

## An assessment of landscape diversity using large scale field-based forest inventory

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### ABSTRACT

Landscape diversity is considered as the variety of land cover classes in a landscape and it is usually calculated on land cover maps of entire landscape. However, in this study it is aimed to present a new procedure, that is, the use of field-based national forest inventories (NFIs) to estimate two diversity indices: Shannon's diversity and inverse Simpson. Specifically, it is also intended to investigate how well a combination estimator can improve the precision of the estimates. The permanent square cluster plots produced more precise (smaller variance) estimate of the indices than temporary ones. In addition, estimated variance of the indices using combination estimator was smaller than both permanent and temporary square cluster plots. The applied procedure in this study is very simple where classes of land cover are usually determined and recorded by field surveyor. The main advantages of using field-based inventories are that there is no need for land cover/ use maps or images of the landscape. In addition, quality of the landscape diversity assessment through remotely-sensed data is still highly dependent on the availability and quality of field data. As long as historical datasets from forest inventories is available in many countries it is thus possible to do trend analysis in landscape diversity over time.

**Key words:** Diversity, Forest, Inventory, Shannon, Simpson.

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### INTRODUCTION

Biodiversity is defined in various ways, from genetic to landscape levels and species diversity is the most common approach to relate biodiversity (Gaston 2000). Loss of biodiversity is one important consequence of landscape fragmentation and landscape change (Lindborg *et al.* 2004, Hanski 2005). Milne (1991) stated that the current patterns of landscapes are the result of interactions of physical, biological, and social factors. On the other hand, landscapes thus are dynamic systems, which change over time. Landscape diversity (as the variety of land cover classes) is of interest for landscape ecologists since a fundamental assumption is that this characteristic of landscapes significantly affects many ecological processes. For instance, the composition of land cover within a landscape plays a large role in regulating stream water quality (Clement *et al.* 2017, Shi *et al.* 2017). Jeanneret *et al.* (2003) demonstrated that the occurrence of butterflies was significantly influenced by the heterogeneity of surrounding habitats. Pino *et al.* (2000) found that the total bird species richness was mainly related to the diversity of landscape. Noss (1990) demonstrated that a highly diverse landscape fulfills many fundamental natural functions such as the maintenance of species diversity and that the diversity of landscapes is an important level of biodiversity. Like species diversity direct measures of landscape diversity over large scale such as regional and national levels are neither possible nor meaningful.

On the other hand, quantification of landscape diversity is a complex task. This characteristic of landscapes, however, can be quantified through indicators such as Shannon's diversity and inverse Simpson's diversity indices. Estimation of these indices is usually conducted on mapped data such as land cover/use maps of entire landscape and or using a two-stage sampling design. In the latter case, at the first stage a set of remotely-sensed data is used (e.g., aerial photo) and at the second stage, point or line interest sampling is applied on units of first stage (Ramezani *et al.* 2010, Ramezani *et al.* 2011).

In some cases, mapped data is not available, particularly for large spatial scale (Remm 2005). In addition, diversity indices have frequently been applied to various ecological applications such as tree species (Baltana's 1992), beetles (Carlton & Robison 1998), ants (Longino *et al.* 2002), and butterflies (Sobero *et al.* 2000; O'Hara 2005). However, no research has focused on the estimation of the diversity indices from forest inventories such as National forest inventories (NFIs).

NFIs are the main source of information on the status and trend of forests. They provide reliable, periodic estimates of forest attributes. Large-scale forest inventories has a long history in many countries, for example it has started 1919 in Norway and 1923 in Sweden (Axelsson *et al.* 2009, Fridman *et al.* 2014). They have usually been designed to assess the production value of forests (Corona *et al.* 2011, Chirici *et al.* 2012).

Magnussen (2010) states that ongoing national forest inventories can also provide reasonable estimates of the number of distinct forest tree species (i.e., richness) in both regional and national levels. Forest resource inventories are shifting from traditional variables related to wood and timber production to the assessment of several non-traditional attributes such carbon sequestration and forest biodiversity (Corona *et al.* 2007).

