Chapter 13

Further Issues II: Importing IPMs and Function-based MPMs

More and more of our imports come from overseas.

— George W. Bush

It is relatively common these days for population ecologists running matrix projection analyses to find themselves wanting to build IPMs and function-based MPMs (fbMPMs) published by other authors. For example, users might find themselves reading an interesting paper utilizing IPMs, such as Childs et al. (2003) or Dahlgren and Ehrlén (2011), and wanting to replicate the analyses. Fortunately, `lefko3` includes tools to make this relatively easy.

The strategy used in `lefko3` is to take all of the characteristics of an IPM or a fbMPM and input those characteristics as data in a `vrm_input` object. This S3 object is essentially a list that contains up to 13 elements, most of which are structured data frames that need to be edited manually. The function that creates these objects is `vrm_import()`.

To use function `vrm_import()`, users should first determine the monitoring occasions or years for which information will be entered, the number of patches to be covered, whether there are any stage groups, which vital rate models should be developed, whether information is provided for interactions between independent terms, whether any independent factors are categorical, and the distributions and associated parameters assumed for size and fecundity. Although a stageframe is not required to create `vrm_input` objects, a stageframe will be required to create the IPMs, fbMPMs, or projections resulting from them, so users should pay serious attention to creating realistic stageframes.

Let's consider this process using the simplest `vrm_input` object, which includes only terms for main effects, three years, and a single patch, with Gaussian primary size and fecundity. Let's say that our monitoring occurred over the years 2020, 2021, and 2022. This yields only two years at time t, since 2022 includes only data on which stages have been transitioned to, and so we include only those two years in the input options (fates in 2022 act only as responses within the vital rate models, so we cannot add 2022 to the input).

```
vrm_example <- vrm_import(years = c(2020, 2021))

vrm_example
> $vrm_frame
>    main_effect_1                  main_1_defined surv obs sizea sizeb sizec
> 1      intercept                     y-intercept    0   0     0     0     0
> 2          size2                  sizea in time t    0   0     0     0     0
> 3          size1                sizea in time t-1    0   0     0     0     0
```

```
> 4         sizeb2                    sizeb in time t    0   0     0     0     0
> 5         sizeb1                  sizeb in time t-1    0   0     0     0     0
> 6         sizec2                    sizec in time t    0   0     0     0     0
> 7         sizec1                  sizec in time t-1    0   0     0     0     0
> 8         repst2      reproductive status in time t    0   0     0     0     0
> 9         repst1    reproductive status in time t-1    0   0     0     0     0
> 10           age                       age in time t    0   0     0     0     0
> 11       density                   density in time t    0   0     0     0     0
> 12      indcova2   individual covariate a in time t    0   0     0     0     0
> 13      indcova1 individual covariate a in time t-1    0   0     0     0     0
> 14      indcovb2   individual covariate b in time t    0   0     0     0     0
> 15      indcovb1 individual covariate b in time t-1    0   0     0     0     0
> 16      indcovc2   individual covariate c in time t    0   0     0     0     0
> 17      indcovc1 individual covariate c in time t-1    0   0     0     0     0
>    repst fec jsurv jobs jsizea jsizeb jsizec jrepst jmatst
> 1      0   0     0    0      0      0      0      0      0
> 2      0   0     0    0      0      0      0      0      0
> 3      0   0     0    0      0      0      0      0      0
> 4      0   0     0    0      0      0      0      0      0
> 5      0   0     0    0      0      0      0      0      0
> 6      0   0     0    0      0      0      0      0      0
> 7      0   0     0    0      0      0      0      0      0
> 8      0   0     0    0      0      0      0      0      0
> 9      0   0     0    0      0      0      0      0      0
> 10     0   0     0    0      0      0      0      0      0
> 11     0   0     0    0      0      0      0      0      0
> 12     0   0     0    0      0      0      0      0      0
> 13     0   0     0    0      0      0      0      0      0
> 14     0   0     0    0      0      0      0      0      0
> 15     0   0     0    0      0      0      0      0      0
> 16     0   0     0    0      0      0      0      0      0
> 17     0   0     0    0      0      0      0      0      0
>
> $year_frame
>   years surv obs sizea sizeb sizec repst fec jsurv jobs jsizea jsizeb jsizec
> 1  2020    0   0     0     0     0     0   0     0    0      0      0      0
> 2  2021    0   0     0     0     0     0   0     0    0      0      0      0
>   jrepst jmatst
> 1      0      0
> 2      0      0
>
> $patch_frame
>   patches surv obs sizea sizeb sizec repst fec jsurv jobs jsizea jsizeb jsizec
> 1       1    0   0     0     0     0     0   0     0    0      0      0      0
>   jrepst jmatst
> 1      0      0
>
> $group2_frame
>   groups surv obs sizea sizeb sizec repst fec jsurv jobs jsizea jsizeb jsizec
> 1      0    0   0     0     0     0     0   0     0    0      0      0      0
>   jrepst jmatst
```

```
> 1      0      0
>
> $group1_frame
>   groups surv obs sizea sizeb sizec repst fec jsurv jobs jsizea jsizeb jsizec
> 1      0    0   0     0     0     0     0   0     0    0      0      0      0
>   jrepst jmatst
> 1      0      0
>
> $dist_frame
>    response     dist
> 1      surv    binom
> 2       obs constant
> 3     sizea gaussian
> 4     sizeb constant
> 5     sizec constant
> 6     repst constant
> 7       fec gaussian
> 8     jsurv constant
> 9      jobs constant
> 10   jsizea constant
> 11   jsizeb constant
> 12   jsizec constant
> 13   jrepst constant
> 14   jmatst constant
>
> $st_frame
>   surv    obs  sizea  sizeb  sizec  repst    fec  jsurv   jobs jsizea jsizeb
>      1      1      1      1      1      1      1      1      1      1      1
> jsizec jrepst jmatst
>      1      1      1
>
> attr(,"class")
> [1] "vrm_input"
```

Our example `vrm_input` objects is a list holding only 7 elements. The first, `vrm_frame`, is a data frame showing us the main effects factors that we can set for each of up to 14 vital rate models. The 14 vital rate models are the same as those listed in the chapter on function-based MPMs (5): survival (`surv`), observation status (`obs`), primary size (`sizea`), secondary size (`sizeb`), tertiary size (`sizec`), reproductive status (`repst`), fecundity (`fec`), juvenile survival (`jsurv`), juvenile observation status (`jobs`), juvenile primary size (`jsizea`), juvenile secondary size (`jsizeb`), juvenile tertiary size (`jsizec`), juvenile reproductive status (`jrepst`), and juvenile maturity status (`jmatst`). We see rows in which we can alter the coefficients to be used in linear models of vital rates, including the y-intercept (`intercept`), primary size in time t (`size2`), tertiary size in time t-1 (`sizec1`), spatial density (`density`), etc. The general strategy is for users to change the coefficients that they have explicit values for, and to leave the rest as `0`.

Object `year_frame` allows us to set specific coefficients for each year associated with each vital rate model. This is particularly useful as the IPM in question used a mixed modeling approach with year as a random term, although it serves the same function with year as a fixed categorical term. Object `patch_frame` functions in the same way, except for patches or subpopulations (we do not currently offer a top-level population category, but the patch level can be used for populations if the latter are not to be subdivided). Objects `group2_frame` and `group1_frame` provide coefficients associated with different life history stage groups in time t and time t-1, respectively, if such information is provided

and stages are grouped in a way that is incorporated into linear modeling.

Object `dist_frame` gives the distribution of each vital rate model's response term. Any vital rate that uses a linear model for estimation needs to be set to `binom` (for binomial distribution), `gaussian` (for the Gaussian distribution), `gamma` (for the gamma distribution), `poisson` (for the Poisson distribution), or `negbin` (for the negative binomial distribution). Unused vital rates should be set to `constant`. Object `st_frame` allows the user to set σ if the distribution is Gaussian, or θ if the distribution is negative binomial (all other cases should be left as `1`).

Let's now take a look at some examples.

13.1 Generating standard ahistorical IPMs and function-based MPMs

Let's start off by recreating the ahistorical IPM set up in Chapter 7. This example will focus on *Lathyrus vernus* (section 1.6.2). To remind ourselves of this plant and its dataset, let's take a look at a data summary. Note that in a real example from the literature, we might not have the original dataset to work with, but would need to infer certain characteristics about the dataset from the publication.

```
data(lathyrus)

summary(lathyrus)
>     SUBPLOT          GENET          Volume88         lnVol88
>  Min.   :1.000   Min.   :  1.0   Min.   :   3.4   Min.   :1.200
>  1st Qu.:2.000   1st Qu.: 48.0   1st Qu.:  63.0   1st Qu.:4.100
>  Median :3.000   Median : 97.0   Median : 732.5   Median :6.600
>  Mean   :3.223   Mean   :110.2   Mean   : 749.4   Mean   :5.538
>  3rd Qu.:4.000   3rd Qu.:167.5   3rd Qu.:1025.5   3rd Qu.:6.900
>  Max.   :6.000   Max.   :284.0   Max.   :7032.0   Max.   :8.900
>                                  NA's   :404      NA's   :404
>     FCODE88          Flow88       Intactseed88 Dead1988       Dormant1988
>  Min.   :0.0000   Min.   : 1.00   Min.   : 0    Mode:logical   Mode:logical
>  1st Qu.:0.0000   1st Qu.: 4.00   1st Qu.: 0    NA's:1119      NA's:1119
>  Median :0.0000   Median : 8.00   Median : 0
>  Mean   :0.3399   Mean   :11.86   Mean   : 3
>  3rd Qu.:1.0000   3rd Qu.:15.00   3rd Qu.: 4
>  Max.   :1.0000   Max.   :66.00   Max.   :34
>  NA's   :404      NA's   :910     NA's   :875
>  Missing1988     Seedling1988      Volume89         lnVol89
>  Mode:logical   Min.   :1.000   Min.   :   1.8   Min.   :0.600
>  NA's:1119      1st Qu.:2.000   1st Qu.:  15.6   1st Qu.:2.700
>                 Median :2.000   Median : 118.8   Median :4.800
>                 Mean   :2.144   Mean   : 573.3   Mean   :4.855
>                 3rd Qu.:3.000   3rd Qu.: 968.8   3rd Qu.:6.900
>                 Max.   :3.000   Max.   :6539.4   Max.   :8.800
>                 NA's   :1022    NA's   :294      NA's   :294
>     FCODE89          Flow89       Intactseed89      Dead1989
>  Min.   :0.0000   Min.   : 1.00   Min.   : 0.000   Min.   :1
>  1st Qu.:0.0000   1st Qu.: 5.00   1st Qu.: 0.000   1st Qu.:1
>  Median :0.0000   Median :11.00   Median : 5.000   Median :1
>  Mean   :0.2667   Mean   :14.88   Mean   : 8.273   Mean   :1
>  3rd Qu.:1.0000   3rd Qu.:20.00   3rd Qu.:13.000   3rd Qu.:1
>  Max.   :1.0000   Max.   :97.00   Max.   :66.000   Max.   :1
```

```
>  NA's   :294      NA's   :906     NA's   :899      NA's   :1077
>   Dormant1989    Missing1989    Seedling1989      Volume90         lnVol90
>  Min.   :1      Min.   :1      Min.   :1.000   Min.   :   2.1   Min.   :0.700
>  1st Qu.:1      1st Qu.:1      1st Qu.:2.000   1st Qu.:  12.6   1st Qu.:2.500
>  Median :1      Median :1      Median :2.000   Median :  61.0   Median :4.100
>  Mean   :1      Mean   :1      Mean   :2.136   Mean   : 244.1   Mean   :4.207
>  3rd Qu.:1      3rd Qu.:1      3rd Qu.:2.000   3rd Qu.: 295.2   3rd Qu.:5.700
>  Max.   :1      Max.   :1      Max.   :3.000   Max.   :4242.8   Max.   :8.400
>  NA's   :1046   NA's   :1112   NA's   :1001    NA's   :245      NA's   :245
>     FCODE90          Flow90        Intactseed90       Dead1990
>  Min.   :0.0000   Min.   : 1.000   Min.   : 0.000   Min.   :1
>  1st Qu.:0.0000   1st Qu.: 3.000   1st Qu.: 0.000   1st Qu.:1
>  Median :0.0000   Median : 6.000   Median : 0.000   Median :1
>  Mean   :0.1581   Mean   : 8.104   Mean   : 2.514   Mean   :1
>  3rd Qu.:0.0000   3rd Qu.:10.750   3rd Qu.: 1.000   3rd Qu.:1
>  Max.   :1.0000   Max.   :54.000   Max.   :37.000   Max.   :1
>  NA's   :246      NA's   :985      NA's   :981      NA's   :1007
>   Dormant1990    Missing1990    Seedling1990      Volume91         lnVol91
>  Min.   :1      Min.   :1      Min.   :1.000   Min.   :   4.0   Min.   :1.400
>  1st Qu.:1      1st Qu.:1      1st Qu.:2.000   1st Qu.:  12.0   1st Qu.:2.500
>  Median :1      Median :1      Median :2.000   Median : 118.5   Median :4.800
>  Mean   :1      Mean   :1      Mean   :2.186   Mean   : 418.7   Mean   :4.642
>  3rd Qu.:1      3rd Qu.:1      3rd Qu.:2.000   3rd Qu.: 689.7   3rd Qu.:6.500
>  Max.   :1      Max.   :1      Max.   :3.000   Max.   :6645.8   Max.   :8.800
>  NA's   :1054   NA's   :1105   NA's   :1049    NA's   :305      NA's   :305
>     FCODE91          Flow91        Intactseed91       Dead1991    Dormant1991
>  Min.   :0.0000   Min.   : 1.00   Min.   : 0.000   Min.   :1     Min.   :1
>  1st Qu.:0.0000   1st Qu.: 4.00   1st Qu.: 0.000   1st Qu.:1     1st Qu.:1
>  Median :0.0000   Median : 8.00   Median : 3.500   Median :1     Median :1
>  Mean   :0.2525   Mean   :11.12   Mean   : 5.805   Mean   :1     Mean   :1
>  3rd Qu.:1.0000   3rd Qu.:15.00   3rd Qu.:10.000   3rd Qu.:1     3rd Qu.:1
>  Max.   :1.0000   Max.   :48.00   Max.   :48.000   Max.   :1     Max.   :1
>  NA's   :307      NA's   :954     NA's   :919      NA's   :925   NA's   :1034
>   Missing1991    Seedling1991
>  Min.   :1      Min.   :1.000
>  1st Qu.:1      1st Qu.:2.000
>  Median :1      Median :2.000
>  Mean   :1      Mean   :1.973
>  3rd Qu.:1      3rd Qu.:2.000
>  Max.   :1      Max.   :3.000
>  NA's   :1095   NA's   :1082
```

The data were collected over four years - 1988 through 1991. Size is given in two formats - either by the total leaf volume (`Volume`), or by the natural logarithm of the total leaf volume (`lnVol`). As in the previous case, let's use the total volume for this example. We also need to note the minimum and maximum size, and whether an unobservable size class is included. The minimum leaf volume appears to be be 1.8, while the maximum appears to be 7032.0, and the literature on this plant shows that it can experience vegetative dormancy, during which there would be no aboveground tissue and hence leaf volume would be 0.

