2.2988          -5.3129
log_k_JSE76      f_cyan_ilr_1     f_cyan_ilr_2
-3.6991          0.6722          4.8596
f_JCZ38_qlogis   f_JSE76_qlogis
13.4678          14.2149

Fixed degradation parameter values:
None

Starting values for random effects (square root of initial entries in omega):
cyan_free_0      log_k_cyan_free  log_k_cyan_free_bound
5.629            0.000           0.000
log_k_cyan_free  0.000           0.446           0.000
log_k_cyan_bound_free      log_k_JCZ38      log_k_J9Z38
0.000           0.000           0.000
log_k_JCZ38      0.000           0.000           0.000
log_k_J9Z38      0.000           0.000           0.000
log_k_JSE76      0.000           0.000           0.000
f_cyan_ilr_1     0.000           0.000           0.000
f_cyan_ilr_2     0.000           0.000           0.000
f_JCZ38_qlogis   0.000           0.000           0.000
f_JSE76_qlogis   0.000           0.000           0.000
cyan_free_0      log_k_cyan_bound_free  log_k_JCZ38  log_k_J9Z38  log_k_JSE76
0.000           0.000           0.0000      0.000       0.0000
log_k_cyan_free  0.000           0.0000      0.000       0.0000
log_k_cyan_bound_free      log_k_JCZ38      log_k_J9Z38  log_k_JSE76
0.000           0.0000      0.0000      0.000       0.0000
log_k_JCZ38      0.000           0.7801      0.000       0.0000
log_k_J9Z38      0.000           0.0000      1.575       0.0000
log_k_JSE76      0.000           0.0000      0.000       0.8078
f_cyan_ilr_1     0.000           0.0000      0.000       0.0000
f_cyan_ilr_2     0.000           0.0000      0.000       0.0000
f_JCZ38_qlogis   0.000           0.0000      0.000       0.0000
f_JSE76_qlogis   0.000           0.0000      0.000       0.0000
cyan_free_0      f_cyan_ilr_1  f_cyan_ilr_2  f_JCZ38_qlogis  f_JSE76_qlogis
0.0000           0.000        0.000         0.00           0.00
log_k_cyan_free  0.0000           0.000        0.00           0.00
log_k_cyan_bound_free      log_k_JCZ38      log_k_J9Z38  log_k_JSE76
0.0000           0.000        0.00           0.00           0.00
log_k_JCZ38      0.0000           0.000        0.00           0.00
log_k_J9Z38      0.0000           0.000        0.00           0.00
log_k_JSE76      0.0000           0.000        0.00           0.00
f_cyan_ilr_1     0.6518           0.000        0.00           0.00
f_cyan_ilr_2     0.0000           9.981        0.00           0.00
f_JCZ38_qlogis   0.0000           0.000        14.26          0.00
f_JSE76_qlogis   0.0000           0.000        0.00           16.17

