Package ‘MPN’

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Title  Most Probable Number and Other Microbial Enumeration Techniques
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Description Calculates the Most Probable Number (MPN) to quantify the concentration (density) of microbes in serial dilutions of a laboratory sample (described in Jarvis, 2010 <doi:10.1111/j.1365-2672.2010.04792.x>). Also calculates the Aerobic Plate Count (APC) for similar microbial enumeration experiments.
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**apc**

*Calculate aerobic plate count (APC)*

**Description**

apc calculates the Aerobic Plate Count (APC) point estimate and confidence interval of colony forming units (CFU). Adjusts for too-numerous-to-count (TNTC) plates using the maximum likelihood method of Haas et al. (2014).

**Usage**

```r
apc(count, amount_scor, amount_tntc = NULL, tntc_limit = 250, conf_level = 0.95)
```

**Arguments**

- **count**: A vector of CFU counts in each scorable (countable) plate.
- **amount_scor**: A vector of inoculum amounts (in ml) in each scorable plate. See Details section.
- **amount_tntc**: A vector of inoculum amounts (in ml) in each TNTC plate.
- **tntc_limit**: A vector (or scalar) of the limit above which the plate counts are considered too-numerous-to-count (often 100, 250, or 300). Each plate can potentially have a different value. Default is 250.
- **conf_level**: A scalar value between zero and one for the confidence level. Typically 0.95 (i.e., a 95 percent confidence interval).

**Details**

As an example, assume we start with four plates and 1 ml of undiluted inoculum. For the first two plates we use a 100-fold dilution; for the other two plates we use a 1,000-fold dilution. The first two plates were TNTC with limits of 300 and 250. The other plates had CFU counts of 28 and 20. We now have `count = c(28, 20)`, `amount_scor = 1 * c(.001, .001)`, `amount_tntc = 1 * c(.01, .01)`, and `tntc_limit = c(300, 250)`.

Currently, confidence intervals can only be calculated using the likelihood ratio (LR) approach described in Haas et al. (2014).

**Value**

A list containing:

- **APC**: The aerobic plate count point estimate in CFU/ml.
- **conf_level**: The confidence level used.
- **LB**: The lower bound of the confidence interval.
- **UB**: The upper bound of the confidence interval.
Warnings

The likelihood ratio confidence interval assumptions depend on asymptotic theory. Therefore, the confidence interval results will be better with larger experiments.

`apc()` will fail in certain cases where the TNTC results are extremely unlikely to occur when taking the scorable (countable) plates into consideration. In other words, if the countable plates suggest a low concentration of microbes, then TNTC plates at higher dilution levels are probably due to experimental error. Mathematically, the probability is so small that the likelihood function is essentially zero.

References


See Also

`mpn` for Most Probable Number

Examples

```r
#------- "Quantitative Microbial Risk Assessment (Haas et al., 2014) -------

# Table 6.1 (Sample A)
my_count <- c(1, 2, 1, 0, 1, 1, 3, 6, 8, 4)
my_amount_scor <- c(1, 1, 1, 1, 2.5, 2.5, 2.5, 2.5, 25, 5, 5)
apc(my_count, my_amount_scor) # 1.08

# Table 6.1 (Sample B)
my_count <- c(1, 0, 5, 1, 0, 5, 0, 1, 5, 1, 8)
my_amount_scor <- c(1, 1, 1, 1, 2.5, 2.5, 2.5, 2.5, 2.5, 5, 5)
apc(my_count, my_amount_scor) # 1.08

# Table 6.2
my_count <- c(12, 8, 15, 40, 58)
my_amount_scor <- c(1, 1, 1, 10, 10)
my_amount_tntc <- c(10, 100, 100, 100)
my_tntc_limit <- 100
apc(my_count, my_amount_scor, my_amount_tntc, my_tntc_limit) # 7 (6.03, 7.96)

#------- "Averaging of TNTC Counts" (Haas & Heller, 1988)-------

# Note:
# Results are slightly different due mostly to differences in how the TNTC
# portion of the likelihood function is formulated (i.e., incomplete gamma
# function vs. infinite Poisson sum--see Haas et al. (2014) for details of
# this mathematical relationship).
```
my_count <- c(10, 12, 23, 48, 63)
my_amount_scor <- c(1, 1, 1, 5, 5)
my_amount_tntc <- c(5, 10, 10)
my_tntc_limit <- 80
apc(my_count, my_amount_scor, my_amount_tntc, my_tntc_limit)
#Haas & Heller: APC = 13.28 CFU/ml

