

# Package ‘bumbl’

August 25, 2021

**Title** Tools for Modeling Bumblebee Colony Growth and Decline

**Version** 1.0.1

**Description** Bumblebee colonies grow during worker production, then decline after switching to production of reproductive individuals (drones and gynes). This package provides tools for modeling and visualizing this pattern by identifying a switchpoint with a growth rate before and a decline rate after the switchpoint. The mathematical models fit by bumbl are described in Crone and Williams (2016) <[doi:10.1111/ele.12581](https://doi.org/10.1111/ele.12581)>.

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**Encoding** UTF-8

**LazyData** true

**URL** <https://github.com/Aariq/bumbl>

**BugReports** <https://github.com/Aariq/bumbl/issues>

**Depends** R (>= 3.0)

**Suggests** testthat (>= 2.1.0), knitr, rmarkdown, covr, car, rsq

**Imports** dplyr, rlang, tidyr (>= 1.0.0), purrr, broom, glue, MASS, ggplot2

**RoxygenNote** 7.1.1

**VignetteBuilder** knitr

**Config/testthat/edition** 3

**NeedsCompilation** no

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**Repository** CRAN

**Date/Publication** 2021-08-25 12:50:15 UTC

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autoplot.bumbldf	<i>Plot observed and fitted results from bumbldf()</i>
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**Description**

Plots observed (points) and fitted (red line) values from the model implemented by `bumbldf()`, faceted by colony.

**Usage**

```
## S3 method for class 'bumbldf'
autoplot(x, colony = NULL)
```

**Arguments**

x	a dataframe produced by <code>bumbldf()</code>
colony	a character vector of colony IDs to plot

**Value**

invisibly returns a ggplot object

**Examples**

```
bombus_subset <- bombus[bombus$colony %in% c("17", "104", "20", "24"), ]
results <- bumbldf(bombus_subset, colonyID = colony, t = week,
                  formula = mass ~ week)
library(ggplot2)
autoplot(results)
```

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bombus	<i>Bombus vosnesenskii colony growth and estimated floral resources</i>
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**Description**

This is a subset of the data from Crone and Williams, 2016. *Bombus vosnesenskii* colonies were placed in sites in a mixed agricultural–natural area in California, USA and weighed weekly.

**Usage**

```
bombus
```

**Format**

A data frame with 178 rows and 10 columns

**site** The site ID

**colony** The colony ID

**wild** The proportion of the habitat for that site classified as wild using GIS

**habitat** The habitat type. Either wild (W), organic agriculture (O), or conventional agriculture (C)

**date** The calendar date the measurements were taken on

**week** Number of weeks since the initial mass was taken

**mass** Colony mass, in grams

**d.mass** Difference in mass from the smallest mass for each colony, in grams

**floral\_resources** Floral density in millions of flowers within a 2km radius around the colony, weighted as a function of distance from colony

**cum\_floral** Cumulative floral resources from the start of the study

**Details**

Floral resources ( $e$ ) are weighted using the equation  $w = e^{(-D/a)}$  where  $D$  is the distance in meters between the resources and the colony and  $a$  is the typical flight distance for the species. This is described in further detail in Williams et al. 2012.

**References**

Crone, E. E., and Williams, N. M. (2016). Bumble bee colony dynamics: quantifying the importance of land use and floral resources for colony growth and queen production. *Ecol. Lett.* 19, 460–468. doi:10.1111/ele.12581.

Williams, N. M., Regetz, J., and Kremen, C. (2012). Landscape-scale resources promote colony growth but not reproductive performance of bumble bees. *Ecology* 93, 1049–1058. doi:10.1890/11-1006.1.

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 bumbl

*Estimate colony growth, switch point, and decay parameters*

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**Description**

Fits generalized linear models that assume bumblebee colonies will switch from growth to gyne production at some point,  $\tau$ . This allows for a different switchpoint ( $\tau$ ) for each colony, chosen by maximum likelihood methods.

**Usage**

```
bumbl(
  data,
  t,
  formula,
  family = gaussian(link = "log"),
  colonyID = NULL,
  augment = FALSE,
  keep.model = FALSE,
  ...
)
```

