Effect sizes and standardization in neighbourhood models of forest stands: potential biases and misinterpretations

Peter Stoll¹, David J. Murrell* & David M. Newbery

Institute of Plant Sciences, University of Bern, Altenbergrain 21, CH-3013 Bern, Switzerland
* Centre for Biodiversity and Environmental Research, Department of Genetics, Evolution and Environment, University College London, Darwin Building, Gower Street, London WC1E 6BT, UK

Running head: effect sizes and standardization

¹ E-mail: peter.stoll@ips.unibe.ch
Summary

1. Effects of conspecific neighbours on survival and growth of trees have been found to be related to species abundance. Both positive and negative relationships may explain observed abundance patterns. Surprisingly, it is rarely tested whether such relationships could be biased or even spurious due to transforming neighbourhood variables or influences of spatial aggregation, distance decay of neighbour effects and standardization of effect sizes.

2. To investigate potential biases, communities of 20 identical species were simulated with log-series abundances but without species-specific interactions. No relationship of conspecific neighbour effects on survival or growth with species abundance was expected. Survival and growth of individuals was simulated in random and aggregated spatial patterns using no, linear, or squared distance decay of neighbour effects.

3. Regression coefficients of statistical neighbourhood models were unbiased and unrelated to species abundance. However, variation in the number of conspecific neighbours was positively or negatively related to species abundance depending on transformations of neighbourhood variables, spatial pattern and distance decay. Consequently, effect sizes and standardized regression coefficients, often used in model fitting across large numbers of species, were also positively or negatively related to species abundance depending on transformation of neighbourhood variables, spatial pattern and distance decay.

4. Tests using randomized tree positions and identities provide the best benchmarks by which to critically evaluate relationships of effect sizes or standardized regression coefficients with tree species abundance. This will better guard against potential misinterpretations.

Key-words: community dynamics; multiple regression; neighbourhood model; population dynamics; tropical forest.
Whether or not conspecific negative density dependence (CNDD) at small neighbourhood scales shapes species abundances in tropical tree communities at larger scales is far from resolved and we probably should not even expect the answer to be simple. In principle, there are several possibilities. First, the strength of CNDD is unrelated to abundance. Second, the strength of CNDD is negatively related to abundance (strong CNDD for abundant but weak CNDD for rare species). This would prevent abundant species becoming even more abundant and thereby competitively excluding other species. Moreover, it would confer a rare-species advantage and possibly lead to a community compensatory trend (CCT, Connell et al. 1984). Third, the strength of CNDD is positively related to abundance (strong CNDD for rare but weak for abundant species). This would explain the rarity and low abundance of the species with strong CNDD and the high abundances of species with weak CNDD (Comita et al. 2010). There remain though two further possibilities which are that either a mix of positive and negative processes is operating, or the observed relationships are simply spurious (i.e. the result of a statistical artefact).

In an empirical study, Newbery & Stoll (2013) showed negative effects of conspecific neighbours on absolute growth rate of medium-sized trees. The argument was that reduced growth of an individual tree will – other factors being equal – translate into survivorship and fecundity reductions and hence affect species abundances. Nevertheless, direct effects of conspecifics on survival could be more relevant for population dynamics of different species within communities. Therefore, the tests reported here simulate both individual survival and growth rate and use a framework of neighbourhood analysis similar to that of Newbery & Stoll (2013) to show that all possible relationships of the strength of CNDD and abundance may emerge without any species-specific or effects of abundances. Moreover, we show that potential biases do not depend on the nature of the dependent variable.
Relationships between the strength of CNDD and abundance were investigated using a simple, spatially explicit and individual-based, model which simulated identical species without any species-specific interactions. Thus, any relationships between the strength of CNDD and abundance in communities simulated under these assumptions would not be expected. Nevertheless, relationships do emerge because of interfering effects of spatial patterns and distance decay (i.e. the functional form relating neighbour effects to distance from focal trees, Fig. 1) and, perhaps more importantly, due to transforming (e.g. log-transformation) and/or scaling (e.g. standardization or z-transformation) of the input variables. For example, if rare species have lower variability in the number of conspecifics in their local neighbourhoods compared to common species, scaling is expected to decrease effect sizes (or standardized partial correlation coefficients) of rare relative to common species, possibly leading to spurious negative relationships between the strength of CNDD and abundances. Scaling is recommended (e.g. Schielzeth 2010) and applied especially in hierarchical Bayesian modelling to speed up or even ensure numerical convergence (e.g. Gelman & Hill 2007).