**mpn**

*Calculate most probable number (MPN)*

**Description**

*mpn* calculates the Most Probable Number (*MPN*) point estimate and confidence interval for microbial concentrations. Also calculates Blodgett’s (2002, 2005, 2010) Rarity Index (*RI*).

**Usage**

```r
mpn(positive, tubes, amount, conf_level = 0.95, CI_method = c("Jarvis", "LR"))
```

**Arguments**

- **positive**: A vector of number of positive tubes at each dilution level.
- **tubes**: A vector of total number of tubes at each dilution level.
- **amount**: A vector of the amount of inoculum per tube at each dilution level. See *Details* section.
- **conf_level**: A scalar value between zero and one for the confidence level. Typically 0.95 (i.e., a 95 percent confidence interval).
- **CI_method**: The method used for calculating the confidence interval. Choices are "Jarvis" or "LR" (likelihood ratio). See *Details* section.

**Details**

As an example, assume we start with 3g of undiluted inoculum per tube, then use a 10-fold dilution for 2 dilutions. We now have `amount = 3 * c(1, .1, .01)`. When all tubes are negative, the point estimate of *MPN* is zero (same approach as Jarvis et al.). The point estimate for the BAM tables "is listed as less than the lowest MPN for an outcome with at least one positive tube" (App.2).

When all tubes are positive, the point estimate for *MPN* is Inf (same approach as Jarvis et al.) since no finite maximum likelihood estimate (MLE) exists. The BAM tables "list the MPN for this outcome as greater than the highest MPN for an outcome with at least one negative tube" (App.2). Here, the difference is probably trivial since the sample should be further diluted if all tubes test positive.
The bias adjustment for the point estimate uses the method of Salama et al. (1978). Also see Haas (1989).

Currently, confidence intervals can only be calculated using the Jarvis (2010) or likelihood ratio (LR) approach (Ridout, 1994). The BAM tables use an alternate approach. We slightly modified Jarvis’ approach when all tubes are positive or all are negative; we use $\alpha$ instead of $\alpha/2$ since these are one-sided intervals. The Ridout (1994) LR approach uses the same technique (with $\alpha$) for these two extreme cases.

If the Rarity Index is less than $1e-04$, the experimental results are highly improbable. The researcher may consider running the experiment again and/or changing the dilution levels.

Value

A list containing:

- **MPN**: The most probable number point estimate for microbial density (concentration).
- **MPN_adj**: The bias-adjusted point estimate for MPN.
- **variance**: The estimated variance (see Jarvis et al.) of the $MPN$ estimate if $CI\_method = "Jarvis"$. If all tubes are positive or all negative, variance will be NA. If $CI\_method$ is not "Jarvis", variance will be NA.
- **var_log**: The estimated variance of the natural log of the MPN estimate (see Jarvis et al.) using the Delta Method. If all tubes are positive or all negative, var_log will be NA. If $CI\_method$ is not "Jarvis", var_log will be NA.
- **conf_level**: The confidence level used.
- **CI\_method**: The confidence interval method used.
- **LB**: The lower bound of the confidence interval.
- **UB**: The upper bound of the confidence interval.
- **RI**: The rarity index.

Warnings

The Jarvis confidence interval assumptions of approximate normality (Delta Method and asymptotic normality of maximum likelihood estimators) depend on large-sample theory. The likelihood ratio assumptions also depend on large-sample theory. Therefore, the Jarvis and LR confidence interval approaches work best with larger experiments.

