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**Visual detection based distance sampling offers efficient density estimation for distinctive low abundance tropical forest tree species in complex terrain**

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**Abstract**

Good density estimates for low abundance tree species are costly to achieve especially in rugged or disturbed forest landscapes. More efficient methods would be of considerable value to managers and conservationists. Here we assess a method that has been neglected in this context. We examine and compare distance-based visual detection line-transects and conventional fixed-width transects for assessing a distinctive low abundance species of conservation significance, *Myrianthus holstii* Engl., in three separate areas, within a steep, disturbed mountain rain forest. Precision and implied accuracy appeared substantially better with the visual detection line-transect than with the fixed-width transect for equivalent costs and effort at all three landscapes but as the two methods provide different estimates there are questions of possible bias in both approaches. We discuss the strengths and weakness of the distance approach and suggest some recommendations concerning its application. We conclude that the distance method is suited to low density species that are easily identified, even when understorey vegetation and terrain severely impair visibility. However, due to the differences in detection probabilities, populations need to be stratified both by tree size and context.
Keywords: bias, detection, efficient-rain-forest-survey, inventory, method-selection, rapid-biodiversity-assessment.

1.0 Introduction

Information on plant species densities is helpful for effective forest management (Wong 2000). Such evaluations are a key part of classical forest inventories and associated sampling theory. But when species are rare, as they typically are in tropical forests, these methods are expensive to apply with satisfactory accuracy.

Various approaches have been suggested to offer more cost-effective means to assess low abundance species. We require approaches that minimise bias and maximise precision for the least amount of field effort and expense (Scott & Gove 2002). Fixed area plot approaches such as belt-transect are commonly used to survey tree species (Philip 1994). These have the advantages of good coverage of habitat heterogeneity and ease of implementation (DeWalt et al. 2003, Hashimoto et al. 2003). Various distance based sampling methods have been used in plant ecology: these include the plot-less approaches that utilise distance measurements from points to the nearest trees, or from trees to their nearest neighbours (e.g. Cottam and Curtis 1956, Pielou, 1977), but such approaches are generally less useful for accurate density estimates.

Novel approaches continue to be advanced: e.g., adaptive cluster sampling (Thompson 1992) and size-limited variable area plots (Sheil et al. 2003). The visual detection line-transect method (“distance” in the rest of this paper) is already popular in estimating animal species densities due to its demonstrated efficiency and practicability (Buckland et al., 2000). This distance approach has gained little attention for the assessment of vegetation including forest trees. The reasons for this neglect are unclear but likely include low awareness as most texts on the methods emphasise animals and are targeted at zoologists. Here we assess one form of this approach, line transects, and compare it with a belt (fixed width) transect, for the assessment of a distinctive, low abundance species, *Myrianthus holstii* Engl., in the Bwindi Impenetrable National Park and World Heritage Site, in South-western Uganda.

The efficiency of any new method should be evaluated for reliability in varying conditions in comparison with the best alternative methods (Hounsome et al., 2005). Here
we compare the distance sampling method and belt-transect method for estimating the density of single tree species. We also evaluate the bias, precision and cost of generating data using the two methods under varying conditions.

2.0 Materials and Methods

2.1 Study area

Our study was conducted in three areas or landscapes with different forest characteristics and altitudinal contexts (A, B, C) in Bwindi Impenetrable National Park (0°53’-1°8’S and 29°35’-29°50’E) between October 2009 and April 2010 (Fig. 1). Bwindi was managed as a production forest reserve from 1942 until in 1991 when it was gazetted as a national park. It covers an area of 331 km² at an altitude of 1160 to 2607 m above sea level (a.s.l.), and has a rugged, undulating topography. The vegetation is classified as “medium altitude moist evergreen forest” and “high altitude sub-montane forest” (Langdale-Brown et al., 1964).

The climate in Bwindi is equatorial with two rainfall peaks, from March to May and September to November, with annual mean rainfall of 1525 mm, and an annual mean temperature of 18.35° (http://www.itfc.org, 20/10/2010).