Motivation to investigate the relationships between the strength of CNDD and abundance more carefully using simulations came from the opposite outcomes of two recent publications. A consistent negative relationship between the strength of CNDD (i.e. effect sizes derived from statistical neighbourhood models) and abundance (total basal area of species) in randomization tests was shown by Newbery & Stoll (2013). By contrast, a strong positive relationship between the strength of CNDD and abundance was found by Comita et al. (2010). Whilst such different results are interesting, and might be explained by different underlying biological mechanisms operating on different species at different locations, before making such a conclusion possible differences arising from artefacts and biases of the statistical methods should first be ruled out.
Materials and Methods

A completely neutral forest without any species-specific effects was simulated. Initial size distributions of individuals (basal area, $ba$) were log-normal with mean 2 and standard deviation 1, and simulations were initialized with no spatial dependency in individual size. Individuals of 20 identical species with log-series abundances (i.e. 2827, 1408, 935, 699, 557, 462, 395, 344, 305, 273, 248, 226, 208, 192, 179, 167, 157, 147, 139, 132) were placed on plots (200 x 400 m) either randomly or with aggregated spatial patterns. The aggregated pattern was realized by dispersing individuals around ‘parent trees’ (assigned random locations according to a homogeneous Poisson process), using a Gaussian dispersal kernel with mean 0 and standard deviation 3 m. Thus the species distributions were modeled as a Thomas cluster process, which in turn is a special case of a Neyman-Scott cluster process (Neyman & Scott 1952), and this method means species are spatially independent of one another.

Individual survival was simulated in three steps. First, a linear predictor ($y$) for survival was simulated for individuals within a border of 20 m using the following multiple regression equation:

$$y = \beta_0 + \beta_1 \log(ba) + \beta_2 \sum_{heterospecific \ neighbours} + \beta_3 \sum_{conspecific \ neighbours}$$

(1)

with $\beta_0$ to $\beta_3$ the regression coefficients, $ba$ the initial size (basal area) of individuals and the two neighbour terms simply summing the number of heterospecific or conspecific neighbours within a neighbourhood radius ($r$) of 20 m without taking size or relative size differences between focal individuals and neighbours into account. The regression coefficients were chosen to lead to roughly 50% mortality for each species. Specifically, $\beta_0 = 5$, $\beta_1 = 2.5$, and $\beta_2 = \beta_3 = -0.05$. Second, the linear predictor was converted to individual
survival probabilities using the inverse logit transformation. Third, binomially distributed errors were used to convert the probabilities to the binary variable survival (0’s and 1’s) by drawing from binomially distributed random numbers. Survival was then used in logistic regressions as the dependent variable. Regressions were run for each species separately. Standardized regression coefficients ($b$) were obtained from regressions with independent variables standardized (or scaled) by subtracting their mean and dividing by their standard deviation. Unlike in the neighbourhood analysis for absolute growth rate ($agr$) as dependent variable (see below), fitted neighbourhood radii were fixed for the logistic regressions at 20 m, because best fitting neighbourhood radii for rarer species were sometime smaller than the simulated 20 m radius. To investigate effects of transformations, the same multiple regression approach as described above, but now with log-transformed neighbour terms was used:

$$y = \beta_0 + \beta_1 \log(\text{nbr}) + \beta_2 \log(1 + \sum_n \text{heterospecific neighbours}) + \beta_3 \log(1 + \sum_n \text{conspecific neighbours})$$  \hspace{1cm} (2)

with $\beta_0$ and $\beta_1$ as above, and $\beta_2 = \beta_3 = -1.3$. The $\beta$’s of the neighbour terms needed to be adjusted in order to maintain 50% mortality. Again, unstandardized ($\beta$) and standardized ($b$) regression coefficients were estimated by logistic regressions (general linear models with binomially distributed error terms). Finally, $\beta_3$ and $b_3$, as well as variability in numbers of conspecific neighbours within the neighbourhood radius $r$ for each species, were correlated with species abundances (i.e. log(number of individuals of each species at the plot level)).