As before, we need to create a stageframe describing the life history and the actual stages that will compose the discretized IPM. We do so below, utilizing the information that we have gleaned from our study of the publication involved, and then show four key variables within that output. Note that

this stageframe covers a complex IPM, involving 100 size-classified stages and three stages that do not fit in the size gradient (dormant seed, seedling, and vegetative dormancy).

```
sizevector <- c(0, 100, 0, 1, 7100)
stagevector <- c("Sd", "Sdl", "Dorm", "ipm", "ipm")
repvector <- c(0, 0, 0, 1, 1)
obsvector <- c(0, 1, 0, 1, 1)
matvector <- c(0, 0, 1, 1, 1)
immvector <- c(1, 1, 0, 0, 0)
propvector <- c(1, 0, 0, 0, 0)
indataset <- c(0, 1, 1, 1, 1)
binvec <- c(0, 100, 0.5, 1, 1)
comments <- c("Dormant seed", "Seedling", "Dormant", "ipm adult stage",
  "ipm adult stage")
lathframeipm <- sf_create(sizes = sizevector, stagenames = stagevector,
  repstatus = repvector, obsstatus = obsvector, propstatus = propvector,
  immstatus = immvector, matstatus = matvector, comments = comments,
  indataset = indataset, binhalfwidth = binvec, ipmbins = 100, roundsize = 3)

lathframeipm[,c("stage", "size", "sizebin_min", "sizebin_max", "comments")]
>            stage     size sizebin_min sizebin_max        comments
> 1             Sd    0.000        0.00        0.00    Dormant seed
> 2            Sdl  100.000        0.00      200.00        Seedling
> 3           Dorm    0.000       -0.50        0.50         Dormant
> 4   sza_36.495_0   36.495        1.00       71.99 ipm adult stage
> 5   sza_107.48_0  107.485       71.99      142.98 ipm adult stage
> 6   sza_178.47_0  178.475      142.98      213.97 ipm adult stage
> 7   sza_249.46_0  249.465      213.97      284.96 ipm adult stage
> 8   sza_320.45_0  320.455      284.96      355.95 ipm adult stage
> 9   sza_391.44_0  391.445      355.95      426.94 ipm adult stage
> 10  sza_462.43_0  462.435      426.94      497.93 ipm adult stage
> 11  sza_533.42_0  533.425      497.93      568.92 ipm adult stage
> 12  sza_604.41_0  604.415      568.92      639.91 ipm adult stage
> 13  sza_675.40_0  675.405      639.91      710.90 ipm adult stage
> 14  sza_746.39_0  746.395      710.90      781.89 ipm adult stage
> 15  sza_817.38_0  817.385      781.89      852.88 ipm adult stage
> 16  sza_888.37_0  888.375      852.88      923.87 ipm adult stage
> 17  sza_959.36_0  959.365      923.87      994.86 ipm adult stage
> 18  sza_1030.3_0 1030.355      994.86     1065.85 ipm adult stage
> 19  sza_1101.3_0 1101.345     1065.85     1136.84 ipm adult stage
> 20  sza_1172.3_0 1172.335     1136.84     1207.83 ipm adult stage
> 21  sza_1243.3_0 1243.325     1207.83     1278.82 ipm adult stage
> 22  sza_1314.3_0 1314.315     1278.82     1349.81 ipm adult stage
> 23  sza_1385.3_0 1385.305     1349.81     1420.80 ipm adult stage
> 24  sza_1456.2_0 1456.295     1420.80     1491.79 ipm adult stage
> 25  sza_1527.2_0 1527.285     1491.79     1562.78 ipm adult stage
> 26  sza_1598.2_0 1598.275     1562.78     1633.77 ipm adult stage
> 27  sza_1669.2_0 1669.265     1633.77     1704.76 ipm adult stage
> 28  sza_1740.2_0 1740.255     1704.76     1775.75 ipm adult stage
> 29  sza_1811.2_0 1811.245     1775.75     1846.74 ipm adult stage
> 30  sza_1882.2_0 1882.235     1846.74     1917.73 ipm adult stage
> 31  sza_1953.2_0 1953.225     1917.73     1988.72 ipm adult stage
```

```
> 32  sza_2024.2_0 2024.215     1988.72     2059.71 ipm adult stage
> 33  sza_2095.2_0 2095.205     2059.71     2130.70 ipm adult stage
> 34  sza_2166.1_0 2166.195     2130.70     2201.69 ipm adult stage
> 35  sza_2237.1_0 2237.185     2201.69     2272.68 ipm adult stage
> 36  sza_2308.1_0 2308.175     2272.68     2343.67 ipm adult stage
> 37  sza_2379.1_0 2379.165     2343.67     2414.66 ipm adult stage
> 38  sza_2450.1_0 2450.155     2414.66     2485.65 ipm adult stage
> 39  sza_2521.1_0 2521.145     2485.65     2556.64 ipm adult stage
> 40  sza_2592.1_0 2592.135     2556.64     2627.63 ipm adult stage
> 41  sza_2663.1_0 2663.125     2627.63     2698.62 ipm adult stage
> 42  sza_2734.1_0 2734.115     2698.62     2769.61 ipm adult stage
> 43  sza_2805.1_0 2805.105     2769.61     2840.60 ipm adult stage
> 44  sza_2876.0_0 2876.095     2840.60     2911.59 ipm adult stage
> 45  sza_2947.0_0 2947.085     2911.59     2982.58 ipm adult stage
> 46  sza_3018.0_0 3018.075     2982.58     3053.57 ipm adult stage
> 47  sza_3089.0_0 3089.065     3053.57     3124.56 ipm adult stage
> 48  sza_3160.0_0 3160.055     3124.56     3195.55 ipm adult stage
> 49  sza_3231.0_0 3231.045     3195.55     3266.54 ipm adult stage
> 50  sza_3302.0_0 3302.035     3266.54     3337.53 ipm adult stage
> 51  sza_3373.0_0 3373.025     3337.53     3408.52 ipm adult stage
> 52  sza_3444.0_0 3444.015     3408.52     3479.51 ipm adult stage
> 53  sza_3515.0_0 3515.005     3479.51     3550.50 ipm adult stage
> 54  sza_3585.9_0 3585.995     3550.50     3621.49 ipm adult stage
> 55  sza_3656.9_0 3656.985     3621.49     3692.48 ipm adult stage
> 56  sza_3727.9_0 3727.975     3692.48     3763.47 ipm adult stage
> 57  sza_3798.9_0 3798.965     3763.47     3834.46 ipm adult stage
> 58  sza_3869.9_0 3869.955     3834.46     3905.45 ipm adult stage
> 59  sza_3940.9_0 3940.945     3905.45     3976.44 ipm adult stage
> 60  sza_4011.9_0 4011.935     3976.44     4047.43 ipm adult stage
> 61  sza_4082.9_0 4082.925     4047.43     4118.42 ipm adult stage
> 62  sza_4153.9_0 4153.915     4118.42     4189.41 ipm adult stage
> 63  sza_4224.9_0 4224.905     4189.41     4260.40 ipm adult stage
> 64  sza_4295.8_0 4295.895     4260.40     4331.39 ipm adult stage
> 65  sza_4366.8_0 4366.885     4331.39     4402.38 ipm adult stage
> 66  sza_4437.8_0 4437.875     4402.38     4473.37 ipm adult stage
> 67  sza_4508.8_0 4508.865     4473.37     4544.36 ipm adult stage
> 68  sza_4579.8_0 4579.855     4544.36     4615.35 ipm adult stage
> 69  sza_4650.8_0 4650.845     4615.35     4686.34 ipm adult stage
> 70  sza_4721.8_0 4721.835     4686.34     4757.33 ipm adult stage
> 71  sza_4792.8_0 4792.825     4757.33     4828.32 ipm adult stage
> 72  sza_4863.8_0 4863.815     4828.32     4899.31 ipm adult stage
> 73  sza_4934.8_0 4934.805     4899.31     4970.30 ipm adult stage
> 74  sza_5005.7_0 5005.795     4970.30     5041.29 ipm adult stage
> 75  sza_5076.7_0 5076.785     5041.29     5112.28 ipm adult stage
> 76  sza_5147.7_0 5147.775     5112.28     5183.27 ipm adult stage
> 77  sza_5218.7_0 5218.765     5183.27     5254.26 ipm adult stage
> 78  sza_5289.7_0 5289.755     5254.26     5325.25 ipm adult stage
> 79  sza_5360.7_0 5360.745     5325.25     5396.24 ipm adult stage
> 80  sza_5431.7_0 5431.735     5396.24     5467.23 ipm adult stage
> 81  sza_5502.7_0 5502.725     5467.23     5538.22 ipm adult stage
> 82  sza_5573.7_0 5573.715     5538.22     5609.21 ipm adult stage
```

```
> 83  sza_5644.7_0 5644.705     5609.21     5680.20 ipm adult stage
> 84  sza_5715.6_0 5715.695     5680.20     5751.19 ipm adult stage
> 85  sza_5786.6_0 5786.685     5751.19     5822.18 ipm adult stage
> 86  sza_5857.6_0 5857.675     5822.18     5893.17 ipm adult stage
> 87  sza_5928.6_0 5928.665     5893.17     5964.16 ipm adult stage
> 88  sza_5999.6_0 5999.655     5964.16     6035.15 ipm adult stage
> 89  sza_6070.6_0 6070.645     6035.15     6106.14 ipm adult stage
> 90  sza_6141.6_0 6141.635     6106.14     6177.13 ipm adult stage
> 91  sza_6212.6_0 6212.625     6177.13     6248.12 ipm adult stage
> 92  sza_6283.6_0 6283.615     6248.12     6319.11 ipm adult stage
> 93  sza_6354.6_0 6354.605     6319.11     6390.10 ipm adult stage
> 94  sza_6425.5_0 6425.595     6390.10     6461.09 ipm adult stage
> 95  sza_6496.5_0 6496.585     6461.09     6532.08 ipm adult stage
> 96  sza_6567.5_0 6567.575     6532.08     6603.07 ipm adult stage
> 97  sza_6638.5_0 6638.565     6603.07     6674.06 ipm adult stage
> 98  sza_6709.5_0 6709.555     6674.06     6745.05 ipm adult stage
> 99  sza_6780.5_0 6780.545     6745.05     6816.04 ipm adult stage
> 100 sza_6851.5_0 6851.535     6816.04     6887.03 ipm adult stage
> 101 sza_6922.5_0 6922.525     6887.03     6958.02 ipm adult stage
> 102 sza_6993.5_0 6993.515     6958.02     7029.01 ipm adult stage
> 103 sza_7064.5_0 7064.505     7029.01     7100.00 ipm adult stage
```

13.1.1 Incorporating information from vital rate equations used in IPMs and fbMPMs

To be useful, publications involving IPMs need to show the parameterizations of their kernels, which are generally composed of vital rate models. These parameterizations vary in complexity, as different authors have different preferences for developing vital rate models. Some choose approaches involving splines or general additive modeling - these approaches produce potentially complex patterns and are difficult to characterize except via saved data structures describing the localized relationships between independent terms and response (for an excellent example of a well-done non-linear IPM, see Garcia et al., 2011). Other approaches utilize linear modeling, and may involve generalized linear modeling (GLM) or generalized linear mixed modeling (GLMM) (e.g., Dahlgren and Ehrlén, 2011; Shefferson et al., 2014). Package `lefko3` is currently set up to allow imports of GLM and GLMM models. We anticipate developing methods to import spline-based kernels in the near future.

Let's assume that our IPM is composed of a kernel that is itself composed of four vital rates: survival probability, sprouting probability, size transition, and fecundity. The kernel for a typical sprouting individual would be given as the following.

$$K(x_j, x_i) = s(x_i, t)r(x_j, t+1)g(x_j, x_i) + f(x_i, t) \tag{13.1}$$

Here, $s(x_i, t)$ is the survival of an individual of discretized size x_i at time t to time t+1, $r(x_j, t+1)$ is the sprouting probability of an individual in discretized size x_j at time t+1 that has survived from time t, $g(x_j, x_i)$ is the probability of size transition from discretized size x_i at time t to discretized size x_j in time t+1 assuming survival and sprouting, and $f(x_i, t)$ is the average offspring production in time t+1 of an individual in discretized size x_i at time t. For a vegetatively dormant individual, the kernel differs because a lack of sprouting prevents any size transition or offspring production from occurring, as in the following.

$$K(x_j, x_i) = s(x_i, t)(1 - r(x_j, t+1)) \tag{13.2}$$

Next we need to scour the publication to find the definitions of the vital rate models defining the kernels. In our case, this means finding the slope coefficients and response distributions for all vital

rate models used, including survival probability, sprouting probability, size transition, fecundity, etc. The probability distributions, as shown in our IPM chapter, should be binomial for vital rates such as survival, observation status (sprouting), reproductive status, and maturity status. They could be Gaussian, gamma, Poisson, or negative binomial for size and fecundity, or might be zero-truncated or zero-inflated versions of the Poisson or negative binomial. We also need to know whether juvenile vital rate models will be used, and what those distributions correspond to.

Chapter 7 provides model summaries (just preceding section 7.2.4). For this example, following the model summaries in the IPM chapter, we see that we need survival, observation status, size transition, and fecundity, and that we will also use juvenile survival, juvenile observation status, and juvenile size transition to model the seedling class. The modeling approach is the generalized linear mixed model, with year as a random categorical factor.

Let's start off by building a skeleton `vrm_input` object. Note that we input only the years capable of being transitioned from in the dataset, which means the three years 1988, 1989, and 1990. We will make this object a bit bigger than before, because we will allow fecundity to be zero-inflated (setting `zi = TRUE` will add seven new columns governing the zero-inflation binomial model for all parameters capable of being zero-inflated). We will also set `use.juv = TRUE` to change some defaults to allow the use of juvenile transitions. Here is the code to produce our skeleton object.

```
lath_vrm <- vrm_import(years = c(1988:1990), zi = TRUE, dist.fec = "negbin",
  use.juv = TRUE)

lath_vrm
> $vrm_frame
>    main_effect_1                    main_1_defined surv obs sizea sizeb sizec
> 1      intercept                       y-intercept    0   0     0     0     0
> 2          size2                     sizea in time t    0   0     0     0     0
> 3          size1                   sizea in time t-1    0   0     0     0     0
> 4         sizeb2                     sizeb in time t    0   0     0     0     0
> 5         sizeb1                   sizeb in time t-1    0   0     0     0     0
> 6         sizec2                     sizec in time t    0   0     0     0     0
> 7         sizec1                   sizec in time t-1    0   0     0     0     0
> 8         repst2      reproductive status in time t    0   0     0     0     0
> 9         repst1    reproductive status in time t-1    0   0     0     0     0
> 10           age                        age in time t    0   0     0     0     0
> 11       density                    density in time t    0   0     0     0     0
> 12      indcova2   individual covariate a in time t    0   0     0     0     0
> 13      indcova1 individual covariate a in time t-1    0   0     0     0     0
> 14      indcovb2   individual covariate b in time t    0   0     0     0     0
> 15      indcovb1 individual covariate b in time t-1    0   0     0     0     0
> 16      indcovc2   individual covariate c in time t    0   0     0     0     0
> 17      indcovc1 individual covariate c in time t-1    0   0     0     0     0
>    repst fec jsurv jobs jsizea jsizeb jsizec jrepst jmatst sizea_zi sizeb_zi
> 1      0   0     0    0      0      0      0      0      0         0         0
> 2      0   0     0    0      0      0      0      0      0         0         0
> 3      0   0     0    0      0      0      0      0      0         0         0
> 4      0   0     0    0      0      0      0      0      0         0         0
> 5      0   0     0    0      0      0      0      0      0         0         0
> 6      0   0     0    0      0      0      0      0      0         0         0
> 7      0   0     0    0      0      0      0      0      0         0         0
> 8      0   0     0    0      0      0      0      0      0         0         0
> 9      0   0     0    0      0      0      0      0      0         0         0
> 10     0   0     0    0      0      0      0      0      0         0         0
```

```
> 11     0   0     0    0      0      0      0      0      0        0        0
> 12     0   0     0    0      0      0      0      0      0        0        0
> 13     0   0     0    0      0      0      0      0      0        0        0
> 14     0   0     0    0      0      0      0      0      0        0        0
> 15     0   0     0    0      0      0      0      0      0        0        0
> 16     0   0     0    0      0      0      0      0      0        0        0
> 17     0   0     0    0      0      0      0      0      0        0        0
>    sizec_zi fec_zi jsizea_zi jsizeb_zi jsizec_zi
> 1         0      0         0         0         0
> 2         0      0         0         0         0
> 3         0      0         0         0         0
> 4         0      0         0         0         0
> 5         0      0         0         0         0
> 6         0      0         0         0         0
> 7         0      0         0         0         0
> 8         0      0         0         0         0
> 9         0      0         0         0         0
> 10        0      0         0         0         0
> 11        0      0         0         0         0
> 12        0      0         0         0         0
> 13        0      0         0         0         0
> 14        0      0         0         0         0
> 15        0      0         0         0         0
> 16        0      0         0         0         0
> 17        0      0         0         0         0
>
> $year_frame
>   years surv obs sizea sizeb sizec repst fec jsurv jobs jsizea jsizeb jsizec
> 1  1988    0   0     0     0     0     0   0     0    0      0      0      0
> 2  1989    0   0     0     0     0     0   0     0    0      0      0      0
> 3  1990    0   0     0     0     0     0   0     0    0      0      0      0
>   jrepst jmatst sizea_zi sizeb_zi sizec_zi fec_zi jsizea_zi jsizeb_zi jsizec_zi
> 1      0      0        0        0        0      0         0         0         0
> 2      0      0        0        0        0      0         0         0         0
> 3      0      0        0        0        0      0         0         0         0
>
> $patch_frame
>   patches surv obs sizea sizeb sizec repst fec jsurv jobs jsizea jsizeb jsizec
> 1       1    0   0     0     0     0     0   0     0    0      0      0      0
>   jrepst jmatst sizea_zi sizeb_zi sizec_zi fec_zi jsizea_zi jsizeb_zi jsizec_zi
> 1      0      0        0        0        0      0         0         0         0
>
> $group2_frame
>   groups surv obs sizea sizeb sizec repst fec jsurv jobs jsizea jsizeb jsizec
> 1      0    0   0     0     0     0     0   0     0    0      0      0      0
>   jrepst jmatst sizea_zi sizeb_zi sizec_zi fec_zi jsizea_zi jsizeb_zi jsizec_zi
> 1      0      0        0        0        0      0         0         0         0
>
> $group1_frame
>   groups surv obs sizea sizeb sizec repst fec jsurv jobs jsizea jsizeb jsizec
> 1      0    0   0     0     0     0     0   0     0    0      0      0      0
```

```
>   jrepst jmatst sizea_zi sizeb_zi sizec_zi fec_zi jsizea_zi jsizeb_zi jsizec_zi
> 1      0      0        0        0        0      0         0         0         0
>
> $dist_frame
>    response     dist
> 1      surv    binom
> 2       obs constant
> 3     sizea gaussian
> 4     sizeb constant
> 5     sizec constant
> 6     repst constant
> 7       fec   negbin
> 8     jsurv    binom
> 9      jobs constant
> 10   jsizea gaussian
> 11   jsizeb constant
> 12   jsizec constant
> 13   jrepst constant
> 14   jmatst constant
>
> $st_frame
>   surv    obs  sizea  sizeb  sizec  repst    fec  jsurv   jobs jsizea jsizeb
>      1      1      1      1      1      1      1      1      1      1      1
> jsizec jrepst jmatst
>      1      1      1
>
> attr(,"class")
> [1] "vrm_input"
```

Now that we have our skeleton `vrm_input` object, let's take a look at the vital rate models. In a typical publication, the authors might present equations showing the linear relationships among terms. Alternatively, they may present some of the output from modeling, giving us the slope coefficients. Since chapter 7 includes the latter, let's instead assume that we have a paper that presents the vital rate models as equations. Below, we see how the survival and sprouting models might be presented, using the real estimated terms.