Landscape A (Buhoma) is located on the western section of the park between 1550 and 1850 m a.s.l. and consists predominantly of secondary and mixed forest, with an understorey of Mimulopsis spp. and ferns on steep slopes. Landscape B (Rushaga) is located in the south between 1805 and 2250 m a.s.l. with open areas and mixed forests, with mixed Mimulopsis spp. Alchornea hirtella and spiny Rubus spp., understorey and steep slopes. Landscape C (Ruhija) is located in the east between 2100 and 2500 m a.s.l. with open forest and scanty mature forest with dense Mimulopsis solmsii and M. arborea, Alchornea hirtella and fern (Pteridium aquilinum) and very steep slopes.

2.2. Study species

Myrianthus holstii Engl. [family (Cecropiaceae) Urticaceae] is a dioecious medium-sized deciduous tree that can grow up to 20 m high. The foliage of M. holstii trees are consumed by various of Bwindi’s larger herbivores including the endangered Mountain gorillas (Gorilla beringei beringei) and elephants (Loxodonta africana) while the tree’s...
fruits are sought by gorillas and various other frugivores including chimpanzees (*Pan troglodytes schweinfurthi*) as well as by humans (Cunningham 1992, Elgart-Berry 2004, Robbins & McNeilage 2003). *Myrianthus holstii* has indeed been judged the “most important gorilla fruit species” with seeds being present in 20% of gorilla fecal samples (and 4% of chimpanzee fecal samples) (Stanford & Nkurunungi 2003). Because of this perceived importance to high value endangered wildlife local people have not been permitted access *Myrianthus* fruit inside the National Park by the park authorities (the Uganda Wildlife Authority) despite numerous requests from local communities (Robert Bitariho pers. comm. June 2011).

*Myrianthus holstii* occurs in sub-montane and montane forests across Central and East Africa (Iversen, 1991). The palmate leaves are dark green above and pale grey-green below with conspicuous venation. This species is relatively distinctive in the context of Bwindi, since few other species possess large palmate leaves, and of those that do, only *M. holstii* possesses leaves with such a toothed margin. The species is therefore readily recognised at a distance.

### 2.3. Sampling procedure and data analysis

#### 2.3.1 Methods and enumeration

The *M. holstii* trees (height > 1.3 m) were categorized into four sub-populations based on tree diameter at 1.3m (Dbh) i.e. seedlings (Dbh ≤ 2.5 cm), saplings (Dbh > 2.5 cm but ≤ 5.0 cm), small adults (Dbh > 5.0 cm but ≤ 10.0 cm) and large adults (Dbh > 10.0 cm). We used two sampling procedures i.e. the conventional belt-transect approach, with a width of 10 m (5m to either side of the center line) and a distance based visual detection line-transect (Buckland et al. 2000). Each of the three landscapes were surveyed using eight horizontal transects of exactly two kilometers running in a north-south direction from the forest boundary into the interior. We generated random numbers and the first transect was randomly placed (selecting a location and using a random number offset) with the other seven placed systematically 700 m apart. Along each transect, *M. holstii* trees were searched for by one assigned observer moving along the transect centre line. The horizontal perpendicular distance along the transect, and the horizontal perpendicular distance from the transect to each *M. holstii* tree sighted (height > 1.3 m) were recorded. Diameter measurements were taken at 1.3 m above the ground from the upper side of the slope using...
vernier caliper for seedlings and a diameter tape for saplings and adults. Multi-stemmed trees were considered as one individual by assigning a diameter equivalent to a hypothetical single stem with a sum cross-sectional area equal to the sum of the individual stems. The heights of trees between 1.3 m and 2.5 m tall were measured by tape, while taller stems were calculated from clinometer measurements.

2.3.2 Data analysis

For the belt-transect method, the density (D) of M. holstii trees was estimated using the equation

\[ D = \frac{N}{A} \]

where \( N \) = total number of trees recorded and \( A \) = total areas of transect in hectares, i.e. \( W \times L \), where \( W \) and \( L \) are total width and length respectively. For the distance method, density was estimated using DISTANCE 6.1 Release 2 Software. This estimates density using the basic equation, \( D = \frac{N}{Pa \times 1/2WL} \) (Buckland et al., 2000) where \( N, W, L \) are as above, and \( Pa \) = the estimated probability of observing an object within a defined area.