In the simulations of individual growth, different distance decays and relative size differences were also taken into account because competition is often size- and distance dependent. Size- and distance dependencies could also have been analysed for survival as dependent variable. However, since the parallel analyses yielded essentially similar conclusions, we present analyses with different distance decays for growth only. For each
individual, one single growth increment (absolute growth rate, agr) was simulated for
individuals within a border of 20 m using the following multiple regression equation:

\[
\log(agr) = \beta_0 + \beta_1 \log(ba) + \beta_2 \log(1 + \sum_r ba_{Het} / w) + \beta_3 \log(1 + \sum_r ba_{Con} / w) + \text{error}
\]  

with \( w = 1 \) (no distance decay), \( w = \text{distance (linear distance decay)} \) or \( w = \text{distance}^2 \) (squared distance decay, Fig. 1). The neighbourhood terms \( (ba_{Het} \text{ and } ba_{Con}) \) summed the basal areas of bigger heterospecific (HET) or bigger conspecific (CON) neighbours within a neighbourhood radius \( (r) \) of 20 m. The random error term was \( N (0, 0.3) \). Regression coefficients were \( \beta_0 = -0.1, \beta_1 = 0.3 \) and \( \beta_2 = \beta_3 = -0.2 \). To verify the simulations, test runs with random errors set to \( N (0, 0) \) were performed. The simulations were realized using C++ (computer code is given in Appendix A of the supplementary material).

Neighbourhood models (as in Stoll & Newbery 2005) were then fitted to the simulated data over all possible combinations of radii for HET and CON neighbours using R (R Development Core Team 2012) and parameter estimates taken from those models yielding the highest adjusted \( R^2 \)-values. Five runs with different seeds were performed and estimates of regression coefficients from best fitting neighbourhood models, effect sizes (Cohen 1988; Nakagawa & Cuthill 2007) or standardized regression coefficients (e.g. Warner 2012) averaged across the five runs. Effect sizes (i.e. squared partial correlation coefficients, \( t^2 / [t^2 + \text{residual degrees of freedom}], t = t\text{-value} \)) and standardized regression coefficients \( (b = \beta' \text{s}) \) obtained from regressions with standardized variables by subtracting their mean and dividing by their standard deviation) were then correlated with species abundances (i.e. plot level basal area, BA, log-transformed). Standardized regression coefficients can also be calculated from unstandardized \( \beta' \text{s} \) as \( b = \beta * \text{SD}_X \), if the dependent variable itself is not standardized (e.g. survival). In the case of continuous dependent variables (e.g. agr), however, the
dependent variable itself is often also standardized as well. In these cases, variability in the
dependent variable is also involved in standardizing regression coefficients and $b = \beta \cdot \text{SD}_X / \text{SD}_Y$. In both cases, a positive correlation of $b$ with abundance implies that less abundant, rare
species have stronger CON effects – $\beta$ is more negative – (as in Comita et al. 2010), whereas
a negative relationship implies more abundant species have stronger CON effects (as in
Newbery & Stoll 2013). Note, however, that possible correlations of $b$ with abundance may
be biased due to correlations of $\text{SD}_X$ (or additionally $\text{SD}_Y$) with abundance. But if $\beta$'s are
negative, large $\text{SD}_X$ lead to more negative $b$-values and the relationship with abundance may
switch direction not because of a difference in the strength of conspecific interactions
between rare and common species, but because of differences in the variability of number
and abundance of conspecific neighbours. Moreover, because the simulations and analyses
for both survival and $agr$ as dependent variables are based on a multiple regression approach,
the basic consequences described above (i.e. possible biases in standardized regression
coefficients because of differences in $\text{SD}_X$ between rare and common species) are essentially
the same independent of the nature of the dependent variable.