Starting values for error model parameters:
a.1 b.1
1 1

```

Results:

Likelihood computed by importance sampling

AIC BIC logLik
2241 2233 -1101

Optimised parameters:

	est.	lower	upper
cyan_free_0	100.95469	NA	NA
log_k_cyan_free	-3.18706	NA	NA
log_k_cyan_free_bound	-3.38455	NA	NA
log_k_cyan_bound_free	-3.75788	NA	NA
log_k_JCZ38	-2.77024	NA	NA
log_k_J9Z38	-5.03665	NA	NA
log_k_JSE76	-3.60289	NA	NA
f_cyan_ilr_1	0.72263	NA	NA
f_cyan_ilr_2	1.45352	NA	NA
f_JCZ38_qlogis	2.00778	NA	NA
f_JSE76_qlogis	941.58570	NA	NA
a.1	2.11130	1.91479	2.30780
b.1	0.06299	0.05152	0.07445
SD.log_k_cyan_free	0.50098	0.18805	0.81390
SD.log_k_cyan_bound_free	0.31671	0.08467	0.54875
SD.log_k_JCZ38	1.25865	0.45932	2.05798
SD.log_k_J9Z38	0.86833	0.27222	1.46444
SD.log_k_JSE76	0.59325	0.14711	1.03940
SD.f_cyan_ilr_1	0.35705	0.12521	0.58890
SD.f_cyan_ilr_2	0.88541	0.13797	1.63286

Correlation is not available

Random effects:

	est.	lower	upper
SD.log_k_cyan_free	0.5010	0.18805	0.8139
SD.log_k_cyan_bound_free	0.3167	0.08467	0.5487
SD.log_k_JCZ38	1.2587	0.45932	2.0580
SD.log_k_J9Z38	0.8683	0.27222	1.4644
SD.log_k_JSE76	0.5933	0.14711	1.0394
SD.f_cyan_ilr_1	0.3571	0.12521	0.5889
SD.f_cyan_ilr_2	0.8854	0.13797	1.6329

Variance model:

	est.	lower	upper
a.1	2.11130	1.91479	2.30780
b.1	0.06299	0.05152	0.07445

Backtransformed parameters:

	est.	lower	upper
cyan_free_0	1.010e+02	NA	NA
k_cyan_free	4.129e-02	NA	NA
k_cyan_free_bound	3.389e-02	NA	NA
k_cyan_bound_free	2.333e-02	NA	NA
k_JCZ38	6.265e-02	NA	NA
k_J9Z38	6.495e-03	NA	NA
k_JSE76	2.724e-02	NA	NA
f_cyan_free_to_JCZ38	6.844e-01	NA	NA
f_cyan_free_to_J9Z38	2.463e-01	NA	NA
f_JCZ38_to_JSE76	8.816e-01	NA	NA
f_JSE76_to_JCZ38	1.000e+00	NA	NA

Estimated Eigenvalues of SFORB model(s):

cyan_b1 cyan_b2 cyan_g
0.08751 0.01101 0.39586

Resulting formation fractions:

	ff
cyan_free_JCZ38	0.68444
cyan_free_J9Z38	0.24633
cyan_free_sink	0.06923
cyan_free	1.00000
JCZ38_JSE76	0.88161
JCZ38_sink	0.11839
JSE76_JCZ38	1.00000
JSE76_sink	0.00000

Estimated disappearance times:

	DT50	DT90	DT50back	DT50_cyan_b1	DT50_cyan_b2
cyan	25.36	163.36	49.18	7.921	62.95
JCZ38	11.06	36.75	NA	NA	NA
J9Z38	106.71	354.49	NA	NA	NA
JSE76	25.44	84.51	NA	NA	NA

Session info

R version 4.4.2 (2024-10-31)
Platform: x86_64-pc-linux-gnu
Running under: Debian GNU/Linux 12 (bookworm)

Matrix products: default
BLAS: /usr/lib/x86_64-linux-gnu/blas/libblas.so.3.11.0
LAPACK: /usr/lib/x86_64-linux-gnu/lapack/liblapack.so.3.11.0

locale:
[1] LC_CTYPE=de_DE.UTF-8 LC_NUMERIC=C
[3] LC_TIME=de_DE.UTF-8 LC_COLLATE=de_DE.UTF-8
[5] LC_MONETARY=de_DE.UTF-8 LC_MESSAGES=de_DE.UTF-8
[7] LC_PAPER=de_DE.UTF-8 LC_NAME=C
[9] LC_ADDRESS=C LC_TELEPHONE=C
[11] LC_MEASUREMENT=de_DE.UTF-8 LC_IDENTIFICATION=C

time zone: Europe/Berlin
tzcode source: system (glibc)

attached base packages:
[1] parallel stats graphics grDevices utils datasets methods
[8] base

other attached packages:
[1] saemix_3.3 npde_3.5 knitr_1.49 mkin_1.2.9
[5] rmarkdown_2.29 nvimcom_0.9-167

loaded via a namespace (and not attached):
[1] gtable_0.3.6 dplyr_1.1.4 compiler_4.4.2 tinytex_0.54
[5] tidyselect_1.2.1 colorout_1.3-2 gridExtra_2.3 callr_3.7.6
[9] scales_1.3.0 yaml_2.3.10 fastmap_1.2.0 readxl_1.4.3
[13] lattice_0.22-6 ggplot2_3.5.1 R6_2.5.1 generics_0.1.3
[17] lmtest_0.9-40 MASS_7.3-61 tibble_3.2.1 munsell_0.5.1
[21] pillar_1.9.0 rlang_1.1.4 utf8_1.2.4 deSolve_1.40
[25] inline_0.3.20 xfun_0.49 cli_3.6.3 magrittr_2.0.3
[29] ps_1.8.1 processx_3.8.4 digest_0.6.37 grid_4.4.2
[33] mclust_6.1.1 lifecycle_1.0.4 nlme_3.1-166 vctrs_0.6.5
[37] evaluate_1.0.1 glue_1.8.0 cellranger_1.1.0 codetools_0.2-20
[41] zoo_1.8-12 pkgbuild_1.4.5 fansi_1.0.6 colorspace_2.1-1
[45] tools_4.4.2 pkgconfig_2.0.3 htmltools_0.5.8.1

Hardware info

CPU model: AMD Ryzen 9 7950X 16-Core Processor
MemTotal: 64927788 kB