**Arguments**

<code>data</code>	a dataframe or tibble with a column for colony ID (as a character or factor), a column for some measure of time (numeric), and a column for some measure of colony growth (numeric), at minimum.
<code>t</code>	the unquoted column name of the time variable.
<code>formula</code>	a formula with the form <code>response ~ time + covariates</code> where <code>response</code> is your measure of colony growth, <code>time</code> is whatever measure of time you have (date, number of weeks, etc.) and <code>covariates</code> are any optional co-variables you want to fit at the colony level.
<code>family</code>	a description of the error distribution and link function. This is passed to <code>glm()</code> except in the case of <code>family = "negbin"</code> , which causes <code>MASS::glm.nb()</code> to be used to fit a negative binomial GLM.
<code>colonyID</code>	the unquoted column name of the colony ID variable. This is required, so to run <code>bumbl()</code> on a single colony, you must create a dummy column with a colony ID.
<code>augment</code>	when <code>FALSE</code> , <code>bumbl</code> returns a summary dataframe with one row for each colonyID. When <code>TRUE</code> , it returns the original data with additional columns containing model coefficients. Cannot be used in conjunction with <code>keep.model = TRUE</code> .
<code>keep.model</code>	If <code>TRUE</code> , then the output will contain a list-column with the models for each colony. This may be useful for extracting statistics and performing model diagnostics not provided by <code>bumbl()</code> . Learn more about working with list columns with <code>vignette("nest", package = "tidyr")</code> .
<code>...</code>	additional arguments passed to <code>glm()</code> or <code>MASS::glm.nb()</code> .

**Details**

Colony growth is modeled as increasing exponentially until the colony switches from producing workers to producing reproductive individuals (drones and gynes), at which time the workers die and gynes leave the colony, causing the colony to decline. The switch point,  $\tau$ , may vary among colonies. `bumbl()` finds the value of  $\tau$  that maximizes likelihood and this "winning" model is used to calculate statistics returned in the output. This function works by fitting generalized linear models (GLMs) to modified colony growth data. Because of this, the assumptions for GLMs apply, namely independence and homogeneity of variance. See `vignette("bumbl", package = "bumbl")` for more details on the underlying math of the model.

**Value**

A data.frame with the additional class `bumbldf` containing a summary of the data with a row for every colony and the following columns:

- `converged` indicates whether the winning model converged.
- `tau` is the switchpoint, in the same units as `t`, for each colonyID. The colony grows for  $\tau$  weeks, then begins to decline in week  $\tau + 1$ .
- `logN0` is the intercept of the growth function. It reflects actual initial colony size, if the colony initially grows exponentially. It would also be lower if there were a few weeks lag before growth started in the field.
- `logLam` is the average (log-scale) colony growth rate (i.e., rate of weight gain per unit `t`) during the growth period.
- `decay` reflects the rate of decline during the decline period. Equivalent to  $\ln(\delta) - \ln(\lambda)$  (see vignette for more in-depth explanation).
- `logNmax` is the maximum weight reached by each colony. It is a function of `tau`, `logN0` and `logLam`
- Additional columns are coefficients for any covariates supplied in the formula

When `augment = TRUE`, the original data are returned with these columns as well as fitted values (`.fitted`) residuals (`.resid`) and standard error (`.se.fit`). When `keep.model = TRUE` a list-column with the `glm` models for each colony is returned as well.

**Note**

This function *assumes* there is a switchpoint and does not test whether the switchpoint model is significantly better than a log-linear model. As a result, it may estimate a switchpoint even if the data do not represent a true switchpoint. See the vignette for an example of how to extract the GLMs—you could compare them to a simpler log-linear model without the switchpoint by AIC or a likelihood ratio test to test the significance of the switchpoint.

**References**

Crone EE, Williams NM (2016) Bumble bee colony dynamics: quantifying the importance of land use and floral resources for colony growth and queen production. *Ecology Letters* 19:460–468. <https://doi.org/10.1111/ele.12581>

**See Also**

[plot.bumbldf\(\)](#)

**Examples**

```
bumbl(bombus, colonyID = colony, t = week, formula = d.mass ~ week)
```

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plot.bumbldf	<i>Plot observed and fitted results from bumbl()</i>
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**Description**

Creates one plot per level of colonyID showing the observed (points) and fitted (red line) values from the model implemented by bumbl().

**Usage**

```
## S3 method for class 'bumbldf'  
plot(x, ..., colony = NULL)
```

**Arguments**

x	a dataframe produced by bumbl().
...	other arguments not used by this method.
colony	optional vector of colony ID's (character) or indexes (numeric) to plot. If not supplied, all colonies will be plotted.

**Value**

invisibly returns a list of dataframes used for building the plots.

**See Also**

[bumbl\(\)](#), [autoplot.bumbldf\(\)](#)

**Examples**

```
set.seed(687)  
colonyID_subset <- sample(bombus$colony, 10)  
colony_subset <- bombus[bombus$colony %in% colonyID_subset, ]  
results <- bumbl(colony_subset, colonyID = colony, t = week,  
                 formula = mass ~ week)  
plot(results)
```

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