‘Distance analysis followed the standard guidelines for DISTANCE software (Anderson & Southwell 1995, Buckland et al., 2000, 2004). Four model types (half-normal, hazard-rate, uniform and negative-exponential), each with cosine, simple polynomial and hermite polynomial adjustments, were fitted to each sub-population in each area surveyed. The data were first right-truncated to eliminate outliers. Data grouped in the correct distance interval based on inspection of the detection frequency histograms. These procedures are all adjusted and judged based on standard procedures in DISTANCE (Anderson & Southwell, 1985, Southwell, 2006). Selection of the most appropriate detection function was based on the minimum Akaike Information Criterion (AIC) (Akaike 1973, Burnham & Anderson 2002). Goodness of fit was tested by chi-square, and variance estimated using a post-stratification variance estimator (Fewster et al. 2009).’

Detection functions can vary with conditions and were thus selected separately for the three landscapes. To assess possible bias between the estimates of the two methods, percent relative bias (PRB) was used. The \( PRB = (D_{\text{strip}} - D_{\text{line}}) / D_{\text{line}} \times 100 \% \) (Ogutu et al., 2006) where \( D_{\text{strip}} \) is the density estimated by belt-transect method and \( D_{\text{line}} \) is the density estimated by visual detection line-transect sampling. The precision of the two methods was also compared using the percent coefficient of variance (\( \% \) CV = \{standard error/density\} \times 100) where a lower coefficient of variance indicates greater precision (Boulanger et al., 2005).

The efficiency of the methods was compared based on number of transects, trees recorded and man-hours. To adjust for unequal effort we compare the implied precision of
the two methods as a function of effort as follows: each approach provides a 95% confidence interval (CI) for the density estimate in each of the three landscapes. In each case we know the number of transects, stems recorded and man hours required. We assume that number of transects, stems recorded and man hours can be considered a linear function of each other (i.e. on average double the effort gives double the number of transects and double the number of stems). We know from basic sampling theory that $\text{CI} \propto \frac{1}{\sqrt{n}}$ where $n$ is number of observations and we assume that such a relationship also applies to the distance approach. This allows us to assume that the $\text{CI} \propto \frac{1}{\sqrt{\text{number of transects}}} \propto \frac{1}{\sqrt{\text{stems}}} \propto \frac{1}{\sqrt{\text{man hours}}}$. This allows us to compare results by CI, and relative CI (that is $\text{CI}/\text{density}$), in terms of transects, stems and man hours.

2.4 Results

The belt-transect method covered a total area of 16 ha per landscape. Total transect length was 16 km per landscape for both methods. The total number of *M. holstii* trees (height ≥ 1.3 m tall) recorded by the belt-transect method was 494 stems and the distance method was 1438 stems. It took 181.5 hours to survey 24 transects using the belt-transect method and 301.71 hours using the distance method.

2.4.1 Selection of best Distance model

DISTANCE software enables the user to select from one of four basic detection functions (Southwell, 2006). The *Half-normal model* (with Cosine series adjustment) was found most suitable for most sub-populations, as judged by low AIC and high goodness of fit (GoF) (Table 1). The *Negative exponential model* in contrast always gave a much higher AIC value and also yielded markedly higher tree density estimates compared to the other detection functions, indicating likely bias.

Is it necessary to use different distance estimation models in the different landscapes? In Distance sampling it is assumed that the detection probability ($p$) is 1.00 on the transect line but declines with perpendicular distance. We examined whether detection is the same for the different size-classes among landscapes and the likely bias in the estimates as result of detection probability. Detection probability for seedlings, saplings, small adults and large adults were higher in landscape C, followed by B and lowest at A (Table 1). The selected detection function curves had wider shoulders and declined less rapidly at landscape C.
compared to A and B (Figure 2). For instance, detection probabilities for combined tree populations dropped from 1.0 – 0.1 before 25 m in landscape A and B while at C detection probability dropped from 1.0 – 0.1 after 35 m.