$$logit(s(x_i, t)) = 2.32571 + 0.00109size(t) + year(t) + indiv(i) \tag{13.3}$$

$$logit(r(x_j, t+1)) = 2.230 + year(t) + indiv(i) \tag{13.4}$$

In these models, we see that both are binomial models using the logit link. Both have y-intercepts (2.32571 in the case of survival, and 2.230 in the case of sprouting). The survival model involves a relationship with size in time t, and that relationship is linear with a slope of 0.00109. Both equations include categorical values for year in time t and individual, because both survival and sprouting probabilities were estimated as mixed models with year in time t and individual as random terms. Let's input all of the main terms into our skeleton `vrm_input` object, particularly getting the y-intercepts and slope coefficients into the appropriate parts of the `vrm_frame`. Let's also change the distribution of the sprouting model from `constant` (the current setting) to `binom`.

```
int.elem <- which(lath_vrm$vrm_frame$main_effect_1 == "intercept")
size2.elem <- which(lath_vrm$vrm_frame$main_effect_1 == "size2")
```

```
lath_vrm$vrm_frame$surv[int.elem] <- 2.32571
lath_vrm$vrm_frame$surv[size2.elem] <- 0.00109
lath_vrm$vrm_frame$obs[int.elem] <- 2.230
lath_vrm$dist_frame$dist[2] <- "binom"

lath_vrm$vrm_frame
>    main_effect_1                    main_1_defined    surv  obs sizea sizeb
> 1      intercept                       y-intercept 2.32571 2.23     0     0
> 2          size2                    sizea in time t 0.00109 0.00     0     0
> 3          size1                  sizea in time t-1 0.00000 0.00     0     0
> 4         sizeb2                    sizeb in time t 0.00000 0.00     0     0
> 5         sizeb1                  sizeb in time t-1 0.00000 0.00     0     0
> 6         sizec2                    sizec in time t 0.00000 0.00     0     0
> 7         sizec1                  sizec in time t-1 0.00000 0.00     0     0
> 8         repst2      reproductive status in time t 0.00000 0.00     0     0
> 9         repst1    reproductive status in time t-1 0.00000 0.00     0     0
> 10           age                       age in time t 0.00000 0.00     0     0
> 11       density                  density in time t 0.00000 0.00     0     0
> 12      indcova2   individual covariate a in time t 0.00000 0.00     0     0
> 13      indcova1 individual covariate a in time t-1 0.00000 0.00     0     0
> 14      indcovb2   individual covariate b in time t 0.00000 0.00     0     0
> 15      indcovb1 individual covariate b in time t-1 0.00000 0.00     0     0
> 16      indcovc2   individual covariate c in time t 0.00000 0.00     0     0
> 17      indcovc1 individual covariate c in time t-1 0.00000 0.00     0     0
>    sizec repst fec jsurv jobs jsizea jsizeb jsizec jrepst jmatst sizea_zi
> 1      0     0   0     0    0      0      0      0      0      0         0
> 2      0     0   0     0    0      0      0      0      0      0         0
> 3      0     0   0     0    0      0      0      0      0      0         0
> 4      0     0   0     0    0      0      0      0      0      0         0
> 5      0     0   0     0    0      0      0      0      0      0         0
> 6      0     0   0     0    0      0      0      0      0      0         0
> 7      0     0   0     0    0      0      0      0      0      0         0
> 8      0     0   0     0    0      0      0      0      0      0         0
> 9      0     0   0     0    0      0      0      0      0      0         0
> 10     0     0   0     0    0      0      0      0      0      0         0
> 11     0     0   0     0    0      0      0      0      0      0         0
> 12     0     0   0     0    0      0      0      0      0      0         0
> 13     0     0   0     0    0      0      0      0      0      0         0
> 14     0     0   0     0    0      0      0      0      0      0         0
> 15     0     0   0     0    0      0      0      0      0      0         0
> 16     0     0   0     0    0      0      0      0      0      0         0
> 17     0     0   0     0    0      0      0      0      0      0         0
>    sizeb_zi sizec_zi fec_zi jsizea_zi jsizeb_zi jsizec_zi
> 1         0        0      0         0         0         0
> 2         0        0      0         0         0         0
> 3         0        0      0         0         0         0
> 4         0        0      0         0         0         0
> 5         0        0      0         0         0         0
> 6         0        0      0         0         0         0
> 7         0        0      0         0         0         0
> 8         0        0      0         0         0         0
```

```
> 9         0        0      0         0         0         0
> 10        0        0      0         0         0         0
> 11        0        0      0         0         0         0
> 12        0        0      0         0         0         0
> 13        0        0      0         0         0         0
> 14        0        0      0         0         0         0
> 15        0        0      0         0         0         0
> 16        0        0      0         0         0         0
> 17        0        0      0         0         0         0
lath_vrm$dist_frame
>    response     dist
> 1      surv    binom
> 2       obs    binom
> 3     sizea gaussian
> 4     sizeb constant
> 5     sizec constant
> 6     repst constant
> 7       fec   negbin
> 8     jsurv    binom
> 9      jobs constant
> 10   jsizea gaussian
> 11   jsizeb constant
> 12   jsizec constant
> 13   jrepst constant
> 14   jmatst constant
```

We have added the fixed main effects to our survival and sprouting models. Next, we will add the appropriate year terms. Year is a random term in both cases, meaning that the average effect of year has actually already been absorbed by the y-intercept and the mean of the year terms should be approximately zero. So, if we cannot find these terms in the paper, then we can simply assume it is 0, or we can produce random numbers if we have information on the variance of the year term in the model. In our case, we see in the output for the survival and sprouting models in the IPM chapter that the standard deviation of the year term is 0, meaning that these coefficients were inestimable under the mixed structure used. So, we will skip adding these terms here. Because we are not interested in predicting individual survival probabilities, we will also not incorporate any individual terms.

Let's move on to size. Our size model has a Gaussian response and so uses the identity link. Thus, our predicted size in time t+1 is given by the equation below.

$$E(size(x_j, t+1)) = 164.0695 + 0.6211 size(z_i, t) + year(t) + indiv(i) \tag{13.5}$$

The probability of becoming size j in time t+1 assuming a Gaussian distribution is the following.

$$g(x_j, x_i) = \frac{1}{\sqrt{2\pi}\sigma(x_j)} e^{-E(size(x_j, t+1))} \tag{13.6}$$

Our size model includes year terms, which are 96.3244, -240.8036, and 144.4792 for years 1988, 1989, and 1990. We also see that $\sigma = 503.6167$, which is shown as the standard deviation of the residual component in the random effects section of the model summary output. We will add these terms below. Note that primary size is set to the Gaussian distribution by default.

```
lath_vrm$vrm_frame$sizea[int.elem] <- 164.0695
lath_vrm$vrm_frame$sizea[size2.elem] <- 0.6211
```

```
lath_vrm$year_frame$sizea <- c(96.3244, -240.8036, 144.4792)
lath_vrm$st_frame[3] <- 503.6167

lath_vrm$vrm_frame
>    main_effect_1                    main_1_defined    surv  obs    sizea sizeb
> 1      intercept                       y-intercept 2.32571 2.23 164.0695     0
> 2          size2                    sizea in time t 0.00109 0.00   0.6211     0
> 3          size1                  sizea in time t-1 0.00000 0.00   0.0000     0
> 4         sizeb2                    sizeb in time t 0.00000 0.00   0.0000     0
> 5         sizeb1                  sizeb in time t-1 0.00000 0.00   0.0000     0
> 6         sizec2                    sizec in time t 0.00000 0.00   0.0000     0
> 7         sizec1                  sizec in time t-1 0.00000 0.00   0.0000     0
> 8         repst2      reproductive status in time t 0.00000 0.00   0.0000     0
> 9         repst1    reproductive status in time t-1 0.00000 0.00   0.0000     0
> 10           age                       age in time t 0.00000 0.00   0.0000     0
> 11       density                  density in time t 0.00000 0.00   0.0000     0
> 12      indcova2   individual covariate a in time t 0.00000 0.00   0.0000     0
> 13      indcova1 individual covariate a in time t-1 0.00000 0.00   0.0000     0
> 14      indcovb2   individual covariate b in time t 0.00000 0.00   0.0000     0
> 15      indcovb1 individual covariate b in time t-1 0.00000 0.00   0.0000     0
> 16      indcovc2   individual covariate c in time t 0.00000 0.00   0.0000     0
> 17      indcovc1 individual covariate c in time t-1 0.00000 0.00   0.0000     0
>    sizec repst fec jsurv jobs jsizea jsizeb jsizec jrepst jmatst sizea_zi
> 1      0     0   0     0    0      0      0      0      0      0         0
> 2      0     0   0     0    0      0      0      0      0      0         0
> 3      0     0   0     0    0      0      0      0      0      0         0
> 4      0     0   0     0    0      0      0      0      0      0         0
> 5      0     0   0     0    0      0      0      0      0      0         0
> 6      0     0   0     0    0      0      0      0      0      0         0
> 7      0     0   0     0    0      0      0      0      0      0         0
> 8      0     0   0     0    0      0      0      0      0      0         0
> 9      0     0   0     0    0      0      0      0      0      0         0
> 10     0     0   0     0    0      0      0      0      0      0         0
> 11     0     0   0     0    0      0      0      0      0      0         0
> 12     0     0   0     0    0      0      0      0      0      0         0
> 13     0     0   0     0    0      0      0      0      0      0         0
> 14     0     0   0     0    0      0      0      0      0      0         0
> 15     0     0   0     0    0      0      0      0      0      0         0
> 16     0     0   0     0    0      0      0      0      0      0         0
> 17     0     0   0     0    0      0      0      0      0      0         0
>    sizeb_zi sizec_zi fec_zi jsizea_zi jsizeb_zi jsizec_zi
> 1         0        0      0         0         0         0
> 2         0        0      0         0         0         0
> 3         0        0      0         0         0         0
> 4         0        0      0         0         0         0
> 5         0        0      0         0         0         0
> 6         0        0      0         0         0         0
> 7         0        0      0         0         0         0
> 8         0        0      0         0         0         0
> 9         0        0      0         0         0         0
> 10        0        0      0         0         0         0
```

```
> 11        0        0      0         0         0         0
> 12        0        0      0         0         0         0
> 13        0        0      0         0         0         0
> 14        0        0      0         0         0         0
> 15        0        0      0         0         0         0
> 16        0        0      0         0         0         0
> 17        0        0      0         0         0         0
lath_vrm$year_frame
>   years surv obs     sizea sizeb sizec repst fec jsurv jobs jsizea jsizeb
> 1  1988    0   0   96.3244     0     0     0   0     0    0      0      0
> 2  1989    0   0 -240.8036     0     0     0   0     0    0      0      0
> 3  1990    0   0  144.4792     0     0     0   0     0    0      0      0
>   jsizec jrepst jmatst sizea_zi sizeb_zi sizec_zi fec_zi jsizea_zi jsizeb_zi
> 1      0      0      0        0        0        0      0         0         0
> 2      0      0      0        0        0        0      0         0         0
> 3      0      0      0        0        0        0      0         0         0
>   jsizec_zi
> 1         0
> 2         0
> 3         0
lath_vrm$st_frame
>     surv      obs    sizea    sizeb    sizec    repst      fec    jsurv
>   1.0000   1.0000 503.6167   1.0000   1.0000   1.0000   1.0000   1.0000
>     jobs   jsizea   jsizeb   jsizec   jrepst   jmatst
>   1.0000   1.0000   1.0000   1.0000   1.0000   1.0000
```

The next model to add is the fecundity model. This will be a zero-inflated negative binomial mixed model. Zero-inflation models are actually composed of two linear models - a binomial model governing the occurrence of zeros, and a second model with the target distribution covering all non-zeros (in this case, a negative binomial with a log link). So, we will need to parameterize both. Here are the two models, as shown in the model output summary in chapter 7.

$$logit(f(x_i) = 0) = 6.252765 - 0.007313size(t) + year(t) + indiv(i) \tag{13.7}$$

$$log(f(x_i) > 0) = 1.517 + year(t) + indiv(i) \tag{13.8}$$

The dispersion parameter for the negative binomial is θ, and we see in the IPM chapter that this is given as 0.2342114. The year terms for the zero-inflation binomial model are 3.741475×10^{-7}, -7.804715×10^{-8}, and -2.533755×10^{-7} for 1988, 1989, and 1990, respectively. The year terms for the conditional model (governing non-zero responses) are -0.41749627, 0.51421684, and -0.07964038, respectively. Let's incorporate all of these values.

```
lath_vrm$vrm_frame$fec[int.elem] <- 1.517
lath_vrm$vrm_frame$fec_zi[int.elem] <- 6.252765
lath_vrm$vrm_frame$fec_zi[size2.elem] <- -0.007313

lath_vrm$year_frame$fec <- c(-0.41749627, 0.51421684, -0.07964038)
lath_vrm$year_frame$fec_zi <- c(3.741475e-07, -7.804715e-08, -2.533755e-07)

lath_vrm$st_frame[7] <- 0.2342114

lath_vrm
```

```
> $vrm_frame
>    main_effect_1                    main_1_defined    surv  obs    sizea sizeb
> 1      intercept                       y-intercept 2.32571 2.23 164.0695     0
> 2          size2                   sizea in time t 0.00109 0.00   0.6211     0
> 3          size1                 sizea in time t-1 0.00000 0.00   0.0000     0
> 4         sizeb2                   sizeb in time t 0.00000 0.00   0.0000     0
> 5         sizeb1                 sizeb in time t-1 0.00000 0.00   0.0000     0
> 6         sizec2                   sizec in time t 0.00000 0.00   0.0000     0
> 7         sizec1                 sizec in time t-1 0.00000 0.00   0.0000     0
> 8         repst2     reproductive status in time t 0.00000 0.00   0.0000     0
> 9         repst1   reproductive status in time t-1 0.00000 0.00   0.0000     0
> 10           age                       age in time t 0.00000 0.00   0.0000     0
> 11       density                 density in time t 0.00000 0.00   0.0000     0
> 12      indcova2  individual covariate a in time t 0.00000 0.00   0.0000     0
> 13      indcova1 individual covariate a in time t-1 0.00000 0.00   0.0000     0
> 14      indcovb2  individual covariate b in time t 0.00000 0.00   0.0000     0
> 15      indcovb1 individual covariate b in time t-1 0.00000 0.00   0.0000     0
> 16      indcovc2  individual covariate c in time t 0.00000 0.00   0.0000     0
> 17      indcovc1 individual covariate c in time t-1 0.00000 0.00   0.0000     0
>    sizec repst   fec jsurv jobs jsizea jsizeb jsizec jrepst jmatst sizea_zi
> 1      0     0 1.517     0    0      0      0      0      0      0         0
> 2      0     0 0.000     0    0      0      0      0      0      0         0
> 3      0     0 0.000     0    0      0      0      0      0      0         0
> 4      0     0 0.000     0    0      0      0      0      0      0         0
> 5      0     0 0.000     0    0      0      0      0      0      0         0
> 6      0     0 0.000     0    0      0      0      0      0      0         0
> 7      0     0 0.000     0    0      0      0      0      0      0         0
> 8      0     0 0.000     0    0      0      0      0      0      0         0
> 9      0     0 0.000     0    0      0      0      0      0      0         0
> 10     0     0 0.000     0    0      0      0      0      0      0         0
> 11     0     0 0.000     0    0      0      0      0      0      0         0
> 12     0     0 0.000     0    0      0      0      0      0      0         0
> 13     0     0 0.000     0    0      0      0      0      0      0         0
> 14     0     0 0.000     0    0      0      0      0      0      0         0
> 15     0     0 0.000     0    0      0      0      0      0      0         0
> 16     0     0 0.000     0    0      0      0      0      0      0         0
> 17     0     0 0.000     0    0      0      0      0      0      0         0
>    sizeb_zi sizec_zi    fec_zi jsizea_zi jsizeb_zi jsizec_zi
> 1         0        0  6.252765         0         0         0
> 2         0        0 -0.007313         0         0         0
> 3         0        0  0.000000         0         0         0
> 4         0        0  0.000000         0         0         0
> 5         0        0  0.000000         0         0         0
> 6         0        0  0.000000         0         0         0
> 7         0        0  0.000000         0         0         0
> 8         0        0  0.000000         0         0         0
> 9         0        0  0.000000         0         0         0
> 10        0        0  0.000000         0         0         0
> 11        0        0  0.000000         0         0         0
> 12        0        0  0.000000         0         0         0
> 13        0        0  0.000000         0         0         0
```

```
> 14        0        0  0.000000         0         0         0
> 15        0        0  0.000000         0         0         0
> 16        0        0  0.000000         0         0         0
> 17        0        0  0.000000         0         0         0
>
> $year_frame
>   years surv obs     sizea sizeb sizec repst         fec jsurv jobs jsizea
> 1  1988    0   0   96.3244     0     0     0 -0.41749627     0    0      0
> 2  1989    0   0 -240.8036     0     0     0  0.51421684     0    0      0
> 3  1990    0   0  144.4792     0     0     0 -0.07964038     0    0      0
>   jsizeb jsizec jrepst jmatst sizea_zi sizeb_zi sizec_zi        fec_zi
> 1      0      0      0      0        0        0        0  3.741475e-07
> 2      0      0      0      0        0        0        0 -7.804715e-08
> 3      0      0      0      0        0        0        0 -2.533755e-07
>   jsizea_zi jsizeb_zi jsizec_zi
> 1         0         0         0
> 2         0         0         0
> 3         0         0         0
>
> $patch_frame
>   patches surv obs sizea sizeb sizec repst fec jsurv jobs jsizea jsizeb jsizec
> 1       1    0   0     0     0     0     0   0     0    0      0      0      0
>   jrepst jmatst sizea_zi sizeb_zi sizec_zi fec_zi jsizea_zi jsizeb_zi jsizec_zi
> 1      0      0        0        0        0      0         0         0         0
>
> $group2_frame
>   groups surv obs sizea sizeb sizec repst fec jsurv jobs jsizea jsizeb jsizec
> 1      0    0   0     0     0     0     0   0     0    0      0      0      0
>   jrepst jmatst sizea_zi sizeb_zi sizec_zi fec_zi jsizea_zi jsizeb_zi jsizec_zi
> 1      0      0        0        0        0      0         0         0         0
>
> $group1_frame
>   groups surv obs sizea sizeb sizec repst fec jsurv jobs jsizea jsizeb jsizec
> 1      0    0   0     0     0     0     0   0     0    0      0      0      0
>   jrepst jmatst sizea_zi sizeb_zi sizec_zi fec_zi jsizea_zi jsizeb_zi jsizec_zi
> 1      0      0        0        0        0      0         0         0         0
>
> $dist_frame
>    response     dist
> 1      surv    binom
> 2       obs    binom
> 3     sizea gaussian
> 4     sizeb constant
> 5     sizec constant
> 6     repst constant
> 7       fec   negbin
> 8     jsurv    binom
> 9      jobs constant
> 10   jsizea gaussian
> 11   jsizeb constant
> 12   jsizec constant
```

```
> 13   jrepst constant
> 14   jmatst constant
>
> $st_frame
>        surv         obs       sizea       sizeb       sizec       repst
>   1.0000000   1.0000000 503.6167000   1.0000000   1.0000000   1.0000000
>         fec       jsurv        jobs      jsizea      jsizeb      jsizec
>   0.2342114   1.0000000   1.0000000   1.0000000   1.0000000   1.0000000
>      jrepst      jmatst
>   1.0000000   1.0000000
>
> attr(,"class")
> [1] "vrm_input"
```