As demonstrated by Kleinn (2000) and Ramezani & Ramezani (2015), the NFIs have also potential to extract some landscape metrics for quantifying landscape pattern, but the previous studies have often been focused on configuration aspect of the landscape pattern. The configuration refers to how landscape elements (e.g., forest patches) are geographically distributed in a landscape. The overall objective of this study is to show a new application of field-based forest inventory and also to estimate landscape diversity as the composition aspect of landscapes. Specifically, it is aimed to estimate diversity indices in terms of Shannon's (*SH*) and inverse Simpson's diversity indices (*D*) as well as their corresponding variances. It is also intended to investigate how well a combination procedure, which would include both permanent and temporary plots, can improve the precision of the estimates. So that, a large dataset from the Swedish National Forest Inventory (NFI) is used.

## MATERIALS AND METHODS

### Material

In this study, a dataset was employed from 2011 provided by the Swedish National Forest Inventory (NFI). The NFI was initiated in the 1920s and the sampling design was a strip survey with a strip 10 m in width (Fridman *et al.* 2014).

However, from 1950s, a square cluster plot design (tract) was introduced into the Swedish NFI (Fig. 1). The country is divided into six regions (strata) and sampling intensity decreases toward the north of the country. Square cluster plots were systematically distributed over the country. From 1980s and onwards, the NFI's sampling design has essentially been the same as today, with permanently located square cluster plots introduced at that time. The permanent square clusters were smaller and with fewer plots than temporary square clusters. Subplots had radius 10 and 7 meters in the permanent and temporary square clusters, respectively. Some information on inventory regions is provided in Table 1.

**Table 1.** Information of the total area of six inventory regions; the number of permanent and temporary square cluster plots in each region and the total number of subplots (sample size).

Inventory regions	Total area (km <sup>2</sup> )	The number of square cluster		The total number of subplots	
		Permanent <sup>a</sup>	Temporary <sup>b</sup>	Permanent	Temporary
1	118130.92	104 (8) <sup>c</sup>	56 (12)	832	672
2-1	68720.46	82 (8)	45 (12)	656	540
2-2	67140.55	86 (8)	45 (12)	688	540
3	69644.09	107 (8)	53 (12)	856	636
4	116848.48	211 (8)	212 (6)	1688	1272
5	34476.76	165 (4)	80 (6)	660	480

<sup>a</sup>10 meters radius plot

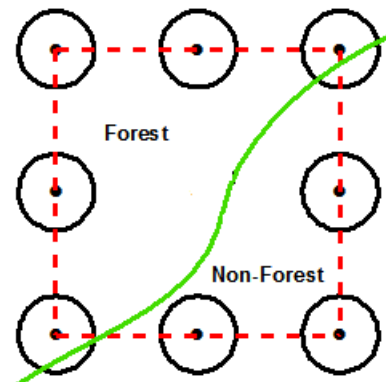
<sup>b</sup>7 meters radius plot

<sup>c</sup> the figures within parenthesis refer to the number of subplot at each square cluster plot

### Diversity index

Diversity measures have been used extensively in a variety of ecological applications. They originally gained as measures of plant and animal species diversity. Over the past decades numerous diversity indices have been proposed, but all information cannot be captured through a single index. In the present study two commonly used indices were applied, including Shannon's and inverse Simpson's diversity indices. These indices have been

applied to measure landscape diversity by landscape ecologists. The estimators of the indices and their corresponding variance estimators are briefly described in the following section.



**Fig. 1.** An example of the permanent square cluster plot with 8 subplots with radius 10 m and virtual sampling line transect between subplots.