**Results**

There were no significant regressions for conspecific density-dependent effects
(regression coefficient $\beta_3$ in Eq. 1) on survival and species abundance (Fig. 2) regardless of
whether untransformed or log-transformed number of conspecific neighbours were used to
quantify the neighbourhood. However, variability in number of conspecific neighbours was
positively correlated with abundance if untransformed (Eq. 1) but negatively related if log-
transformed (Eq. 2). Consequently, standardized regression coefficients were negatively
correlated with abundance if number of conspecific neighbours was quantified on the
untransformed but positively correlated with abundance if number of conspecific neighbours
were log-transformed. Frequency distributions for the rarest (n = 132) and most common (n = 2827) simulated species on untransformed and log-transformed scales (Fig. 3) demonstrate that log-transforming the number of conspecific neighbours for rare species (small values) expands variability but compresses the variability in number of conspecific neighbours for common species (large values). This variability in number of conspecific neighbours (SDX) increases from rare to common species on untransformed scales but decreases from rare to common species on transformed scales.

There were no significant regressions for conspecific density-dependent effects on growth (regression coefficient β3 in Eq. 3) and species abundance (plot level basal area) regardless of distance decay or spatial pattern (Fig. 4). Variation in parameter estimates was largest for squared distance decay and random spatial pattern. Best fitting radii for bigger conspecific neighbours were unbiased in neighbourhood models without distance decay and random spatial pattern (Table 1). However, in the aggregated pattern and with linear distance decay they were slightly underestimated. With estimates (mean ± SD) of 15.9 ± 2.6 in the random spatial pattern and 14.5 ± 3.2, the underestimation was more pronounced with squared distance decay.

Variability in local conspecific neighbour density (within 20 m) varied depending on distance decay and spatial pattern (Fig. 5). A strong negative regression with abundance emerged without distance decay in both spatial patterns. With linear distance decay, the regression was not significant with random spatial pattern but still negative in the aggregated pattern. With squared distance decay, the regression switched to positive in the random pattern, but it was not significant in the aggregated pattern.

As a consequence of variation in local conspecific neighbour density, effect sizes (Fig. 6) and standardized regression coefficients (b3, Fig. 7) showed various relations with abundance depending on distance decay and spatial pattern. Without distance decay both
effect sizes and standardized regression coefficients were positively related with abundance, regardless of spatial pattern. This was also the case for effect sizes and linear distance decay, whereas standardized regression coefficients were not significantly related with abundance in random spatial pattern but still positively related with abundance in the aggregated pattern. For squared distance decay, both effect sizes and standardized regression coefficients were negatively related with abundance in random spatial patterns but unrelated in aggregated patterns. Apparently, the squared distance decay cancelled the effect of aggregation.

**Discussion**

The simulations and neighbourhood analyses with individual survival or growth as dependent variable showed that estimates of regression coefficients ($\beta$) were unrelated to species abundances independent of transformations, spatial pattern and distance decay — as expected based on the simulations of identical species without species-specific interactions. However, variability in local density of conspecifics ($SD_X$) showed various relationships with species abundances depending on transformations of neighbourhood variables, degree of spatial pattern and form of distance decay. As a consequence (i.e. $b = \beta \times SD_X$), relationships between effect sizes, or standardized regression coefficients ($b$), and species abundances were either non-significant, positive or negative.

If untransformed scales are used to quantify conspecific neighbourhoods, relationships with variability and abundance are expected to be generally positive (Fig. B2 in Appendix B) at least in the cases and range of abundances investigated here. In these cases, relationships between standardized effect sizes with abundance will be negative. If, however, log-transformed scales are used to quantify conspecific neighbourhoods, relationships with variability and abundance (Fig. B2) can be modified in all possible ways, i.e. be absent, positive or negative, depending on spatial pattern, exact form of distance decay, but also on
whether or not relative size differences are taken into account. There are many and
sometimes rather non-transparent possibilities making it very difficult to systematically
evaluate the published literature on neighbourhood models and possible relationships
between the strength of CNDD and species abundance, especially where details of how
variables were handled are incompletely reported, and data have not been archived to allow
independent checks.