Next we will need to input the associated parameters for any other model included in the IPM. Particularly, we know that vital rate models were also estimated for seedlings, and that these models were incorporated as juvenile vital rate models. The juvenile vital rates include survival, sprouting, and size transition. The equations for these models are as follows.

$$logit(s_{juv}(x_i, t)) = 1.03 + year(t) + indiv(i) \tag{13.9}$$

$$logit(r_{juv}(x_j, t+1)) = 10.390 + year(t) + indiv(i) \tag{13.10}$$

$$E_{juv}(size(x_j, t+1)) = 3.0559 + 0.8482size(t) + year(t) + indiv(i) \tag{13.11}$$

Together with the residual σ for the size model and year terms for sprouting and size, let's add all of these terms to our `vrm_input` object.

```
lath_vrm$vrm_frame$jsurv[int.elem] <- 1.03
lath_vrm$vrm_frame$jobs[int.elem] <- 10.390
lath_vrm$vrm_frame$jsizea[int.elem] <- 3.0559
lath_vrm$vrm_frame$jsizea[size2.elem] <- 0.8482

lath_vrm$st_frame[10] <- 5.831

lath_vrm$year_frame$jobs <- c(-0.7459843, 0.6118826, -0.9468618)
lath_vrm$year_frame$jsizea <- c(0.5937962, 1.4551236, -2.0489198)

lath_vrm$dist_frame$dist[9] <- "binom"

lath_vrm
> $vrm_frame
>    main_effect_1                    main_1_defined    surv  obs    sizea sizeb
> 1      intercept                       y-intercept 2.32571 2.23 164.0695     0
> 2          size2                     sizea in time t 0.00109 0.00   0.6211     0
> 3          size1                   sizea in time t-1 0.00000 0.00   0.0000     0
> 4         sizeb2                     sizeb in time t 0.00000 0.00   0.0000     0
> 5         sizeb1                   sizeb in time t-1 0.00000 0.00   0.0000     0
> 6         sizec2                     sizec in time t 0.00000 0.00   0.0000     0
> 7         sizec1                   sizec in time t-1 0.00000 0.00   0.0000     0
> 8         repst2      reproductive status in time t 0.00000 0.00   0.0000     0
```

```
> 9         repst1    reproductive status in time t-1 0.00000 0.00   0.0000     0
> 10           age                      age in time t 0.00000 0.00   0.0000     0
> 11       density                  density in time t 0.00000 0.00   0.0000     0
> 12      indcova2   individual covariate a in time t 0.00000 0.00   0.0000     0
> 13      indcova1 individual covariate a in time t-1 0.00000 0.00   0.0000     0
> 14      indcovb2   individual covariate b in time t 0.00000 0.00   0.0000     0
> 15      indcovb1 individual covariate b in time t-1 0.00000 0.00   0.0000     0
> 16      indcovc2   individual covariate c in time t 0.00000 0.00   0.0000     0
> 17      indcovc1 individual covariate c in time t-1 0.00000 0.00   0.0000     0
>    sizec repst   fec jsurv  jobs jsizea jsizeb jsizec jrepst jmatst sizea_zi
> 1      0     0 1.517  1.03 10.39 3.0559      0      0      0      0         0
> 2      0     0 0.000  0.00  0.00 0.8482      0      0      0      0         0
> 3      0     0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 4      0     0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 5      0     0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 6      0     0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 7      0     0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 8      0     0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 9      0     0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 10     0     0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 11     0     0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 12     0     0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 13     0     0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 14     0     0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 15     0     0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 16     0     0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 17     0     0 0.000  0.00  0.00 0.0000      0      0      0      0         0
>    sizeb_zi sizec_zi    fec_zi jsizea_zi jsizeb_zi jsizec_zi
> 1         0        0  6.252765         0         0         0
> 2         0        0 -0.007313         0         0         0
> 3         0        0  0.000000         0         0         0
> 4         0        0  0.000000         0         0         0
> 5         0        0  0.000000         0         0         0
> 6         0        0  0.000000         0         0         0
> 7         0        0  0.000000         0         0         0
> 8         0        0  0.000000         0         0         0
> 9         0        0  0.000000         0         0         0
> 10        0        0  0.000000         0         0         0
> 11        0        0  0.000000         0         0         0
> 12        0        0  0.000000         0         0         0
> 13        0        0  0.000000         0         0         0
> 14        0        0  0.000000         0         0         0
> 15        0        0  0.000000         0         0         0
> 16        0        0  0.000000         0         0         0
> 17        0        0  0.000000         0         0         0
>
> $year_frame
>   years surv obs     sizea sizeb sizec repst         fec jsurv       jobs
> 1  1988    0   0   96.3244     0     0     0 -0.41749627     0 -0.7459843
> 2  1989    0   0 -240.8036     0     0     0  0.51421684     0  0.6118826
> 3  1990    0   0  144.4792     0     0     0 -0.07964038     0 -0.9468618
```

```
>       jsizea jsizeb jsizec jrepst jmatst sizea_zi sizeb_zi sizec_zi
> 1  0.5937962      0      0      0      0        0        0        0
> 2  1.4551236      0      0      0      0        0        0        0
> 3 -2.0489198      0      0      0      0        0        0        0
>          fec_zi jsizea_zi jsizeb_zi jsizec_zi
> 1  3.741475e-07         0         0         0
> 2 -7.804715e-08         0         0         0
> 3 -2.533755e-07         0         0         0
>
> $patch_frame
>   patches surv obs sizea sizeb sizec repst fec jsurv jobs jsizea jsizeb jsizec
> 1       1    0   0     0     0     0     0   0     0    0      0      0      0
>   jrepst jmatst sizea_zi sizeb_zi sizec_zi fec_zi jsizea_zi jsizeb_zi jsizec_zi
> 1      0      0        0        0        0      0         0         0         0
>
> $group2_frame
>   groups surv obs sizea sizeb sizec repst fec jsurv jobs jsizea jsizeb jsizec
> 1      0    0   0     0     0     0     0   0     0    0      0      0      0
>   jrepst jmatst sizea_zi sizeb_zi sizec_zi fec_zi jsizea_zi jsizeb_zi jsizec_zi
> 1      0      0        0        0        0      0         0         0         0
>
> $group1_frame
>   groups surv obs sizea sizeb sizec repst fec jsurv jobs jsizea jsizeb jsizec
> 1      0    0   0     0     0     0     0   0     0    0      0      0      0
>   jrepst jmatst sizea_zi sizeb_zi sizec_zi fec_zi jsizea_zi jsizeb_zi jsizec_zi
> 1      0      0        0        0        0      0         0         0         0
>
> $dist_frame
>    response     dist
> 1      surv    binom
> 2       obs    binom
> 3     sizea gaussian
> 4     sizeb constant
> 5     sizec constant
> 6     repst constant
> 7       fec   negbin
> 8     jsurv    binom
> 9      jobs    binom
> 10   jsizea gaussian
> 11   jsizeb constant
> 12   jsizec constant
> 13   jrepst constant
> 14   jmatst constant
>
> $st_frame
>       surv         obs       sizea       sizeb       sizec       repst
>   1.0000000   1.0000000 503.6167000   1.0000000   1.0000000   1.0000000
>         fec       jsurv        jobs      jsizea      jsizeb      jsizec
>   0.2342114   1.0000000   1.0000000   5.8310000   1.0000000   1.0000000
>      jrepst      jmatst
>   1.0000000   1.0000000
```

```
>
> attr(,"class")
> [1] "vrm_input"
```

Voilà!

13.1.2 Fitting vital rate models to the matrix estimation functions in `lefko3`

At this point, we have created all of our main IPM vital rate model inputs. However, there are still a few missing pieces that we need to fit in order to create the IPM properly. Our next step is to include instructions that tell `lefko3` how the vital rate models fit together. Let's see how this works.

By default, elements in survival-transition matrices created by functions `flefko2()`, `flefko3()`, `aflefko2()`, and `fleslie()` are estimated via the following two kernels, the first for adults and the second for juveniles.

$$e_{j,i} = surv_{kernel} obs_{kernel} sizea_{kernel} sizeb_{kernel} sizec_{kernel} repr_{kernel} \tag{13.12}$$

$$e_{j,i} = jsurv_{kernel} jobs_{kernel} jsizea_{kernel} jsizeb_{kernel} jsizec_{kernel} jrepr_{kernel} jmatst_{kernel} \tag{13.13}$$

Here, $e_{j,i}$ refers to the element at the j_{th} row and the i_{th} column. The terms to the right of the equal sign refer to the values developed by kernels representing different vital rates. So, $surv_{kernel}$ is the kernel developing the probability of survival, obs_{kernel} is the kernel developing the probability of observation (or its complement), $sizea_{kernel}$ is the probability of size transition in the primary size variable, $sizeb_{kernel}$ is the probability of size transition in the secondary size variable, $sizec_{kernel}$ is the probability of size transition in the tertiary size variable, and $repst_{kernel}$ is the probability of becoming reproductive or its complement. The juvenile kernel is composed of similar vital rate kernels, but also includes $jmatst_{kernel}$, which is the probability of becoming mature or its complement.

Package `lefko3` uses the vital rate kernels above to produce values in essentially all cases, and so vital rate kernel values can shift to a constant value of 1 if a vital rate is not used. There are also circumstances in which vital rates may be fixed to 0 or even other constants, though these are relatively rare (this may occur is a juvenile size class is not utilized, because then juvenile vital rates should generally equal zero during matrix creation). The key is to fix unused vital rates to constant values of 1. We do this by changing the y-intercept of unused vital rate models to exactly `1`, and changing the distribution listed for the vital rate in `dist_frame` as `constant`. Note that we do not need to bother doing this with zero-inflation components of unused vital rates. In our case, all unused vital rate models are already set to `constant`, so we will just change the intercepts to `1`.

```
lath_vrm$vrm_frame$sizeb[1] <- 1
lath_vrm$vrm_frame$sizec[1] <- 1
lath_vrm$vrm_frame$repst[1] <- 1

lath_vrm$vrm_frame$jsizeb[1] <- 1
lath_vrm$vrm_frame$jsizec[1] <- 1
lath_vrm$vrm_frame$jrepst[1] <- 1
lath_vrm$vrm_frame$jmatst[1] <- 1

lath_vrm
> $vrm_frame
>    main_effect_1                    main_1_defined    surv  obs    sizea sizeb
> 1      intercept                       y-intercept 2.32571 2.23 164.0695     1
> 2          size2                     sizea in time t 0.00109 0.00   0.6211     0
```

```
> 3          size1                  sizea in time t-1 0.00000 0.00   0.0000     0
> 4         sizeb2                    sizeb in time t 0.00000 0.00   0.0000     0
> 5         sizeb1                  sizeb in time t-1 0.00000 0.00   0.0000     0
> 6         sizec2                    sizec in time t 0.00000 0.00   0.0000     0
> 7         sizec1                  sizec in time t-1 0.00000 0.00   0.0000     0
> 8         repst2      reproductive status in time t 0.00000 0.00   0.0000     0
> 9         repst1    reproductive status in time t-1 0.00000 0.00   0.0000     0
> 10           age                       age in time t 0.00000 0.00   0.0000     0
> 11       density                  density in time t 0.00000 0.00   0.0000     0
> 12      indcova2   individual covariate a in time t 0.00000 0.00   0.0000     0
> 13      indcova1 individual covariate a in time t-1 0.00000 0.00   0.0000     0
> 14      indcovb2   individual covariate b in time t 0.00000 0.00   0.0000     0
> 15      indcovb1 individual covariate b in time t-1 0.00000 0.00   0.0000     0
> 16      indcovc2   individual covariate c in time t 0.00000 0.00   0.0000     0
> 17      indcovc1 individual covariate c in time t-1 0.00000 0.00   0.0000     0
>    sizec repst   fec jsurv  jobs jsizea jsizeb jsizec jrepst jmatst sizea_zi
> 1      1     1 1.517  1.03 10.39 3.0559      1      1      1      1         0
> 2      0     0 0.000  0.00  0.00 0.8482      0      0      0      0         0
> 3      0     0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 4      0     0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 5      0     0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 6      0     0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 7      0     0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 8      0     0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 9      0     0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 10     0     0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 11     0     0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 12     0     0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 13     0     0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 14     0     0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 15     0     0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 16     0     0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 17     0     0 0.000  0.00  0.00 0.0000      0      0      0      0         0
>    sizeb_zi sizec_zi    fec_zi jsizea_zi jsizeb_zi jsizec_zi
> 1         0        0  6.252765         0         0         0
> 2         0        0 -0.007313         0         0         0
> 3         0        0  0.000000         0         0         0
> 4         0        0  0.000000         0         0         0
> 5         0        0  0.000000         0         0         0
> 6         0        0  0.000000         0         0         0
> 7         0        0  0.000000         0         0         0
> 8         0        0  0.000000         0         0         0
> 9         0        0  0.000000         0         0         0
> 10        0        0  0.000000         0         0         0
> 11        0        0  0.000000         0         0         0
> 12        0        0  0.000000         0         0         0
> 13        0        0  0.000000         0         0         0
> 14        0        0  0.000000         0         0         0
> 15        0        0  0.000000         0         0         0
> 16        0        0  0.000000         0         0         0
> 17        0        0  0.000000         0         0         0
```

```
>
> $year_frame
>   years surv obs     sizea sizeb sizec repst         fec jsurv       jobs
> 1  1988    0   0   96.3244     0     0     0 -0.41749627     0 -0.7459843
> 2  1989    0   0 -240.8036     0     0     0  0.51421684     0  0.6118826
> 3  1990    0   0  144.4792     0     0     0 -0.07964038     0 -0.9468618
>       jsizea jsizeb jsizec jrepst jmatst sizea_zi sizeb_zi sizec_zi
> 1  0.5937962      0      0      0      0        0        0        0
> 2  1.4551236      0      0      0      0        0        0        0
> 3 -2.0489198      0      0      0      0        0        0        0
>          fec_zi jsizea_zi jsizeb_zi jsizec_zi
> 1  3.741475e-07         0         0         0
> 2 -7.804715e-08         0         0         0
> 3 -2.533755e-07         0         0         0
>
> $patch_frame
>   patches surv obs sizea sizeb sizec repst fec jsurv jobs jsizea jsizeb jsizec
> 1       1    0   0     0     0     0     0   0     0    0      0      0      0
>   jrepst jmatst sizea_zi sizeb_zi sizec_zi fec_zi jsizea_zi jsizeb_zi jsizec_zi
> 1      0      0        0        0        0      0         0         0         0
>
> $group2_frame
>   groups surv obs sizea sizeb sizec repst fec jsurv jobs jsizea jsizeb jsizec
> 1      0    0   0     0     0     0     0   0     0    0      0      0      0
>   jrepst jmatst sizea_zi sizeb_zi sizec_zi fec_zi jsizea_zi jsizeb_zi jsizec_zi
> 1      0      0        0        0        0      0         0         0         0
>
> $group1_frame
>   groups surv obs sizea sizeb sizec repst fec jsurv jobs jsizea jsizeb jsizec
> 1      0    0   0     0     0     0     0   0     0    0      0      0      0
>   jrepst jmatst sizea_zi sizeb_zi sizec_zi fec_zi jsizea_zi jsizeb_zi jsizec_zi
> 1      0      0        0        0        0      0         0         0         0
>
> $dist_frame
>    response     dist
> 1      surv    binom
> 2       obs    binom
> 3     sizea gaussian
> 4     sizeb constant
> 5     sizec constant
> 6     repst constant
> 7       fec   negbin
> 8     jsurv    binom
> 9      jobs    binom
> 10   jsizea gaussian
> 11   jsizeb constant
> 12   jsizec constant
> 13   jrepst constant
> 14   jmatst constant
>
> $st_frame
```

```
>        surv         obs       sizea       sizeb       sizec       repst
>   1.0000000   1.0000000 503.6167000   1.0000000   1.0000000   1.0000000
>         fec       jsurv        jobs      jsizea      jsizeb      jsizec
>   0.2342114   1.0000000   1.0000000   5.8310000   1.0000000   1.0000000
>      jrepst      jmatst
>   1.0000000   1.0000000
>
> attr(,"class")
> [1] "vrm_input"
```

Next, we will add supplemental information not covered by IPM vital rate models. Let's add that portion now.

```
lathsupp2 <- supplemental(stage3 = c("Sd", "Sdl", "Sd", "Sdl"),
  stage2 = c("Sd", "Sd", "rep", "rep"),
  givenrate = c(0.345, 0.054, NA, NA),
  multiplier = c(NA, NA, 0.345, 0.054),
  type = c(1, 1, 3, 3), stageframe = lathframeipm, historical = FALSE)

lathsupp2
>   stage3 stage2 stage1 eststage3 eststage2 eststage1 givenrate multiplier
> 1     Sd     Sd   <NA>      <NA>      <NA>      <NA>     0.345      1.000
> 2    Sdl     Sd   <NA>      <NA>      <NA>      <NA>     0.054      1.000
> 3     Sd    rep   <NA>      <NA>      <NA>      <NA>        NA      0.345
> 4    Sdl    rep   <NA>      <NA>      <NA>      <NA>        NA      0.054
>   convtype convtype_t12
> 1        1            1
> 2        1            1
> 3        3            1
> 4        3            1
```

Finally, let's build our IPM using the `flefko2()` function.

```
lathmat2_importipm <- flefko2(stageframe = lathframeipm, modelsuite = lath_vrm,
  supplement = lathsupp2, reduce = FALSE)

summary(lathmat2_importipm)
>
> This ahistorical lefkoMat object contains 3 matrices.
>
> Each matrix is square with 103 rows and columns, and a total of 10609 elements.
> A total of 26926 survival transitions were estimated, with 8975.333 per matrix.
> A total of 600 fecundity transitions were estimated, with 200 per matrix.
> This lefkoMat object covers 1 population, 1 patch, and 3 time steps.
>
> Survival probability sum check (each matrix represented by column in order):
>          [,1]  [,2]  [,3]
> Min.    0.000 0.000 0.000
> 1st Qu. 0.979 0.956 0.980
> Median  0.998 0.998 0.998
> Mean    0.951 0.922 0.954
```

```
> 3rd Qu. 1.000 1.000 1.000
> Max.    1.000 1.000 1.000
```

Users exploring the output and comparing against the original published IPM will notice that the element values are almost the same, but differ by tiny amounts (often on the order of 10_{-5} or smaller). These small differences occur because of the rounding that happens when authors publish their models, and are not a cause of concern nor will they cause dramatic differences in inference.