2.4.2 Bias

The density estimates obtained from the distance method were consistently higher than those from the belt-transect (Table 1). The probability of this occurring by chance if neither method were biased (or bias were equal) is $(\frac{1}{2})^{12}, p = 0.000244$, strongly suggesting that at least one of the approaches is biased. We note that the discrepancy was greatest for seedlings and saplings in landscape A and B respectively (Table 2). Given the dense understory undergrowth in some of these landscapes we believe that the most likely explanation is that the 10 m wide belt transect is subject to errors of omission – this is also indicated by the detection functions from the Distance approach which show a marked drop below 1.0 even within the first 5 m – especially for the shortest stature populations (seedlings and saplings) (figure 2).

Another possible source of bias can be investigated by considering whether the combined estimates for subpopulations is the same as that where the subpopulations are pooled prior to estimating the density. With the belt-transect method, the sum of sub-populations density estimates is necessarily equal to the combined population density estimate. In contrast, for the distance approach, the sum of sub-populations yielded consistently higher estimates than the total population (combined size-class) estimates at all the landscapes (Table 1). This difference is 12.67, 25.15 and 27.56 % for the landscapes A, B, and C respectively.

2.4.4 Effort and relative efficiency

The distance method approach had lower percent coefficient of variation (% CV) compared to the belt-transect method for all populations (Table 2). This means the distance method approach provided better precision as indicated by very low values of % CV for the estimated densities of the different tree populations – but it also took more time per transect. The Distance approach generally required 50 to 70% more time to complete a transect, but generally involved measuring many more trees: with 2.7, 2.9 and 3.5 times more for landscapes A, B and C respectively (Table 3). The cost of locating and measuring a tree
(trees per man hour) is lower using the distance method compared to the belt-transect method at all the study landscapes (Table 3).

Comparing the relationship of estimated confidence intervals for density against effort (number of transects, trees and man-hours) for the three landscapes shows that while the differences vary considerably with local conditions the distance method is consistently more precise in both absolute and relative terms than the belt-transect method for nearly all measures of effort (Fig. 3a-f). An exception is landscape A, considered on a per stem basis (Fig. 3b).

2.5 Discussion

2.5.1 Suitability for rain forest conditions

Our study appears to be among the first applications of the Distance approach to tropical rain forest trees – though there has been some application to plant populations e.g. cowslips (*Primula scotica* and *P. veris*) in Scotland, by Shewry et al. 2002 and Buckland *et al.* 2007, and six understorey tree species in China, by Chen *et al* 2009). We have found only two other applications to rain forest trees: one concerned the quantification of fruiting species in unlogged and logged forests in New Guinea (Marsden & Pilgrim 2003) while the other involved a modified application for the selection of *Milicia excelsa* Welw. C.C. Berg. trees for morphological comparisons in Benin (Ouinsavi & Sokpon 2010). Our study thus appears to be the first rain forest application seeking to simply estimate stem densities for a given species.

The ability to search large areas with relatively limited cost even under demanding field conditions is desirable and, as we shall discuss in greater detail below, relative accuracy and efficiency suggests that the method has wide applicability in assessing rain forest trees –.

Though the analytical steps required by the Distance approach are statistically sophisticated, the use of the software meant that model selection, and the resulting density estimation, proved reasonably simple.

2.5.2 Variation in detectability

*Myrianthus holstii* is a distinctive tree species: it is reasonably easy to detect even at considerable distances as long as visibility allows. Thick undergrowth and steep terrain influence such visibility. The fitted detection functions (Fig. 2) indicate how visibility varied among subpopulations and landscapes. As would be expected larger trees are detected with greater probability at extended distances than are smaller stems. The higher detection of all
populations (Table 1) and the wider shoulder of the detection function curves at landscape C compared to B and A (Fig.2) reflects differences in vegetation and terrain and associated visibility. Other studies have found that detection varies with plant height and distinctive morphology (conspicuous flowers and distinctive fruits, Chen et al. 2009). Similar observations have been made for animals: e.g., Shorrocks et al. (2008) found that dik-dik are much more easily detected in areas with short than tall grasses which influences the detection functions. Species that are less conspicuous or harder to distinguish would require additional effort and skill. The major difference among landscapes suggests a need for stratification over large-scale surveys over heterogeneous areas when population abundance and visibility may co-vary (finer scale co-variation is a lesser concern and remains a focus of theoretical consideration and development for animal detection, e.g. Ramsey and Harrison 2004, Royle et al. 2004).