By using neighbourhood models without distance decay and unstandardized input
variables, in single-species analyses, a negative relationship between CNDD and forest-level
abundance was found, at least for the first of the two 10-year periods analyzed (Newbery &
Stoll 2013). Using no distance decay, yet standardizing before fitting their models, Lin et al.
(2012) found positive relationships over their dry-season interval. Using an exponential
distance decay, Comita et al. (2010) centered (subtracted the mean) but did not standardize
(divide by standard deviation) their input variables (L. Comita, pers. comm.) and found a
strong positive relationship too. Whereas Lin et al. (2012) fitted mixed models using
maximum likelihood estimation, i.e. without any prior information being involved, Comita et
al. (2010) used a hierarchical Bayesian analysis with non-informative priors distributed
according to the scaled inverse-Wishart function. This conjugate distribution models the
covariance matrix of the species-level regression. Nevertheless, both studies did find positive
relationships, thereby apparently supporting one another’s conclusions.

The specific scale and distribution of the priors used by Comita et al. (2010) might
have introduced additional critical information that determined in part the estimation of their
coefficients, in a similar way as standardization did in our simulations, and may also have
done for Lin et al. (2012). Gelman & Hill (2007) discuss the use of the inverse Wishart
distribution in some detail, and highlight in particular the need to confirm that Bayesian
priors are indeed non-informative across the same ranges of independent variables that result
in the posterior probabilities. Dennis (1996) has discussed fundamental issues concerning the
use of non-informative priors and Bayesian analysis for ecology in general.

The results of Newbery & Stoll (2013) dealt with effects of conspecific neighbours (as
large tree abundance) on growth of small trees, whereas those of Comita et al. (2010)
concerned conspecific neighbour effects (as either local tree seedling density or tree
abundance) on survival of those seedlings. Their result could be more generally important if
confirmed to be fully robust to statistical treatment. It might then support the notion that
fundamentally different density dependent processes are likely operating at the seedling as
opposed to the small-tree stage in tropical forest dynamics (Uriarte et al. 2004 a, b; Newbery
& Stoll 2013).

Because of conceptual similarities of neighbourhood analyses of Comita et al. (2010)
and those of others (e.g. Uriarte et al. 2004a, b; Lin et al. 2012), the analysis presented here
could be more widely relevant. Since standardization can lead to spurious relationships
between CNDD and species abundances, its potential influence needs to be carefully
considered when interpreting relationships of small-scale effects of conspecific neighbours
on larger scale abundance patterns within diverse tree communities. Similarly, care should be
taken when specifying and justifying prior information in hierarchical Bayesian analyses. Our
recommendation, following from Newbery & Stoll (2013), is that tests that randomize tree
positions and identities indeed provide the best benchmark by which to critically evaluate and
judge relationships between effect sizes, or standardized regression coefficients, and tree
species abundances.

Acknowledgements

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Supplementary Materials

Appendix A
Documented computer code used for the simulations. A detailed description of input parameters and simulation output is provided in the file named growth_files.rtf.

Appendix B
Relationships of variability in local neighbourhoods with species abundances in different competitive scenarios, spatial patterns and various distance decays.

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TABLE 1. Average best fitting radii ± standard deviation (SD) for bigger con specifics in neighbourhood models (Eq. 3) across 20 species with identical initial size distributions and log-species abundances and random or aggregated spatial patterns.

<table>
<thead>
<tr>
<th>Spatial pattern</th>
<th>Distance decay</th>
<th>random</th>
<th>aggregated</th>
</tr>
</thead>
<tbody>
<tr>
<td>no</td>
<td>20.0 ± 0.0</td>
<td>19.8 ± 0.4</td>
<td></td>
</tr>
<tr>
<td>linear</td>
<td>19.6 ± 0.5</td>
<td>19.1 ± 1.0</td>
<td></td>
</tr>
<tr>
<td>squared</td>
<td>15.9 ± 2.6</td>
<td>14.5 ± 3.2</td>
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Figure legends

Figure 1. Distance decay of neighbourhood effects. In the cut-off model (dashed), the sizes of bigger neighbours with a distance < cut-off are summed. In the linear distance decay (black), the sizes of bigger neighbours are weighed by 1/distance. This is similar to an exponential distance decay (red), which, however, gives somewhat more weight at intermediate distances. A decay of 1/distance^2 (blue) yields a very rapidly decreasing function. Beyond 20, all three functions give essentially zero weights.