13.2 Importing more complex IPMs and fbMPMs

Users may wish to import more complex structures using further terms or interactions. The approach above works in these cases, as well. For example, suppose that we wished to import the historical IPM for *Lathyrus* shown in the IPM chapter. That IPM involves models with historical size and some two-way interactions. We can also produce imported IPMs for this more complicated case, but need to expand the `vrm_input` object by noting `interactions = TRUE` in the input to that function, as below.

```
lath3_vrm <- vrm_import(years = c(1988:1990), interactions = TRUE, zi = TRUE,
  dist.fec = "negbin", use.juv = TRUE)

lath3_vrm
> $vrm_frame
>     main_effect_1                    main_1_defined main_effect_2
> 1       intercept                       y-intercept
> 2           size2                   sizea in time t
> 3           size1                 sizea in time t-1
> 4          sizeb2                   sizeb in time t
> 5          sizeb1                 sizeb in time t-1
> 6          sizec2                   sizec in time t
> 7          sizec1                 sizec in time t-1
> 8          repst2      reproductive status in time t
> 9          repst1    reproductive status in time t-1
> 10            age                      age in time t
> 11        density                  density in time t
> 12       indcova2   individual covariate a in time t
> 13       indcova1 individual covariate a in time t-1
> 14       indcovb2   individual covariate b in time t
> 15       indcovb1 individual covariate b in time t-1
> 16       indcovc2   individual covariate c in time t
> 17       indcovc1 individual covariate c in time t-1
> 18         repst1    reproductive status in time t-1        repst2
> 19          size1                 sizea in time t-1         size2
> 20          size1                 sizea in time t-1        repst1
> 21          size2                   sizea in time t        repst2
> 22          size2                   sizea in time t        repst1
> 23          size1                 sizea in time t-1        repst2
> 24            age                      age in time t         size1
> 25            age                      age in time t         size2
> 26            age                      age in time t        repst1
> 27            age                      age in time t        repst2
> 28       indcova2   individual covariate a in time t         size2
```

```
> 29       indcovb2   individual covariate b in time t         size2
> 30       indcovc2   individual covariate c in time t         size2
> 31       indcova2   individual covariate a in time t        repst2
> 32       indcovb2   individual covariate b in time t        repst2
> 33       indcovc2   individual covariate c in time t        repst2
> 34       indcova1 individual covariate a in time t-1         size1
> 35       indcovb1 individual covariate b in time t-1         size1
> 36       indcovc1 individual covariate c in time t-1         size1
> 37       indcova1 individual covariate a in time t-1        repst1
> 38       indcovb1 individual covariate b in time t-1        repst1
> 39       indcovc1 individual covariate c in time t-1        repst1
> 40       indcova2   individual covariate a in time t      indcovb2
> 41       indcova2   individual covariate a in time t      indcovc2
> 42       indcovb2   individual covariate b in time t      indcovc2
> 43       indcova1 individual covariate a in time t-1      indcovb1
> 44       indcova1 individual covariate a in time t-1      indcovc1
> 45       indcovb1 individual covariate b in time t-1      indcovc1
> 46       indcova2   individual covariate a in time t      indcovb1
> 47       indcova1 individual covariate a in time t-1      indcovb2
> 48       indcova2   individual covariate a in time t      indcovc1
> 49       indcova1 individual covariate a in time t-1      indcovc2
> 50       indcovb2   individual covariate b in time t      indcovc1
> 51       indcovb1 individual covariate b in time t-1      indcovc2
> 52         sizeb2                    sizeb in time t        sizeb1
> 53         sizec2                    sizec in time t        sizec1
> 54          size1                  sizea in time t-1        sizeb1
> 55          size1                  sizea in time t-1        sizec1
> 56         sizeb1                  sizeb in time t-1        sizec1
> 57          size2                    sizea in time t        sizeb2
> 58          size2                    sizea in time t        sizec2
> 59         sizeb2                    sizeb in time t        sizec2
> 60          size1                  sizea in time t-1        sizeb2
> 61          size1                  sizea in time t-1        sizec2
> 62         sizeb1                  sizeb in time t-1        sizec2
> 63          size2                    sizea in time t        sizeb1
> 64          size2                    sizea in time t        sizec1
> 65         sizeb2                    sizeb in time t        sizec1
> 66        density                  density in time t         size2
> 67        density                  density in time t        sizeb2
> 68        density                  density in time t        sizec2
> 69        density                  density in time t         size1
> 70        density                  density in time t        sizeb1
> 71        density                  density in time t        sizec1
> 72        density                  density in time t        repst2
> 73        density                  density in time t        repst1
> 74         sizeb2                    sizeb in time t        repst2
> 75         sizec2                    sizec in time t        repst2
> 76         sizeb1                  sizeb in time t-1        repst1
> 77         sizeb2                    sizeb in time t        repst1
> 78         sizeb1                  sizeb in time t-1        repst2
> 79         sizec1                  sizec in time t-1        repst1
```

```
> 80         sizec2                    sizec in time t        repst1
> 81         sizec1                  sizec in time t-1        repst2
> 82         sizeb2                    sizeb in time t           age
> 83         sizec2                    sizec in time t           age
> 84        density                  density in time t           age
> 85         sizeb1                  sizeb in time t-1           age
> 86         sizec1                  sizec in time t-1           age
> 87       indcova2   individual covariate a in time t        sizeb2
> 88       indcova2   individual covariate a in time t        sizec2
> 89       indcova2   individual covariate a in time t       density
> 90       indcova1 individual covariate a in time t-1        sizeb1
> 91       indcova1 individual covariate a in time t-1        sizec1
> 92       indcova1 individual covariate a in time t-1        sizeb2
> 93       indcova1 individual covariate a in time t-1        sizec2
> 94       indcova2   individual covariate a in time t        sizeb1
> 95       indcova2   individual covariate a in time t        sizec1
> 96       indcova1 individual covariate a in time t-1       density
> 97       indcovb2   individual covariate b in time t        sizeb2
> 98       indcovb2   individual covariate b in time t        sizec2
> 99       indcovb2   individual covariate b in time t       density
> 100      indcovb1 individual covariate b in time t-1        sizeb1
> 101      indcovb1 individual covariate b in time t-1        sizec1
> 102      indcovb1 individual covariate b in time t-1        sizeb2
> 103      indcovb1 individual covariate b in time t-1        sizec2
> 104      indcovb2   individual covariate b in time t        sizeb1
> 105      indcovb2   individual covariate b in time t        sizec1
> 106      indcovb1 individual covariate b in time t-1       density
> 107      indcovc2   individual covariate c in time t        sizeb2
> 108      indcovc2   individual covariate c in time t        sizec2
> 109      indcovc2   individual covariate c in time t       density
> 110      indcovc1 individual covariate c in time t-1        sizeb1
> 111      indcovc1 individual covariate c in time t-1        sizec1
> 112      indcovc1 individual covariate c in time t-1        sizeb2
> 113      indcovc1 individual covariate c in time t-1        sizec2
> 114      indcovc2   individual covariate c in time t        sizeb1
> 115      indcovc2   individual covariate c in time t        sizec1
> 116      indcovc1 individual covariate c in time t-1       density
> 117      indcova2   individual covariate a in time t         size1
> 118      indcovb2   individual covariate b in time t         size1
> 119      indcovc2   individual covariate c in time t         size1
> 120      indcova1 individual covariate a in time t-1         size2
> 121      indcovb1 individual covariate b in time t-1         size2
> 122      indcovc1 individual covariate c in time t-1         size2
> 123      indcova2   individual covariate a in time t        repst1
> 124      indcovb2   individual covariate b in time t        repst1
> 125      indcovc2   individual covariate c in time t        repst1
> 126      indcova1 individual covariate a in time t-1        repst2
> 127      indcovb1 individual covariate b in time t-1        repst2
> 128      indcovc1 individual covariate c in time t-1        repst2
>                        main_2_defined surv obs sizea sizeb sizec repst fec
> 1                                       0   0     0     0     0     0   0
```

```
> 2                                    0  0  0  0  0  0  0
> 3                                    0  0  0  0  0  0  0
> 4                                    0  0  0  0  0  0  0
> 5                                    0  0  0  0  0  0  0
> 6                                    0  0  0  0  0  0  0
> 7                                    0  0  0  0  0  0  0
> 8                                    0  0  0  0  0  0  0
> 9                                    0  0  0  0  0  0  0
> 10                                   0  0  0  0  0  0  0
> 11                                   0  0  0  0  0  0  0
> 12                                   0  0  0  0  0  0  0
> 13                                   0  0  0  0  0  0  0
> 14                                   0  0  0  0  0  0  0
> 15                                   0  0  0  0  0  0  0
> 16                                   0  0  0  0  0  0  0
> 17                                   0  0  0  0  0  0  0
> 18       reproductive status in time t  0  0  0  0  0  0  0
> 19                     sizea in time t  0  0  0  0  0  0  0
> 20     reproductive status in time t-1  0  0  0  0  0  0  0
> 21       reproductive status in time t  0  0  0  0  0  0  0
> 22     reproductive status in time t-1  0  0  0  0  0  0  0
> 23       reproductive status in time t  0  0  0  0  0  0  0
> 24                   sizea in time t-1  0  0  0  0  0  0  0
> 25                     sizea in time t  0  0  0  0  0  0  0
> 26     reproductive status in time t-1  0  0  0  0  0  0  0
> 27       reproductive status in time t  0  0  0  0  0  0  0
> 28                     sizea in time t  0  0  0  0  0  0  0
> 29                     sizea in time t  0  0  0  0  0  0  0
> 30                     sizea in time t  0  0  0  0  0  0  0
> 31       reproductive status in time t  0  0  0  0  0  0  0
> 32       reproductive status in time t  0  0  0  0  0  0  0
> 33       reproductive status in time t  0  0  0  0  0  0  0
> 34                   sizea in time t-1  0  0  0  0  0  0  0
> 35                   sizea in time t-1  0  0  0  0  0  0  0
> 36                   sizea in time t-1  0  0  0  0  0  0  0
> 37     reproductive status in time t-1  0  0  0  0  0  0  0
> 38     reproductive status in time t-1  0  0  0  0  0  0  0
> 39     reproductive status in time t-1  0  0  0  0  0  0  0
> 40    individual covariate b in time t  0  0  0  0  0  0  0
> 41    individual covariate c in time t  0  0  0  0  0  0  0
> 42    individual covariate c in time t  0  0  0  0  0  0  0
> 43  individual covariate b in time t-1  0  0  0  0  0  0  0
> 44  individual covariate c in time t-1  0  0  0  0  0  0  0
> 45  individual covariate c in time t-1  0  0  0  0  0  0  0
> 46  individual covariate b in time t-1  0  0  0  0  0  0  0
> 47    individual covariate b in time t  0  0  0  0  0  0  0
> 48  individual covariate c in time t-1  0  0  0  0  0  0  0
> 49    individual covariate c in time t  0  0  0  0  0  0  0
> 50  individual covariate c in time t-1  0  0  0  0  0  0  0
> 51    individual covariate c in time t  0  0  0  0  0  0  0
> 52                   sizeb in time t-1  0  0  0  0  0  0  0
```

```
> 53                  sizec in time t-1    0   0     0     0     0     0   0
> 54                  sizeb in time t-1    0   0     0     0     0     0   0
> 55                  sizec in time t-1    0   0     0     0     0     0   0
> 56                  sizec in time t-1    0   0     0     0     0     0   0
> 57                    sizeb in time t    0   0     0     0     0     0   0
> 58                    sizec in time t    0   0     0     0     0     0   0
> 59                    sizec in time t    0   0     0     0     0     0   0
> 60                    sizeb in time t    0   0     0     0     0     0   0
> 61                    sizec in time t    0   0     0     0     0     0   0
> 62                    sizec in time t    0   0     0     0     0     0   0
> 63                  sizeb in time t-1    0   0     0     0     0     0   0
> 64                  sizec in time t-1    0   0     0     0     0     0   0
> 65                  sizec in time t-1    0   0     0     0     0     0   0
> 66                    sizea in time t    0   0     0     0     0     0   0
> 67                    sizeb in time t    0   0     0     0     0     0   0
> 68                    sizec in time t    0   0     0     0     0     0   0
> 69                  sizea in time t-1    0   0     0     0     0     0   0
> 70                  sizeb in time t-1    0   0     0     0     0     0   0
> 71                  sizec in time t-1    0   0     0     0     0     0   0
> 72      reproductive status in time t    0   0     0     0     0     0   0
> 73    reproductive status in time t-1    0   0     0     0     0     0   0
> 74      reproductive status in time t    0   0     0     0     0     0   0
> 75      reproductive status in time t    0   0     0     0     0     0   0
> 76    reproductive status in time t-1    0   0     0     0     0     0   0
> 77    reproductive status in time t-1    0   0     0     0     0     0   0
> 78      reproductive status in time t    0   0     0     0     0     0   0
> 79    reproductive status in time t-1    0   0     0     0     0     0   0
> 80    reproductive status in time t-1    0   0     0     0     0     0   0
> 81      reproductive status in time t    0   0     0     0     0     0   0
> 82                      age in time t    0   0     0     0     0     0   0
> 83                      age in time t    0   0     0     0     0     0   0
> 84                      age in time t    0   0     0     0     0     0   0
> 85                      age in time t    0   0     0     0     0     0   0
> 86                      age in time t    0   0     0     0     0     0   0
> 87                    sizeb in time t    0   0     0     0     0     0   0
> 88                    sizec in time t    0   0     0     0     0     0   0
> 89                  density in time t    0   0     0     0     0     0   0
> 90                  sizeb in time t-1    0   0     0     0     0     0   0
> 91                  sizec in time t-1    0   0     0     0     0     0   0
> 92                    sizeb in time t    0   0     0     0     0     0   0
> 93                    sizec in time t    0   0     0     0     0     0   0
> 94                  sizeb in time t-1    0   0     0     0     0     0   0
> 95                  sizec in time t-1    0   0     0     0     0     0   0
> 96                  density in time t    0   0     0     0     0     0   0
> 97                    sizeb in time t    0   0     0     0     0     0   0
> 98                    sizec in time t    0   0     0     0     0     0   0
> 99                  density in time t    0   0     0     0     0     0   0
> 100                 sizeb in time t-1    0   0     0     0     0     0   0
> 101                 sizec in time t-1    0   0     0     0     0     0   0
> 102                   sizeb in time t    0   0     0     0     0     0   0
> 103                   sizec in time t    0   0     0     0     0     0   0
```

```
> 104                  sizeb in time t-1    0   0     0     0     0     0   0
> 105                  sizec in time t-1    0   0     0     0     0     0   0
> 106                  density in time t    0   0     0     0     0     0   0
> 107                    sizeb in time t    0   0     0     0     0     0   0
> 108                    sizec in time t    0   0     0     0     0     0   0
> 109                  density in time t    0   0     0     0     0     0   0
> 110                  sizeb in time t-1    0   0     0     0     0     0   0
> 111                  sizec in time t-1    0   0     0     0     0     0   0
> 112                    sizeb in time t    0   0     0     0     0     0   0
> 113                    sizec in time t    0   0     0     0     0     0   0
> 114                  sizeb in time t-1    0   0     0     0     0     0   0
> 115                  sizec in time t-1    0   0     0     0     0     0   0
> 116                  density in time t    0   0     0     0     0     0   0
> 117                  sizea in time t-1    0   0     0     0     0     0   0
> 118                  sizea in time t-1    0   0     0     0     0     0   0
> 119                  sizea in time t-1    0   0     0     0     0     0   0
> 120                    sizea in time t    0   0     0     0     0     0   0
> 121                    sizea in time t    0   0     0     0     0     0   0
> 122                    sizea in time t    0   0     0     0     0     0   0
> 123    reproductive status in time t-1    0   0     0     0     0     0   0
> 124    reproductive status in time t-1    0   0     0     0     0     0   0
> 125    reproductive status in time t-1    0   0     0     0     0     0   0
> 126      reproductive status in time t    0   0     0     0     0     0   0
> 127      reproductive status in time t    0   0     0     0     0     0   0
> 128      reproductive status in time t    0   0     0     0     0     0   0
>     jsurv jobs jsizea jsizeb jsizec jrepst jmatst sizea_zi sizeb_zi sizec_zi
> 1       0    0      0      0      0      0      0        0        0        0
> 2       0    0      0      0      0      0      0        0        0        0
> 3       0    0      0      0      0      0      0        0        0        0
> 4       0    0      0      0      0      0      0        0        0        0
> 5       0    0      0      0      0      0      0        0        0        0
> 6       0    0      0      0      0      0      0        0        0        0
> 7       0    0      0      0      0      0      0        0        0        0
> 8       0    0      0      0      0      0      0        0        0        0
> 9       0    0      0      0      0      0      0        0        0        0
> 10      0    0      0      0      0      0      0        0        0        0
> 11      0    0      0      0      0      0      0        0        0        0
> 12      0    0      0      0      0      0      0        0        0        0
> 13      0    0      0      0      0      0      0        0        0        0
> 14      0    0      0      0      0      0      0        0        0        0
> 15      0    0      0      0      0      0      0        0        0        0
> 16      0    0      0      0      0      0      0        0        0        0
> 17      0    0      0      0      0      0      0        0        0        0
> 18      0    0      0      0      0      0      0        0        0        0
> 19      0    0      0      0      0      0      0        0        0        0
> 20      0    0      0      0      0      0      0        0        0        0
> 21      0    0      0      0      0      0      0        0        0        0
> 22      0    0      0      0      0      0      0        0        0        0
> 23      0    0      0      0      0      0      0        0        0        0
> 24      0    0      0      0      0      0      0        0        0        0
> 25      0    0      0      0      0      0      0        0        0        0
```