2.5.3 Biases

Our results show that the distance based density estimates were consistently higher than those from the belt transects. Distance methods can overestimate densities if perpendicular distances are not actually perpendicular (Marshall et al., 2008). We minimized this bias by using a compass to fix perpendicular distance – and note that errors of judgment that may be associated with moving animals are avoided with fixed location trees. Under-estimation in the belt transect can result from failure to count all the individuals (Burnham et al., 1985).

Our initial assumption was that the 10 m width belt-transect method was unbiased and would provide a reference for the distance estimates. Our field experiences forced us to revise this view. Although considerable effort was made to ensure complete census within the belt-transect, the dense undergrowth/climbers, difficult terrain and animal damage likely allowed some underestimation of smaller stems that may have been hidden in the thick vegetation. These results are consistent with many other vegetation studies indicating that incomplete detection of plants is common in field studies, even under reasonably benign field conditions (Chen et al. 2009, Moore et al. 2011). In our study poor detection is consistent with the larger discrepancy being associated with smaller stems and was most marked where the understorey is dense and where trees were broken (M. holstii is often broken by elephants, gorillas and other animals). Of course such errors can be reduced by increased effort: for example if transects where surveyed by multiple observers (e.g. five in line spaced 2m apart). However, the distance approach addresses such bias directly by assuming a detection probability that declines with distance (Buckland et al., 2000 & 2004).
Similar results have been reported in animal studies: e.g., Ogutu et al (2006) and Shorrocks et al (2008) who found distance methods provided higher density estimates than belt-transect approach when applied to African grassland herbivores.

We believe that detection probabilities along the central transect line are indistinguishable from 100%. Violation of this assumption would cause underestimation. Such conditions could arise in assessing short plants in a tall dense thicket understory. Such conditions require specific methods to ensure detection such as careful destructive clearing of the center line or more selective sampling to estimate the degree of under-detection.

Nonetheless we do not believe that our application of the distance approach is wholly unbiased. The summed density of sub-populations appears to differ in a relatively consistent manner from estimates based on the total (combined) population (Table 1). According to Buckland et al (2004) the ‘pooling robustness’ property of Conventional distance sampling (CDS) method estimators ensures that moderate amounts of unmodeled heterogeneity do not contribute much bias. Nonetheless we are surprised that biases are not greater, considering the variation in visibility of the various sub-populations and the different impact this must have on detection. We are not sure which estimates are most accurate but expect that adding subpopulations reduces some of the size-dependent influences that may otherwise be operating. We speculate that analytical methods might allow even more efficient (and less biased) estimators if information on detection probabilities could be directly modeled as a function of stem-size thus utilizing information lost in the current approach.

2.5.3 Efficiency as determined by the two methods

The distance method achieved better precision than the belt-transect in all three landscapes for all the populations (Table 2). The low % CV produced by the distance method approaches compared to the belt-transect method for all the population indicates the improved ability of the distance model approach to minimize standard error. The low abundance of *M. holstii* contributes to a high standard error due to large variance but the distance approach minimizes standard errors better than the belt-transect method since it utilizes the additional information derived from more stem observations and the fitted detection function. Bias can still arise with the distance method, especially if the sample size is small, due to uncertainties when selecting the best model (Buckland, et al., 2000).

For the belt method the estimated precision has a fairly predictable relationship with stem density and stem number – the relationship for the distance method is more complex.
Buckland, *et al* (2000) suggested that to model detection functions, a minimum of thirty observations are required from a sampled area. Marshall *et al* (2008) found that 60 – 80 observations are required to accurately model detection functions. Our analysis using distance method approaches yielded precisions between orders of 4.50 – 14.67 % providing a reliable estimate for future monitoring (see Plumptre, 2000).

If the goal is to estimate density and or record stem properties the distance method is more efficient than the belt-transect method because more precise estimates and more stems are characterized for the same field effort. We estimate that about 40 % of the time used in the distance method was spent on measuring the perpendicular distances – greater efficiency might be achieved if this could be simplified, e.g. using an automatic range finder.