Figure 2. Regressions of conspecific effects (regression coefficient, \( \beta_3 \) in Eq. 1) on individual survival, variability in number of conspecific neighbours within neighbourhood radius \( r = 20 \), and standardized regression coefficients \( b_3 \) against species abundances (number of individuals at plot level). Twenty species with identical initial size distributions and log-series abundances were simulated in a random spatial pattern. Note that in the panels of the bottom row, the number of neighbours was log-transformed. Data points are means (± 1 SD) from five replicate simulations. The simulated input value of \( \beta_3 \) (dotted lines) was -0.05 (top left) and -1.3 (bottom left). Continuous lines indicate significant (P < 0.05) positive (blue) or negative (red) regressions.

Figure 3. Frequency distributions of number of conspecific neighbours within neighbourhood radius \( r \) (20 m) for individuals of rare (n = 132) and common (n = 2827) species in simulated communities with random spatial patterns. Note that the x-axis in the panels of the top row have identical scales. This is also true for the panels of the bottom row. Moreover, the number of conspecific neighbours was log-transformed in the panels of the bottom row. SD indicates the standard deviation of each distribution.
Figure. 4. Regressions of conspecific negative density dependence (regression coefficient, $\beta_3$ in Eq. 3) and species abundances (plot level basal area). Twenty species with identical initial size distributions and log-series abundances were simulated without, linear (1/distance) or squared (1/distance$^2$) distance decay of conspecific neighbour effects within 20 m radius in random or aggregated spatial patterns. Data points are means ($\pm$ 1 SD) from five replicate simulations. The simulated input value of $\beta_3$ was -0.2 (green line).

Figure. 5. Regressions of variation in conspecific neighbour density (expressed as SD in basal area of bigger conspecifics, $ba_{CON}$ within 20 m) and species abundances (plot level basal area). Twenty species with identical initial size distributions and log-series abundances were simulated with random or aggregated spatial patterns without, linear (1/distance) or squared (1/distance$^2$) distance decay of conspecific neighbour effects. Data points are means ($\pm$ 1 SD) from five replicate simulations. Continuous lines indicate significant (P < 0.05) negative (red) or positive (blue) regressions.

Figure. 6. Regressions of effect sizes (squared partial correlation coefficients of $\beta_3$ in Eq. 3) and species abundances (plot level basal area). Twenty species with identical initial size distributions and log-series abundances were simulated with random or aggregated spatial patterns without, linear (1/distance) or squared (1/distance$^2$) distance decay of conspecific neighbour effects within 20 m radius. Data points are means ($\pm$ 1 SD) from five replicate simulations. Continuous lines indicate significant (P < 0.05) positive (blue) or negative (red) regressions.

Figure. 7. Regressions of standardized regression coefficients ($b_3$) and species abundances (plot level basal area). Twenty species with identical initial size distributions and log-series
abundances were simulated with random or aggregated spatial patterns without, linear
(1/distance) or squared (1/distance^2) distance decay of conspecific neighbour effects within
20 m radius. Data points are means (± 1 SD) from five replicate simulations. Continuous
lines indicate significant (P < 0.05) positive (blue) or negative (red) regressions.
FIG. 1.
FIG. 2

Regression coefficient ($\beta$)

SD(\sum \text{con neighbours})

Abundance (number of individuals, log-scale)

Standardised regression coefficient ($b_3$)
FIG. 3

rare species

SD = 2.01

common species

SD = 7.21

Number of conspecific neighbours within 20 m

Frequency

log(1 + number of conspecific neighbours within 20 m)

SD = 0.51

SD = 0.12
FIG. 4.

Regression coefficient ($\beta_3$)

Basal area (log-scale)

Random spatial pattern

No decay

Linear decay

Squared decay

Aggregated spatial pattern

Basal area (log-scale)
FIG. 5.
FIG. 6.
FIG. 7.