> 26	0	0	0	0	0	0	0	0	0	0
> 27	0	0	0	0	0	0	0	0	0	0
> 28	0	0	0	0	0	0	0	0	0	0
> 29	0	0	0	0	0	0	0	0	0	0
> 30	0	0	0	0	0	0	0	0	0	0
> 31	0	0	0	0	0	0	0	0	0	0
> 32	0	0	0	0	0	0	0	0	0	0
> 33	0	0	0	0	0	0	0	0	0	0
> 34	0	0	0	0	0	0	0	0	0	0
> 35	0	0	0	0	0	0	0	0	0	0
> 36	0	0	0	0	0	0	0	0	0	0
> 37	0	0	0	0	0	0	0	0	0	0
> 38	0	0	0	0	0	0	0	0	0	0
> 39	0	0	0	0	0	0	0	0	0	0
> 40	0	0	0	0	0	0	0	0	0	0
> 41	0	0	0	0	0	0	0	0	0	0
> 42	0	0	0	0	0	0	0	0	0	0
> 43	0	0	0	0	0	0	0	0	0	0
> 44	0	0	0	0	0	0	0	0	0	0
> 45	0	0	0	0	0	0	0	0	0	0
> 46	0	0	0	0	0	0	0	0	0	0
> 47	0	0	0	0	0	0	0	0	0	0
> 48	0	0	0	0	0	0	0	0	0	0
> 49	0	0	0	0	0	0	0	0	0	0
> 50	0	0	0	0	0	0	0	0	0	0
> 51	0	0	0	0	0	0	0	0	0	0
> 52	0	0	0	0	0	0	0	0	0	0
> 53	0	0	0	0	0	0	0	0	0	0
> 54	0	0	0	0	0	0	0	0	0	0
> 55	0	0	0	0	0	0	0	0	0	0
> 56	0	0	0	0	0	0	0	0	0	0
> 57	0	0	0	0	0	0	0	0	0	0
> 58	0	0	0	0	0	0	0	0	0	0
> 59	0	0	0	0	0	0	0	0	0	0
> 60	0	0	0	0	0	0	0	0	0	0
> 61	0	0	0	0	0	0	0	0	0	0
> 62	0	0	0	0	0	0	0	0	0	0
> 63	0	0	0	0	0	0	0	0	0	0
> 64	0	0	0	0	0	0	0	0	0	0
> 65	0	0	0	0	0	0	0	0	0	0
> 66	0	0	0	0	0	0	0	0	0	0
> 67	0	0	0	0	0	0	0	0	0	0
> 68	0	0	0	0	0	0	0	0	0	0
> 69	0	0	0	0	0	0	0	0	0	0
> 70	0	0	0	0	0	0	0	0	0	0
> 71	0	0	0	0	0	0	0	0	0	0
> 72	0	0	0	0	0	0	0	0	0	0
> 73	0	0	0	0	0	0	0	0	0	0
> 74	0	0	0	0	0	0	0	0	0	0
> 75	0	0	0	0	0	0	0	0	0	0
> 76	0	0	0	0	0	0	0	0	0	0

> 77	0	0	0	0	0	0	0	0	0	0
> 78	0	0	0	0	0	0	0	0	0	0
> 79	0	0	0	0	0	0	0	0	0	0
> 80	0	0	0	0	0	0	0	0	0	0
> 81	0	0	0	0	0	0	0	0	0	0
> 82	0	0	0	0	0	0	0	0	0	0
> 83	0	0	0	0	0	0	0	0	0	0
> 84	0	0	0	0	0	0	0	0	0	0
> 85	0	0	0	0	0	0	0	0	0	0
> 86	0	0	0	0	0	0	0	0	0	0
> 87	0	0	0	0	0	0	0	0	0	0
> 88	0	0	0	0	0	0	0	0	0	0
> 89	0	0	0	0	0	0	0	0	0	0
> 90	0	0	0	0	0	0	0	0	0	0
> 91	0	0	0	0	0	0	0	0	0	0
> 92	0	0	0	0	0	0	0	0	0	0
> 93	0	0	0	0	0	0	0	0	0	0
> 94	0	0	0	0	0	0	0	0	0	0
> 95	0	0	0	0	0	0	0	0	0	0
> 96	0	0	0	0	0	0	0	0	0	0
> 97	0	0	0	0	0	0	0	0	0	0
> 98	0	0	0	0	0	0	0	0	0	0
> 99	0	0	0	0	0	0	0	0	0	0
> 100	0	0	0	0	0	0	0	0	0	0
> 101	0	0	0	0	0	0	0	0	0	0
> 102	0	0	0	0	0	0	0	0	0	0
> 103	0	0	0	0	0	0	0	0	0	0
> 104	0	0	0	0	0	0	0	0	0	0
> 105	0	0	0	0	0	0	0	0	0	0
> 106	0	0	0	0	0	0	0	0	0	0
> 107	0	0	0	0	0	0	0	0	0	0
> 108	0	0	0	0	0	0	0	0	0	0
> 109	0	0	0	0	0	0	0	0	0	0
> 110	0	0	0	0	0	0	0	0	0	0
> 111	0	0	0	0	0	0	0	0	0	0
> 112	0	0	0	0	0	0	0	0	0	0
> 113	0	0	0	0	0	0	0	0	0	0
> 114	0	0	0	0	0	0	0	0	0	0
> 115	0	0	0	0	0	0	0	0	0	0
> 116	0	0	0	0	0	0	0	0	0	0
> 117	0	0	0	0	0	0	0	0	0	0
> 118	0	0	0	0	0	0	0	0	0	0
> 119	0	0	0	0	0	0	0	0	0	0
> 120	0	0	0	0	0	0	0	0	0	0
> 121	0	0	0	0	0	0	0	0	0	0
> 122	0	0	0	0	0	0	0	0	0	0
> 123	0	0	0	0	0	0	0	0	0	0
> 124	0	0	0	0	0	0	0	0	0	0
> 125	0	0	0	0	0	0	0	0	0	0
> 126	0	0	0	0	0	0	0	0	0	0
> 127	0	0	0	0	0	0	0	0	0	0

```
> 128     0    0      0      0      0      0      0        0        0        0
>     fec_zi jsizea_zi jsizeb_zi jsizec_zi
> 1        0         0         0         0
> 2        0         0         0         0
> 3        0         0         0         0
> 4        0         0         0         0
> 5        0         0         0         0
> 6        0         0         0         0
> 7        0         0         0         0
> 8        0         0         0         0
> 9        0         0         0         0
> 10       0         0         0         0
> 11       0         0         0         0
> 12       0         0         0         0
> 13       0         0         0         0
> 14       0         0         0         0
> 15       0         0         0         0
> 16       0         0         0         0
> 17       0         0         0         0
> 18       0         0         0         0
> 19       0         0         0         0
> 20       0         0         0         0
> 21       0         0         0         0
> 22       0         0         0         0
> 23       0         0         0         0
> 24       0         0         0         0
> 25       0         0         0         0
> 26       0         0         0         0
> 27       0         0         0         0
> 28       0         0         0         0
> 29       0         0         0         0
> 30       0         0         0         0
> 31       0         0         0         0
> 32       0         0         0         0
> 33       0         0         0         0
> 34       0         0         0         0
> 35       0         0         0         0
> 36       0         0         0         0
> 37       0         0         0         0
> 38       0         0         0         0
> 39       0         0         0         0
> 40       0         0         0         0
> 41       0         0         0         0
> 42       0         0         0         0
> 43       0         0         0         0
> 44       0         0         0         0
> 45       0         0         0         0
> 46       0         0         0         0
> 47       0         0         0         0
> 48       0         0         0         0
> 49       0         0         0         0
```

```
> 50      0       0       0       0
> 51      0       0       0       0
> 52      0       0       0       0
> 53      0       0       0       0
> 54      0       0       0       0
> 55      0       0       0       0
> 56      0       0       0       0
> 57      0       0       0       0
> 58      0       0       0       0
> 59      0       0       0       0
> 60      0       0       0       0
> 61      0       0       0       0
> 62      0       0       0       0
> 63      0       0       0       0
> 64      0       0       0       0
> 65      0       0       0       0
> 66      0       0       0       0
> 67      0       0       0       0
> 68      0       0       0       0
> 69      0       0       0       0
> 70      0       0       0       0
> 71      0       0       0       0
> 72      0       0       0       0
> 73      0       0       0       0
> 74      0       0       0       0
> 75      0       0       0       0
> 76      0       0       0       0
> 77      0       0       0       0
> 78      0       0       0       0
> 79      0       0       0       0
> 80      0       0       0       0
> 81      0       0       0       0
> 82      0       0       0       0
> 83      0       0       0       0
> 84      0       0       0       0
> 85      0       0       0       0
> 86      0       0       0       0
> 87      0       0       0       0
> 88      0       0       0       0
> 89      0       0       0       0
> 90      0       0       0       0
> 91      0       0       0       0
> 92      0       0       0       0
> 93      0       0       0       0
> 94      0       0       0       0
> 95      0       0       0       0
> 96      0       0       0       0
> 97      0       0       0       0
> 98      0       0       0       0
> 99      0       0       0       0
> 100     0       0       0       0
```

```
> 101      0         0         0         0
> 102      0         0         0         0
> 103      0         0         0         0
> 104      0         0         0         0
> 105      0         0         0         0
> 106      0         0         0         0
> 107      0         0         0         0
> 108      0         0         0         0
> 109      0         0         0         0
> 110      0         0         0         0
> 111      0         0         0         0
> 112      0         0         0         0
> 113      0         0         0         0
> 114      0         0         0         0
> 115      0         0         0         0
> 116      0         0         0         0
> 117      0         0         0         0
> 118      0         0         0         0
> 119      0         0         0         0
> 120      0         0         0         0
> 121      0         0         0         0
> 122      0         0         0         0
> 123      0         0         0         0
> 124      0         0         0         0
> 125      0         0         0         0
> 126      0         0         0         0
> 127      0         0         0         0
> 128      0         0         0         0
>
> $year_frame
>   years surv obs sizea sizeb sizec repst fec jsurv jobs jsizea jsizeb jsizec
> 1  1988    0   0     0     0     0     0   0     0    0      0      0      0
> 2  1989    0   0     0     0     0     0   0     0    0      0      0      0
> 3  1990    0   0     0     0     0     0   0     0    0      0      0      0
>   jrepst jmatst sizea_zi sizeb_zi sizec_zi fec_zi jsizea_zi jsizeb_zi jsizec_zi
> 1      0      0        0        0        0      0         0         0         0
> 2      0      0        0        0        0      0         0         0         0
> 3      0      0        0        0        0      0         0         0         0
>
> $patch_frame
>   patches surv obs sizea sizeb sizec repst fec jsurv jobs jsizea jsizeb jsizec
> 1       1    0   0     0     0     0     0   0     0    0      0      0      0
>   jrepst jmatst sizea_zi sizeb_zi sizec_zi fec_zi jsizea_zi jsizeb_zi jsizec_zi
> 1      0      0        0        0        0      0         0         0         0
>
> $group2_frame
>   groups surv obs sizea sizeb sizec repst fec jsurv jobs jsizea jsizeb jsizec
> 1      0    0   0     0     0     0     0   0     0    0      0      0      0
>   jrepst jmatst sizea_zi sizeb_zi sizec_zi fec_zi jsizea_zi jsizeb_zi jsizec_zi
> 1      0      0        0        0        0      0         0         0         0
>
```

```
> $group1_frame
>   groups surv obs sizea sizeb sizec repst fec jsurv jobs jsizea jsizeb jsizec
> 1      0    0   0     0     0     0     0   0     0    0      0      0      0
>   jrepst jmatst sizea_zi sizeb_zi sizec_zi fec_zi jsizea_zi jsizeb_zi jsizec_zi
> 1      0      0        0        0        0      0         0         0         0
>
> $dist_frame
>    response     dist
> 1      surv    binom
> 2       obs constant
> 3     sizea gaussian
> 4     sizeb constant
> 5     sizec constant
> 6     repst constant
> 7       fec   negbin
> 8     jsurv    binom
> 9      jobs constant
> 10   jsizea gaussian
> 11   jsizeb constant
> 12   jsizec constant
> 13   jrepst constant
> 14   jmatst constant
>
> $st_frame
>   surv    obs  sizea  sizeb  sizec  repst    fec  jsurv   jobs jsizea jsizeb
>      1      1      1      1      1      1      1      1      1      1      1
> jsizec jrepst jmatst
>      1      1      1
>
> attr(,"class")
> [1] "vrm_input"
```

Our new `vrm_input` object is bigger. The difference in size is a direct result of an increased number of rows in the `vrm_frame` element. Previously, that data frame held 17 rows, but now in holds 128. The first seventeen correspond to the main effects, as before, while the remaining 111 rows correspond to the two-way interactions.

Let's start off by changing the distributions, as before.

```
lath3_vrm$dist_frame$dist[2] <- "binom"
lath3_vrm$dist_frame$dist[9] <- "binom"
```

Now let's take a look at our vital rate models. The equations are as follows.

$$logit(s(x_i,t)) = 2.060 + 0.0009891 size(t) + 0.001531 size(t-1) - 0.0000004125 size(t) size(t-1) + year(t) + indiv(i) \tag{13.14}$$

$$logit(r(x_j,t+1)) = 2.230 + year(t) + indiv(i) \tag{13.15}$$

$$E(size(x_j,t+1)) = 89.98 + 0.5954 size(t) + 0.3119 size(t-1) - 0.00009417 size(t) size(t-1) + year(t) + indiv(i) \tag{13.16}$$

$$logit(f(x_i) = 0) = 6.252765 - 0.007313size(t) + year(t) + indiv(i) \tag{13.17}$$

$$log(f(x_i) > 0) = 1.517 + year(t) + indiv(i) \tag{13.18}$$

$$logit(s_{juv}(x_i, t)) = 1.03 + year(t) + indiv(i) \tag{13.19}$$

$$logit(r_{juv}(x_j, t + 1)) = 10.390 + year(t) + indiv(i) \tag{13.20}$$

$$E_{juv}(size(x_j, t + 1)) = 3.0559 + 0.8482size(t) + year(t) + indiv(i) \tag{13.21}$$