The selection of an appropriate sampling method involves consideration of the efficiency of each method under the specific circumstances of the study. Distance methods allow more precise density estimates than the belt-transect method under most conditions. Nonetheless there are differences with location and criteria used (Fig.3). If we simply consider number of transects we see that the biggest differences in confidence by method arises in landscape C (Fig 3a). The use of Distance in landscape C also provides the greatest precision by stem and per man hour (Fig 3b,c) though there is less overall variation by the latter two measures. This reflects the much lower number of observations from the belt-transect method compared to the distance method in landscape C, where visibility is better than in the other two landscapes, allowing higher detection probabilities at a given distance and improved precision and accuracy. The one exception where the belt method outperforms the Distance approach occurs in landscape A where the Distance method is just marginally less precise. This reflects low visibility with few additional trees recorded beyond the belt transects – notably the Distance method still performs better per man-hour even under these conditions. When we consider relative confidence the overall variation seems more marked though the distance methods outperform the belt transects in all cases – the most precise estimates derive from landscape B reflecting the intermediate conditions of the other two landscapes in terms of visibility and in that landscape and a low variation among the transects. The belt transect perform especially poorly in the low density population of landscape C, especially per transect and per man-hour (Fig 3d, f) while the distance approach for this landscape achieves a relative precision comparable to that for the other landscapes.

**Conclusions**
Estimates from the visual detection line-transect method were more reliable than the belt-transect method for a given amount of effort. We recommend that the visual detection line-transect can be effectively used to inventory low abundance but distinctive tree species even in situations with relatively low visibility and considerable variation in size – though further studies on the nature of associated biases and how they may be minimized is justified.

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References


Table 1 Comparison of density estimated by the belt-transect method and the selected distance models within the three study landscapes (A, B & C) in Bwindi Impenetrable National Park

<table>
<thead>
<tr>
<th>Landscape</th>
<th>Tree population</th>
<th>Density estimate</th>
<th>Distance model parameters</th>
<th>---- 95 % CI ----</th>
<th>ESW (m) and *</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Belt (trees/ha)</td>
<td>Distance (trees/ha)</td>
<td>Model/ Series AIC</td>
<td>GoF (p-value)</td>
</tr>
<tr>
<td>A</td>
<td>Seedlings</td>
<td>3.38 ± 0.46</td>
<td>3.91 ± 0.61</td>
<td>H/C 191.4</td>
<td>0.67</td>
</tr>
<tr>
<td>A</td>
<td>Saplings</td>
<td>2.00 ± 0.33</td>
<td>3.17 ± 0.40</td>
<td>Hn/C 156.9</td>
<td>0.95</td>
</tr>
<tr>
<td>A</td>
<td>Small adults</td>
<td>3.31 ± 0.38</td>
<td>3.32 ± 0.42</td>
<td>Hn/C 293.4</td>
<td>0.56</td>
</tr>
<tr>
<td>A</td>
<td>Large adults</td>
<td>6.75 ± 0.52</td>
<td>7.28 ± 0.78</td>
<td>Hn/C 1151</td>
<td>0.68</td>
</tr>
<tr>
<td>A</td>
<td>All sizes</td>
<td>15.44 ± 0.41</td>
<td>16.34 ± 0.85</td>
<td>Hn/C 1932</td>
<td>0.41</td>
</tr>
<tr>
<td></td>
<td>Summation of sub-populations</td>
<td>15.44</td>
<td>17.68</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Seedlings</td>
<td>2.94 ± 0.35</td>
<td>4.83 ± 0.82</td>
<td>H/C 148.7</td>
<td>0.79</td>
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<tr>
<td>B</td>
<td>Saplings</td>
<td>2.06 ± 0.39</td>
<td>2.81 ± 0.41</td>
<td>H/C 158.7</td>
<td>0.4</td>
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<tr>
<td>B</td>
<td>Small adults</td>
<td>1.69 ± 0.36</td>
<td>2.13 ± 0.37</td>
<td>Hn/C 168.4</td>
<td>0.38</td>
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<tr>
<td>B</td>
<td>Large adults</td>
<td>4.44 ± 0.39</td>
<td>4.85 ± 0.46</td>
<td>Hn/C 895.1</td>
<td>0.71</td>
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<tr>
<td>B</td>
<td>All sizes</td>
<td>11.13 ± 0.31</td>
<td>11.47 ± 0.94</td>
<td>Hn/C 566.5</td>
<td>0.67</td>
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<tr>
<td></td>
<td>Summation of sub-populations</td>
<td>11.13</td>
<td>14.87</td>
<td></td>
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<tr>
<td>C</td>
<td>Seedlings</td>
<td>1.68 ± 0.46</td>
<td>2.23 ± 0.47</td>
<td>Hn/SP 118.3</td>
<td>0.93</td>
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<td>C</td>
<td>Saplings</td>
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<td>0.56</td>
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<tr>
<td>C</td>
<td>Small adults</td>
<td>0.50 ± 0.25</td>
<td>1.16 ± 0.32</td>
<td>Hn/SP 105.8</td>
<td>0.91</td>
</tr>
<tr>
<td>C</td>
<td>Large adults</td>
<td>1.13 ± 0.60</td>
<td>1.22 ± 0.35</td>
<td>U/C 294.3</td>
<td>0.99</td>
</tr>
<tr>
<td>C</td>
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<td>4.31 ± 0.84</td>
<td>4.99 ± 0.68</td>
<td>Hn/C 633.3</td>
<td>0.71</td>
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<tr>
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<td>Summation of sub-populations</td>
<td>4.31</td>
<td>5.95</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Density estimate = Mean ± standard error; Hn/P = Half-normal/Simple Polynomial, Hn/C = Half-normal/Cosine, U/C = Uniform/Cosine and H/C = Hazard/Cosine.
AIC = Akaike Information Criterion; GoF = Goodness of fit test probability value; 95% confidence interval (CI); ESW = Distance effective strip width used; * = Fixed strip width of the belt (5m).
Table 2 Coefficient of variation (% CV), per cent relative bias (PRB) of the visual detection line-transect and the belt-line transect density estimates for different populations of *M. holstii* trees at A, B and C, Bwindi Impenetrable National Park.