References


**See Also**

Shiny app: https://mpncalc.galaxytrakr.org/  
apc for Aerobic Plate Count

**Examples**

```r
# Compare MPN, 95% CI, and RI to Jarvis -------------------------------

# Table 1
mpn(positive = c(3, 1, 1), tubes = c(3, 3, 3), amount = c(1, .1, .01))  
#Jarvis: 7.5 (1.9, 30) RI = .209

mpn(positive = c(0, 0, 0), tubes = c(3, 3, 3), amount = c(1, .1, .01))  
#Jarvis: 0 (0, 1.1) RI = 1

mpn(positive = c(0, 0, 0), tubes = c(3, 3, 3), amount = c(1, .1, .01),  
conf_level = .975)$UB #alpha / 2

mpn(positive = c(3, 3, 3), tubes = c(3, 3, 3), amount = c(1, .1, .01))  
#Jarvis: Inf (36, Inf) RI = 1

mpn(positive = c(3, 3, 3), tubes = c(3, 3, 3), amount = c(1, .1, .01),  
conf_level = .975)$LB #alpha / 2

# Table 2
mpn(positive = c(20, 14, 3), tubes = c(20, 20, 20), amount = c(1, .1, .01))  
#Jarvis: 13 (7.6, 21) RI = .794

mpn(positive = c(50, 35, 7), tubes = c(50, 50, 50),  
amount = 2 * c(1, .1, .01))  
#Jarvis: 6.3 (4.5, 8.7) RI = .806

mpn(positive = c(1, 5, 3, 1, 1), tubes = c(1, 5, 5, 5, 5),  
amount = c(5, 1, .5, .1, .05))  
#Jarvis: 2.7 (1.3, 5.5) RI = .512

# Compare MPN and 95% CI to BAM tables ----------------------------------

# Table 1
```
mpn(positive = c(0, 0, 0), tubes = c(3, 3, 3), amount = c(.1, .01, .001))
#BAM: <3.0 (-, 9.5)

mpn(positive = c(0, 0, 1), tubes = c(3, 3, 3), amount = c(.1, .01, .001))
#BAM: 3.0 (0.15, 9.6)

mpn(positive = c(2, 2, 0), tubes = c(3, 3, 3), amount = c(.1, .01, .001))
#BAM: 21 (4.5, 42)

mpn(positive = c(3, 3, 3), tubes = c(3, 3, 3), amount = c(.1, .01, .001))
#BAM: >1100 (420, -)

# Table 2
mpn(positive = c(0, 0, 0), tubes = c(5, 5, 5), amount = c(.1, .01, .001))
#BAM: <1.8 (-, 6.8)

mpn(positive = c(0, 0, 1), tubes = c(5, 5, 5), amount = c(.1, .01, .001))$MPN

mpn(positive = c(4, 0, 2), tubes = c(5, 5, 5), amount = c(.1, .01, .001))
#BAM: 21 (6.8, 40)

mpn(positive = c(5, 5, 5), tubes = c(5, 5, 5), amount = c(.1, .01, .001))
#BAM: >1600 (700, -)

mpn(positive = c(5, 5, 4), tubes = c(5, 5, 5), amount = c(.1, .01, .001))$MPN

# Compare MPN and 95% LR CI to Ridout (1994) ----------------------------

# Table 1
mpn(positive = c(0, 0, 0), tubes = c(3, 3, 3), amount = c(.1, .01, .001),
   CI_method = "LR")
#Ridout: 0 (0, 9.0)

mpn(positive = c(2, 2, 0), tubes = c(3, 3, 3), amount = c(.1, .01, .001),
   CI_method = "LR")
#Ridout: 21.1 (6.2, 54.3)

mpn(positive = c(3, 3, 3), tubes = c(3, 3, 3), amount = c(.1, .01, .001),
   CI_method = "LR")
#Ridout: Inf (465.1, Inf)
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