Some of these models are the same as in the ahistorical case, but a number are quite different. We will add these coefficients to the `vrm_frame` as before, but paying special attention to interaction terms. We will also add constant values of `1` for the intercepts of unused vital rate models.

```
int.elem <- which(lath3_vrm$vrm_frame$main_effect_1 == "intercept")
size2.elem <- which(lath3_vrm$vrm_frame$main_effect_1 == "size2")[1]
size1.elem <- which(lath3_vrm$vrm_frame$main_effect_1 == "size1")[1]
size2.size1.elem <- intersect(which(lath3_vrm$vrm_frame$main_effect_1 == "size1"),
  which(lath3_vrm$vrm_frame$main_effect_2 == "size2"))

lath3_vrm$vrm_frame$surv[int.elem] <- 2.060
lath3_vrm$vrm_frame$surv[size2.elem] <- 0.0009891
lath3_vrm$vrm_frame$surv[size1.elem] <- 0.001531
lath3_vrm$vrm_frame$surv[size2.size1.elem] <- -0.0000004125

lath3_vrm$vrm_frame$obs[int.elem] <- 2.230

lath3_vrm$vrm_frame$sizea[int.elem] <- 89.98
lath3_vrm$vrm_frame$sizea[size2.elem] <- 0.5954
lath3_vrm$vrm_frame$sizea[size1.elem] <- 0.3119
lath3_vrm$vrm_frame$sizea[size2.size1.elem] <- -0.00009417

lath3_vrm$vrm_frame$fec[int.elem] <- 1.517
lath3_vrm$vrm_frame$fec_zi[int.elem] <- 6.252765
lath3_vrm$vrm_frame$fec_zi[size2.elem] <- -0.007313

lath3_vrm$vrm_frame$jsurv[int.elem] <- 1.03
lath3_vrm$vrm_frame$jobs[int.elem] <- 10.390
lath3_vrm$vrm_frame$jsizea[int.elem] <- 3.0559
lath3_vrm$vrm_frame$jsizea[size2.elem] <- 0.8482

lath3_vrm$vrm_frame$sizeb[1] <- 1
lath3_vrm$vrm_frame$sizec[1] <- 1
lath3_vrm$vrm_frame$repst[1] <- 1

lath3_vrm$vrm_frame$jsizeb[1] <- 1
lath3_vrm$vrm_frame$jsizec[1] <- 1
lath3_vrm$vrm_frame$jrepst[1] <- 1
lath3_vrm$vrm_frame$jmatst[1] <- 1
```

```
lath3_vrm
> $vrm_frame
>     main_effect_1                    main_1_defined main_effect_2
> 1       intercept                       y-intercept
> 2           size2                   sizea in time t
> 3           size1                 sizea in time t-1
> 4          sizeb2                   sizeb in time t
> 5          sizeb1                 sizeb in time t-1
> 6          sizec2                   sizec in time t
> 7          sizec1                 sizec in time t-1
> 8          repst2      reproductive status in time t
> 9          repst1    reproductive status in time t-1
> 10            age                      age in time t
> 11        density                  density in time t
> 12       indcova2   individual covariate a in time t
> 13       indcova1 individual covariate a in time t-1
> 14       indcovb2   individual covariate b in time t
> 15       indcovb1 individual covariate b in time t-1
> 16       indcovc2   individual covariate c in time t
> 17       indcovc1 individual covariate c in time t-1
> 18         repst1    reproductive status in time t-1        repst2
> 19          size1                 sizea in time t-1         size2
> 20          size1                 sizea in time t-1        repst1
> 21          size2                   sizea in time t        repst2
> 22          size2                   sizea in time t        repst1
> 23          size1                 sizea in time t-1        repst2
> 24            age                      age in time t         size1
> 25            age                      age in time t         size2
> 26            age                      age in time t        repst1
> 27            age                      age in time t        repst2
> 28       indcova2   individual covariate a in time t         size2
> 29       indcovb2   individual covariate b in time t         size2
> 30       indcovc2   individual covariate c in time t         size2
> 31       indcova2   individual covariate a in time t        repst2
> 32       indcovb2   individual covariate b in time t        repst2
> 33       indcovc2   individual covariate c in time t        repst2
> 34       indcova1 individual covariate a in time t-1         size1
> 35       indcovb1 individual covariate b in time t-1         size1
> 36       indcovc1 individual covariate c in time t-1         size1
> 37       indcova1 individual covariate a in time t-1        repst1
> 38       indcovb1 individual covariate b in time t-1        repst1
> 39       indcovc1 individual covariate c in time t-1        repst1
> 40       indcova2   individual covariate a in time t      indcovb2
> 41       indcova2   individual covariate a in time t      indcovc2
> 42       indcovb2   individual covariate b in time t      indcovc2
> 43       indcova1 individual covariate a in time t-1      indcovb1
> 44       indcova1 individual covariate a in time t-1      indcovc1
> 45       indcovb1 individual covariate b in time t-1      indcovc1
> 46       indcova2   individual covariate a in time t      indcovb1
> 47       indcova1 individual covariate a in time t-1      indcovb2
> 48       indcova2   individual covariate a in time t      indcovc1
```

```
> 49       indcova1 individual covariate a in time t-1      indcovc2
> 50       indcovb2   individual covariate b in time t      indcovc1
> 51       indcovb1 individual covariate b in time t-1      indcovc2
> 52         sizeb2                   sizeb in time t        sizeb1
> 53         sizec2                   sizec in time t        sizec1
> 54          size1                  sizea in time t-1        sizeb1
> 55          size1                  sizea in time t-1        sizec1
> 56         sizeb1                  sizeb in time t-1        sizec1
> 57          size2                    sizea in time t        sizeb2
> 58          size2                    sizea in time t        sizec2
> 59         sizeb2                    sizeb in time t        sizec2
> 60          size1                  sizea in time t-1        sizeb2
> 61          size1                  sizea in time t-1        sizec2
> 62         sizeb1                  sizeb in time t-1        sizec2
> 63          size2                    sizea in time t        sizeb1
> 64          size2                    sizea in time t        sizec1
> 65         sizeb2                    sizeb in time t        sizec1
> 66        density                  density in time t         size2
> 67        density                  density in time t        sizeb2
> 68        density                  density in time t        sizec2
> 69        density                  density in time t         size1
> 70        density                  density in time t        sizeb1
> 71        density                  density in time t        sizec1
> 72        density                  density in time t        repst2
> 73        density                  density in time t        repst1
> 74         sizeb2                    sizeb in time t        repst2
> 75         sizec2                    sizec in time t        repst2
> 76         sizeb1                  sizeb in time t-1        repst1
> 77         sizeb2                    sizeb in time t        repst1
> 78         sizeb1                  sizeb in time t-1        repst2
> 79         sizec1                  sizec in time t-1        repst1
> 80         sizec2                    sizec in time t        repst1
> 81         sizec1                  sizec in time t-1        repst2
> 82         sizeb2                    sizeb in time t           age
> 83         sizec2                    sizec in time t           age
> 84        density                  density in time t           age
> 85         sizeb1                  sizeb in time t-1           age
> 86         sizec1                  sizec in time t-1           age
> 87       indcova2   individual covariate a in time t        sizeb2
> 88       indcova2   individual covariate a in time t        sizec2
> 89       indcova2   individual covariate a in time t       density
> 90       indcova1 individual covariate a in time t-1        sizeb1
> 91       indcova1 individual covariate a in time t-1        sizec1
> 92       indcova1 individual covariate a in time t-1        sizeb2
> 93       indcova1 individual covariate a in time t-1        sizec2
> 94       indcova2   individual covariate a in time t        sizeb1
> 95       indcova2   individual covariate a in time t        sizec1
> 96       indcova1 individual covariate a in time t-1       density
> 97       indcovb2   individual covariate b in time t        sizeb2
> 98       indcovb2   individual covariate b in time t        sizec2
> 99       indcovb2   individual covariate b in time t       density
```

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> 100      indcovb1 individual covariate b in time t-1        sizeb1
> 101      indcovb1 individual covariate b in time t-1        sizec1
> 102      indcovb1 individual covariate b in time t-1        sizeb2
> 103      indcovb1 individual covariate b in time t-1        sizec2
> 104      indcovb2   individual covariate b in time t        sizeb1
> 105      indcovb2   individual covariate b in time t        sizec1
> 106      indcovb1 individual covariate b in time t-1       density
> 107      indcovc2   individual covariate c in time t        sizeb2
> 108      indcovc2   individual covariate c in time t        sizec2
> 109      indcovc2   individual covariate c in time t       density
> 110      indcovc1 individual covariate c in time t-1        sizeb1
> 111      indcovc1 individual covariate c in time t-1        sizec1
> 112      indcovc1 individual covariate c in time t-1        sizeb2
> 113      indcovc1 individual covariate c in time t-1        sizec2
> 114      indcovc2   individual covariate c in time t        sizeb1
> 115      indcovc2   individual covariate c in time t        sizec1
> 116      indcovc1 individual covariate c in time t-1       density
> 117      indcova2   individual covariate a in time t         size1
> 118      indcovb2   individual covariate b in time t         size1
> 119      indcovc2   individual covariate c in time t         size1
> 120      indcova1 individual covariate a in time t-1         size2
> 121      indcovb1 individual covariate b in time t-1         size2
> 122      indcovc1 individual covariate c in time t-1         size2
> 123      indcova2   individual covariate a in time t        repst1
> 124      indcovb2   individual covariate b in time t        repst1
> 125      indcovc2   individual covariate c in time t        repst1
> 126      indcova1 individual covariate a in time t-1        repst2
> 127      indcovb1 individual covariate b in time t-1        repst2
> 128      indcovc1 individual covariate c in time t-1        repst2
>                        main_2_defined       surv  obs      sizea sizeb sizec
> 1                                       2.060e+00 2.23  8.998e+01     1     1
> 2                                       9.891e-04 0.00  5.954e-01     0     0
> 3                                       1.531e-03 0.00  3.119e-01     0     0
> 4                                       0.000e+00 0.00  0.000e+00     0     0
> 5                                       0.000e+00 0.00  0.000e+00     0     0
> 6                                       0.000e+00 0.00  0.000e+00     0     0
> 7                                       0.000e+00 0.00  0.000e+00     0     0
> 8                                       0.000e+00 0.00  0.000e+00     0     0
> 9                                       0.000e+00 0.00  0.000e+00     0     0
> 10                                      0.000e+00 0.00  0.000e+00     0     0
> 11                                      0.000e+00 0.00  0.000e+00     0     0
> 12                                      0.000e+00 0.00  0.000e+00     0     0
> 13                                      0.000e+00 0.00  0.000e+00     0     0
> 14                                      0.000e+00 0.00  0.000e+00     0     0
> 15                                      0.000e+00 0.00  0.000e+00     0     0
> 16                                      0.000e+00 0.00  0.000e+00     0     0
> 17                                      0.000e+00 0.00  0.000e+00     0     0
> 18       reproductive status in time t  0.000e+00 0.00  0.000e+00     0     0
> 19                     sizea in time t -4.125e-07 0.00 -9.417e-05     0     0
> 20     reproductive status in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 21       reproductive status in time t  0.000e+00 0.00  0.000e+00     0     0
```

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> 22     reproductive status in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 23       reproductive status in time t  0.000e+00 0.00  0.000e+00     0     0
> 24                   sizea in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 25                     sizea in time t  0.000e+00 0.00  0.000e+00     0     0
> 26     reproductive status in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 27       reproductive status in time t  0.000e+00 0.00  0.000e+00     0     0
> 28                     sizea in time t  0.000e+00 0.00  0.000e+00     0     0
> 29                     sizea in time t  0.000e+00 0.00  0.000e+00     0     0
> 30                     sizea in time t  0.000e+00 0.00  0.000e+00     0     0
> 31       reproductive status in time t  0.000e+00 0.00  0.000e+00     0     0
> 32       reproductive status in time t  0.000e+00 0.00  0.000e+00     0     0
> 33       reproductive status in time t  0.000e+00 0.00  0.000e+00     0     0
> 34                   sizea in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 35                   sizea in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 36                   sizea in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 37     reproductive status in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 38     reproductive status in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 39     reproductive status in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 40    individual covariate b in time t  0.000e+00 0.00  0.000e+00     0     0
> 41    individual covariate c in time t  0.000e+00 0.00  0.000e+00     0     0
> 42    individual covariate c in time t  0.000e+00 0.00  0.000e+00     0     0
> 43  individual covariate b in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 44  individual covariate c in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 45  individual covariate c in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 46  individual covariate b in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 47    individual covariate b in time t  0.000e+00 0.00  0.000e+00     0     0
> 48  individual covariate c in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 49    individual covariate c in time t  0.000e+00 0.00  0.000e+00     0     0
> 50  individual covariate c in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 51    individual covariate c in time t  0.000e+00 0.00  0.000e+00     0     0
> 52                   sizeb in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 53                   sizec in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 54                   sizeb in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 55                   sizec in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 56                   sizec in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 57                     sizeb in time t  0.000e+00 0.00  0.000e+00     0     0
> 58                     sizec in time t  0.000e+00 0.00  0.000e+00     0     0
> 59                     sizec in time t  0.000e+00 0.00  0.000e+00     0     0
> 60                     sizeb in time t  0.000e+00 0.00  0.000e+00     0     0
> 61                     sizec in time t  0.000e+00 0.00  0.000e+00     0     0
> 62                     sizec in time t  0.000e+00 0.00  0.000e+00     0     0
> 63                   sizeb in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 64                   sizec in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 65                   sizec in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 66                     sizea in time t  0.000e+00 0.00  0.000e+00     0     0
> 67                     sizeb in time t  0.000e+00 0.00  0.000e+00     0     0
> 68                     sizec in time t  0.000e+00 0.00  0.000e+00     0     0
> 69                   sizea in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 70                   sizeb in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 71                   sizec in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 72       reproductive status in time t  0.000e+00 0.00  0.000e+00     0     0
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> 73     reproductive status in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 74       reproductive status in time t  0.000e+00 0.00  0.000e+00     0     0
> 75       reproductive status in time t  0.000e+00 0.00  0.000e+00     0     0
> 76     reproductive status in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 77     reproductive status in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 78       reproductive status in time t  0.000e+00 0.00  0.000e+00     0     0
> 79     reproductive status in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 80     reproductive status in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 81       reproductive status in time t  0.000e+00 0.00  0.000e+00     0     0
> 82                         age in time t  0.000e+00 0.00  0.000e+00     0     0
> 83                         age in time t  0.000e+00 0.00  0.000e+00     0     0
> 84                         age in time t  0.000e+00 0.00  0.000e+00     0     0
> 85                         age in time t  0.000e+00 0.00  0.000e+00     0     0
> 86                         age in time t  0.000e+00 0.00  0.000e+00     0     0
> 87                       sizeb in time t  0.000e+00 0.00  0.000e+00     0     0
> 88                       sizec in time t  0.000e+00 0.00  0.000e+00     0     0
> 89                     density in time t  0.000e+00 0.00  0.000e+00     0     0
> 90                     sizeb in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 91                     sizec in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 92                       sizeb in time t  0.000e+00 0.00  0.000e+00     0     0
> 93                       sizec in time t  0.000e+00 0.00  0.000e+00     0     0
> 94                     sizeb in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 95                     sizec in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 96                     density in time t  0.000e+00 0.00  0.000e+00     0     0
> 97                       sizeb in time t  0.000e+00 0.00  0.000e+00     0     0
> 98                       sizec in time t  0.000e+00 0.00  0.000e+00     0     0
> 99                     density in time t  0.000e+00 0.00  0.000e+00     0     0
> 100                    sizeb in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 101                    sizec in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 102                      sizeb in time t  0.000e+00 0.00  0.000e+00     0     0
> 103                      sizec in time t  0.000e+00 0.00  0.000e+00     0     0
> 104                    sizeb in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 105                    sizec in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 106                    density in time t  0.000e+00 0.00  0.000e+00     0     0
> 107                      sizeb in time t  0.000e+00 0.00  0.000e+00     0     0
> 108                      sizec in time t  0.000e+00 0.00  0.000e+00     0     0
> 109                    density in time t  0.000e+00 0.00  0.000e+00     0     0
> 110                    sizeb in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 111                    sizec in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 112                      sizeb in time t  0.000e+00 0.00  0.000e+00     0     0
> 113                      sizec in time t  0.000e+00 0.00  0.000e+00     0     0
> 114                    sizeb in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 115                    sizec in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 116                    density in time t  0.000e+00 0.00  0.000e+00     0     0
> 117                    sizea in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 118                    sizea in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 119                    sizea in time t-1  0.000e+00 0.00  0.000e+00     0     0
> 120                      sizea in time t  0.000e+00 0.00  0.000e+00     0     0
> 121                      sizea in time t  0.000e+00 0.00  0.000e+00     0     0
> 122                      sizea in time t  0.000e+00 0.00  0.000e+00     0     0
> 123    reproductive status in time t-1  0.000e+00 0.00  0.000e+00     0     0
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> 124    reproductive status in time t-1  0.000e+00 0.00  0.000e+00      0      0
> 125    reproductive status in time t-1  0.000e+00 0.00  0.000e+00      0      0
> 126      reproductive status in time t  0.000e+00 0.00  0.000e+00      0      0
> 127      reproductive status in time t  0.000e+00 0.00  0.000e+00      0      0
> 128      reproductive status in time t  0.000e+00 0.00  0.000e+00      0      0
>     repst   fec jsurv  jobs jsizea jsizeb jsizec jrepst jmatst sizea_zi
> 1       1 1.517  1.03 10.39 3.0559      1      1      1      1         0
> 2       0 0.000  0.00  0.00 0.8482      0      0      0      0         0
> 3       0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 4       0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 5       0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 6       0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 7       0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 8       0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 9       0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 10      0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 11      0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 12      0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 13      0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 14      0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 15      0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 16      0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 17      0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 18      0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 19      0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 20      0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 21      0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 22      0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 23      0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 24      0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 25      0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 26      0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 27      0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 28      0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 29      0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 30      0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 31      0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 32      0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 33      0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 34      0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 35      0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 36      0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 37      0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 38      0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 39      0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 40      0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 41      0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 42      0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 43      0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 44      0 0.000  0.00  0.00 0.0000      0      0      0      0         0
> 45      0 0.000  0.00  0.00 0.0000      0      0      0      0         0
```