<table>
<thead>
<tr>
<th>Landscape</th>
<th>Tree category</th>
<th>% CV (VDLT method)</th>
<th>% CV (Belt-transect method)</th>
<th>PRB</th>
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<tbody>
<tr>
<td>A</td>
<td>Seedlings</td>
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<td>6.55</td>
<td>8.80</td>
<td>-7.28</td>
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<td>4.72</td>
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<td>22.93</td>
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</table>

% CV = 100 x {(Standard error/Density)} and PRB = 100 x {(Estimated Density by the belt-transect method – Estimated density by the distance method)/ Estimated density by the distance method. Bold figures show population were the visual detection line-transect approaches had better precision. VDLT = Visual detection line-transect method.

Table 3 Comparison of economic efficiencies of belt and distance sampling methods at A, B and C study landscapes in Bwindi Impenetrable National Park.

<table>
<thead>
<tr>
<th>Study landscape</th>
<th>Efficiency Parameters</th>
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<tr>
<td></td>
<td>a) Belt sampling</td>
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<tr>
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<td>Trees within a transect/ man-hrs (No/hr)</td>
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<tr>
<td></td>
<td>Man – hours/transect (hr)</td>
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<td>1.25</td>
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<td>C</td>
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</table>

Same number of field crews was employed in each of the method and cost of man-hour (Ug.Sh.) = 1424.
Figure 1 Map showing the study landscapes (A, B, C) and orientation of transects within Bwindi Impenetrable National Park.
Figure 2 Observed frequency histograms of distance data and the selected best detection functions for different populations of *M. holstii* (Table 1) at A, B and C landscapes in Bwindi Impenetrable National Park.
**Figure 3** Width of the complete 95% confidence interval (upper to lower) around the estimated stem density (a, b, c,) and relative 95% confidence interval (upper to lower divided by mean, d, e, f) for three landscapes using both distance (Dist) and belt transects (Belt) for three measures of effort: number of transects (a, d), number of stems recorded (b, e) and man hours (c, f). In figure (a) the Dist A and Belt B lines lie nearly on top of each other and in figure (e) Dist A and Belt A and Dist B and Belt C are nearly on top of each other, while in figure (f) Dist A and Belt A are nearly on top of each other.