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> 46      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 47      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 48      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 49      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 50      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 51      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 52      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 53      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 54      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 55      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 56      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 57      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 58      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 59      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 60      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 61      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 62      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 63      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 64      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 65      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 66      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 67      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 68      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 69      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 70      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 71      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 72      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 73      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 74      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 75      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 76      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 77      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 78      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 79      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 80      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 81      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 82      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 83      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 84      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 85      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 86      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 87      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 88      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 89      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 90      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 91      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 92      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 93      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 94      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 95      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
> 96      0 0.000  0.00  0.00 0.0000      0      0      0      0      0
```

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> 97      0 0.000  0.00  0.00 0.0000       0       0       0       0         0
> 98      0 0.000  0.00  0.00 0.0000       0       0       0       0         0
> 99      0 0.000  0.00  0.00 0.0000       0       0       0       0         0
> 100     0 0.000  0.00  0.00 0.0000       0       0       0       0         0
> 101     0 0.000  0.00  0.00 0.0000       0       0       0       0         0
> 102     0 0.000  0.00  0.00 0.0000       0       0       0       0         0
> 103     0 0.000  0.00  0.00 0.0000       0       0       0       0         0
> 104     0 0.000  0.00  0.00 0.0000       0       0       0       0         0
> 105     0 0.000  0.00  0.00 0.0000       0       0       0       0         0
> 106     0 0.000  0.00  0.00 0.0000       0       0       0       0         0
> 107     0 0.000  0.00  0.00 0.0000       0       0       0       0         0
> 108     0 0.000  0.00  0.00 0.0000       0       0       0       0         0
> 109     0 0.000  0.00  0.00 0.0000       0       0       0       0         0
> 110     0 0.000  0.00  0.00 0.0000       0       0       0       0         0
> 111     0 0.000  0.00  0.00 0.0000       0       0       0       0         0
> 112     0 0.000  0.00  0.00 0.0000       0       0       0       0         0
> 113     0 0.000  0.00  0.00 0.0000       0       0       0       0         0
> 114     0 0.000  0.00  0.00 0.0000       0       0       0       0         0
> 115     0 0.000  0.00  0.00 0.0000       0       0       0       0         0
> 116     0 0.000  0.00  0.00 0.0000       0       0       0       0         0
> 117     0 0.000  0.00  0.00 0.0000       0       0       0       0         0
> 118     0 0.000  0.00  0.00 0.0000       0       0       0       0         0
> 119     0 0.000  0.00  0.00 0.0000       0       0       0       0         0
> 120     0 0.000  0.00  0.00 0.0000       0       0       0       0         0
> 121     0 0.000  0.00  0.00 0.0000       0       0       0       0         0
> 122     0 0.000  0.00  0.00 0.0000       0       0       0       0         0
> 123     0 0.000  0.00  0.00 0.0000       0       0       0       0         0
> 124     0 0.000  0.00  0.00 0.0000       0       0       0       0         0
> 125     0 0.000  0.00  0.00 0.0000       0       0       0       0         0
> 126     0 0.000  0.00  0.00 0.0000       0       0       0       0         0
> 127     0 0.000  0.00  0.00 0.0000       0       0       0       0         0
> 128     0 0.000  0.00  0.00 0.0000       0       0       0       0         0
>     sizeb_zi sizec_zi    fec_zi jsizea_zi jsizeb_zi jsizec_zi
> 1          0        0  6.252765         0         0         0
> 2          0        0 -0.007313         0         0         0
> 3          0        0  0.000000         0         0         0
> 4          0        0  0.000000         0         0         0
> 5          0        0  0.000000         0         0         0
> 6          0        0  0.000000         0         0         0
> 7          0        0  0.000000         0         0         0
> 8          0        0  0.000000         0         0         0
> 9          0        0  0.000000         0         0         0
> 10         0        0  0.000000         0         0         0
> 11         0        0  0.000000         0         0         0
> 12         0        0  0.000000         0         0         0
> 13         0        0  0.000000         0         0         0
> 14         0        0  0.000000         0         0         0
> 15         0        0  0.000000         0         0         0
> 16         0        0  0.000000         0         0         0
> 17         0        0  0.000000         0         0         0
> 18         0        0  0.000000         0         0         0
```

```
> 19          0          0  0.000000          0          0          0
> 20          0          0  0.000000          0          0          0
> 21          0          0  0.000000          0          0          0
> 22          0          0  0.000000          0          0          0
> 23          0          0  0.000000          0          0          0
> 24          0          0  0.000000          0          0          0
> 25          0          0  0.000000          0          0          0
> 26          0          0  0.000000          0          0          0
> 27          0          0  0.000000          0          0          0
> 28          0          0  0.000000          0          0          0
> 29          0          0  0.000000          0          0          0
> 30          0          0  0.000000          0          0          0
> 31          0          0  0.000000          0          0          0
> 32          0          0  0.000000          0          0          0
> 33          0          0  0.000000          0          0          0
> 34          0          0  0.000000          0          0          0
> 35          0          0  0.000000          0          0          0
> 36          0          0  0.000000          0          0          0
> 37          0          0  0.000000          0          0          0
> 38          0          0  0.000000          0          0          0
> 39          0          0  0.000000          0          0          0
> 40          0          0  0.000000          0          0          0
> 41          0          0  0.000000          0          0          0
> 42          0          0  0.000000          0          0          0
> 43          0          0  0.000000          0          0          0
> 44          0          0  0.000000          0          0          0
> 45          0          0  0.000000          0          0          0
> 46          0          0  0.000000          0          0          0
> 47          0          0  0.000000          0          0          0
> 48          0          0  0.000000          0          0          0
> 49          0          0  0.000000          0          0          0
> 50          0          0  0.000000          0          0          0
> 51          0          0  0.000000          0          0          0
> 52          0          0  0.000000          0          0          0
> 53          0          0  0.000000          0          0          0
> 54          0          0  0.000000          0          0          0
> 55          0          0  0.000000          0          0          0
> 56          0          0  0.000000          0          0          0
> 57          0          0  0.000000          0          0          0
> 58          0          0  0.000000          0          0          0
> 59          0          0  0.000000          0          0          0
> 60          0          0  0.000000          0          0          0
> 61          0          0  0.000000          0          0          0
> 62          0          0  0.000000          0          0          0
> 63          0          0  0.000000          0          0          0
> 64          0          0  0.000000          0          0          0
> 65          0          0  0.000000          0          0          0
> 66          0          0  0.000000          0          0          0
> 67          0          0  0.000000          0          0          0
> 68          0          0  0.000000          0          0          0
> 69          0          0  0.000000          0          0          0
```

```
> 70    0    0  0.000000    0    0    0
> 71    0    0  0.000000    0    0    0
> 72    0    0  0.000000    0    0    0
> 73    0    0  0.000000    0    0    0
> 74    0    0  0.000000    0    0    0
> 75    0    0  0.000000    0    0    0
> 76    0    0  0.000000    0    0    0
> 77    0    0  0.000000    0    0    0
> 78    0    0  0.000000    0    0    0
> 79    0    0  0.000000    0    0    0
> 80    0    0  0.000000    0    0    0
> 81    0    0  0.000000    0    0    0
> 82    0    0  0.000000    0    0    0
> 83    0    0  0.000000    0    0    0
> 84    0    0  0.000000    0    0    0
> 85    0    0  0.000000    0    0    0
> 86    0    0  0.000000    0    0    0
> 87    0    0  0.000000    0    0    0
> 88    0    0  0.000000    0    0    0
> 89    0    0  0.000000    0    0    0
> 90    0    0  0.000000    0    0    0
> 91    0    0  0.000000    0    0    0
> 92    0    0  0.000000    0    0    0
> 93    0    0  0.000000    0    0    0
> 94    0    0  0.000000    0    0    0
> 95    0    0  0.000000    0    0    0
> 96    0    0  0.000000    0    0    0
> 97    0    0  0.000000    0    0    0
> 98    0    0  0.000000    0    0    0
> 99    0    0  0.000000    0    0    0
> 100   0    0  0.000000    0    0    0
> 101   0    0  0.000000    0    0    0
> 102   0    0  0.000000    0    0    0
> 103   0    0  0.000000    0    0    0
> 104   0    0  0.000000    0    0    0
> 105   0    0  0.000000    0    0    0
> 106   0    0  0.000000    0    0    0
> 107   0    0  0.000000    0    0    0
> 108   0    0  0.000000    0    0    0
> 109   0    0  0.000000    0    0    0
> 110   0    0  0.000000    0    0    0
> 111   0    0  0.000000    0    0    0
> 112   0    0  0.000000    0    0    0
> 113   0    0  0.000000    0    0    0
> 114   0    0  0.000000    0    0    0
> 115   0    0  0.000000    0    0    0
> 116   0    0  0.000000    0    0    0
> 117   0    0  0.000000    0    0    0
> 118   0    0  0.000000    0    0    0
> 119   0    0  0.000000    0    0    0
> 120   0    0  0.000000    0    0    0
```

```
> 121        0        0  0.000000         0         0         0
> 122        0        0  0.000000         0         0         0
> 123        0        0  0.000000         0         0         0
> 124        0        0  0.000000         0         0         0
> 125        0        0  0.000000         0         0         0
> 126        0        0  0.000000         0         0         0
> 127        0        0  0.000000         0         0         0
> 128        0        0  0.000000         0         0         0
>
> $year_frame
>   years surv obs sizea sizeb sizec repst fec jsurv jobs jsizea jsizeb jsizec
> 1  1988    0   0     0     0     0     0   0     0    0      0      0      0
> 2  1989    0   0     0     0     0     0   0     0    0      0      0      0
> 3  1990    0   0     0     0     0     0   0     0    0      0      0      0
>   jrepst jmatst sizea_zi sizeb_zi sizec_zi fec_zi jsizea_zi jsizeb_zi jsizec_zi
> 1      0      0        0        0        0      0         0         0         0
> 2      0      0        0        0        0      0         0         0         0
> 3      0      0        0        0        0      0         0         0         0
>
> $patch_frame
>   patches surv obs sizea sizeb sizec repst fec jsurv jobs jsizea jsizeb jsizec
> 1       1    0   0     0     0     0     0   0     0    0      0      0      0
>   jrepst jmatst sizea_zi sizeb_zi sizec_zi fec_zi jsizea_zi jsizeb_zi jsizec_zi
> 1      0      0        0        0        0      0         0         0         0
>
> $group2_frame
>   groups surv obs sizea sizeb sizec repst fec jsurv jobs jsizea jsizeb jsizec
> 1      0    0   0     0     0     0     0   0     0    0      0      0      0
>   jrepst jmatst sizea_zi sizeb_zi sizec_zi fec_zi jsizea_zi jsizeb_zi jsizec_zi
> 1      0      0        0        0        0      0         0         0         0
>
> $group1_frame
>   groups surv obs sizea sizeb sizec repst fec jsurv jobs jsizea jsizeb jsizec
> 1      0    0   0     0     0     0     0   0     0    0      0      0      0
>   jrepst jmatst sizea_zi sizeb_zi sizec_zi fec_zi jsizea_zi jsizeb_zi jsizec_zi
> 1      0      0        0        0        0      0         0         0         0
>
> $dist_frame
>    response     dist
> 1      surv    binom
> 2       obs    binom
> 3     sizea gaussian
> 4     sizeb constant
> 5     sizec constant
> 6     repst constant
> 7       fec   negbin
> 8     jsurv    binom
> 9      jobs    binom
> 10   jsizea gaussian
> 11   jsizeb constant
> 12   jsizec constant
```

```
> 13   jrepst constant
> 14   jmatst constant
>
> $st_frame
>   surv    obs  sizea  sizeb  sizec  repst    fec  jsurv   jobs jsizea jsizeb
>      1      1      1      1      1      1      1      1      1      1      1
> jsizec jrepst jmatst
>      1      1      1
>
> attr(,"class")
> [1] "vrm_input"
```

Now we will add the appropriate year terms and the values of σ and θ, and the year coefficients.

```
lath3_vrm$st_frame[3] <- 480.4092
lath3_vrm$st_frame[7] <- 0.2342114
lath3_vrm$st_frame[10] <- 5.831241

lath3_vrm$year_frame$sizea <- c(193.44474, -277.14757, 83.70283)
lath3_vrm$year_frame$fec <- c(-0.41749627, 0.51421684, -0.07964038)
lath3_vrm$year_frame$fec_zi <- c(3.741475e-07, -7.804715e-08, -2.533755e-07)

lath3_vrm$year_frame$sizea <- c(193.44474, -277.14757, 83.70283)

lath3_vrm$year_frame$jobs <- c(-0.7459843, 0.6118826, -0.9468618)
lath_vrm$year_frame$jsizea <- c(0.5937962, 1.4551236, -2.0489198)
```

As before, we still need to supply supplemental information. We'll do that below.

```
lathsupp3 <- supplemental(stage3 = c("Sd","Sd","Sdl","Sdl","npr","Sd","Sdl"),
  stage2 = c("Sd", "Sd", "Sd", "Sd", "Sdl", "rep", "rep"),
  stage1 = c("Sd", "rep", "Sd", "rep", "Sd", "mat", "mat"),
  eststage3 = c(NA, NA, NA, NA, "npr", NA, NA),
  eststage2 = c(NA, NA, NA, NA, "Sdl", NA, NA),
  eststage1 = c(NA, NA, NA, NA, "Sdl", NA, NA),
  givenrate = c(0.345, 0.345, 0.054, 0.054, NA, NA, NA),
  multiplier = c(NA, NA, NA, NA, NA, 0.345, 0.054),
  type = c(1, 1, 1, 1, 1, 3, 3), type_t12 = c(1, 2, 1, 2, 1, 1, 1),
  stageframe = lathframeipm, historical = TRUE)
```

Finally we can produce our historical IPMs.

```
lathmat3_importipm <- flefko3(stageframe = lathframeipm, modelsuite = lath3_vrm,
  supplement = lathsupp3, reduce = FALSE)

summary(lathmat3_importipm)
>
> This historical lefkoMat object contains 3 matrices.
>
> Each matrix is square with 10609 rows and columns, and a total of 112550881 elements.
> A total of 2684746 survival transitions were estimated, with 894915.333 per matrix.
```

```
> A total of 60600 fecundity transitions were estimated, with 20200 per matrix.
> This lefkoMat object covers 1 population, 1 patch, and 3 time steps.
>
> Survival probability sum check (each matrix represented by column in order):
>          [,1]  [,2]  [,3]
> Min.    0.000 0.000 0.000
> 1st Qu. 0.989 0.981 0.988
> Median  0.997 0.996 0.997
> Mean    0.955 0.945 0.954
> 3rd Qu. 0.999 0.998 0.999
> Max.    1.000 1.000 1.000
```

As before, we can use this IPM in any way that might use a normal fbMPM in `lefko3`. The general approach shown above can also be used to develop age-based (Leslie) or age-by-stage function-based MPMs.

13.3 Running projections from imported IPMs and function-based MPMs

The `vrm_input` approach can also be used to run custom function-based projections.

```
lath_proj <- f_projection3(format = 3, stageframe = lathframeipm,
  supplement = lathsupp2, modelsuite = lath_vrm, nreps = 10, times = 10,
  stochastic = TRUE)
> Warning: Option patch not set, so will set to first patch/population.

summary(lath_proj)
>
> The input lefkoProj object covers 1 population-patches.
> It includes 10 projected steps per replicate and 10 replicates.
> The number of replicates with population size above the threshold size of 1 is as in
> the following matrix, with pop-patches given by column and milepost times given by row:
> $milepost_sums
>    1 1
> 1   10
> 3   10
> 6   10
> 8   10
> 11  10
>
> $extinction_times
> [1] NA
```

Let's take a look at what our projection replicates look like.

```
plot(lath_proj)
```

All other kinds of projections - ordered, cyclical, and stochastic - are also possible, as are density dependent projections in all cases. We encourage users to experiment with these methods.

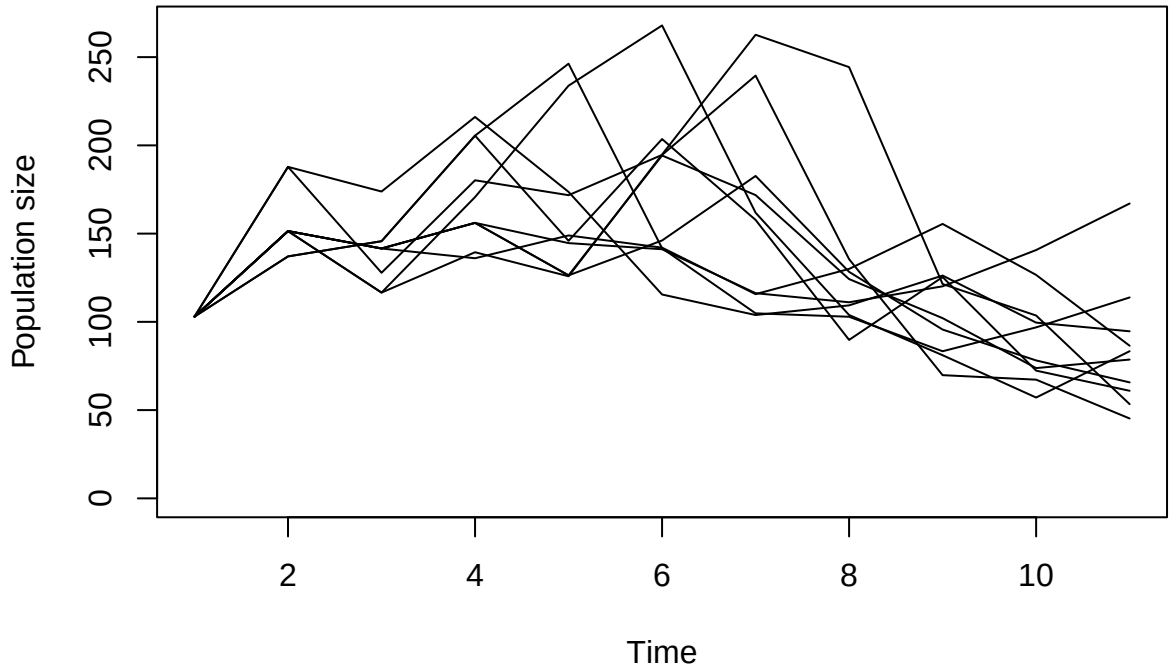

Figure 13.1: Replicated projection resulting from imported Lathyrus IPM

13.4 Points to remember

1. Users may import IPMs and fbMPMs into `lefko3` if they are presented as kernels of linear models, with function `vrm_import()`.
2. Imported IPMs and fbMPMs may also be loaded into projections, including function-based projections that create new matrices at each time step with function `f_projection3()`.