### Shannon's diversity index (SH)

The estimator of Shannon's diversity index (Shannon and Weaver 1949), SH is defined as 
$$\widehat{SH} = -\frac{\sum_{j=1}^s \hat{p}_j \ln(\hat{p}_j)}{\ln(s)} \quad (1)$$

where  $s$  is the total number of land cover classes considered (here is 16 classes) and  $p_j$  is the area proportion of the  $j^{\text{th}}$  land cover class which can be estimated unbiasedly by  $\hat{p} = \frac{1}{n} \sum_{j=1}^n y_j$  and then insert into Eq .1 in order to estimate the SH index.  $y_i$  takes the value 1 if the  $i^{\text{th}}$  sampling point (subplots center) falls in the area of interest and 0 otherwise and  $n$  is the sample size (the total number of subplots). For  $p_j = 0$ ,  $p_j \cdot \ln(p_j)$  is set to zero. The resulting value of the index is between 0 and 1, where values close to 0 indicate a landscape dominated by one or a few land cover classes, while values close to 1 indicate a landscape in which land cover classes present have roughly equal proportion.

### Variance estimation of SH

For variance estimation, we applied simple random sampling estimator framework, despite the fact that the cluster plots are systematically distributed across the country. In such cases, random sampling estimators deliver conservative estimates (Gregoire & Valentine 2008). To estimate the variance of Shannon's diversity index Taylor approximation was applied to linearize the estimator. The approximate variance estimator (derivation is presented in Ramezani *et al.* 2010) is

$$\hat{V}(\widehat{SH}) \approx \frac{1}{n} \left[ \sum_{i: \hat{p}_i > 0} \hat{p}_i \ln^2(\hat{p}_i) / \ln^2(s) - \widehat{SH}^2 \right] \quad (2)$$

### Inverse Simpson's diversity index (D)

Inverse Simpson's diversity index (Simpson 1949) is another popular diversity measure. This index is considered a dominance index, because it weighs towards the abundance of the most common land cover class. The value of the index takes 0 when the landscape contains only one land cover class (i.e., no diversity), whereas  $D$  approaches 1 as the number of different land cover classes increases and the proportional distribution of area among land cover classes becomes more equitable. The index  $D$  is then estimated by

$$\widehat{D} = \frac{1}{s} \cdot \frac{1}{\sum_{j=1}^s \hat{p}_j^2} \quad (3)$$

We assume once to take a simple random sampling of size  $n$ . From the sample we estimate the  $p_j$  by  $\hat{p}_j = m_j / m$ , where  $m_j$  is the number of individuals in land cover class  $j$  in the sample.

### Variance estimation of D

Once again, a Taylor expansion can be used to derive the formula

$$V(\hat{D}) = \frac{1}{s^2} \cdot \frac{1}{(\sum_{j=1}^s p_j^2)^4} \cdot (\sum_{j=1}^s p_j^3 - (\sum_{j=1}^s p_j^2)^2) / n \quad (4)$$

for the true (theoretical) variance of  $\hat{D}$ . An estimator of the variance is obtained by replacing all  $p_j$  in (4) by its estimator  $\hat{p}_j$ .

### Combination estimator

As pointed out previously, in the Swedish NFI, both permanent and temporary square cluster plots are in use across the country. A linear combination (of permanent and temporary) estimator was used for estimating two diversity indices and their corresponding variances. A general linear combination of two independent estimators is defined as (e.g., Rannbt *et al.* 1987).

$$\hat{Y} = w \cdot \hat{Y}_1 + (1 - w) \cdot \hat{Y}_2 \quad (5)$$

and the corresponding variance estimator is

$$\widehat{var}(\hat{Y}) = w^2 \cdot \widehat{var}(\hat{Y}_1) + (1 - w)^2 \cdot \widehat{var}(\hat{Y}_2) \quad (6)$$

where the more weight was given to the largest inventory (see the following formula for  $w$ ).

$$w = n_1 \cdot a_1 / (n_1 \cdot a_1 + n_2 \cdot a_2)$$

where  $n_1$  is the total number of subplots (sample size) and  $a_1$  is the subplot size for a given inventory region (see details as illustrated in Table 1).

## RESULTS

Using described estimators, the values of Shannon's ( $SH$ ) and inverse Simpson's ( $D$ ) diversity indices and their corresponding variance was estimated for both permanent and temporary square cluster plots; combination estimator and for each inventory region separately. The estimated diversity indices are summarized in Tables 2 and 3. In all cases, both Shannon's and inverse Simpson's diversity indices were estimated with acceptable precision. In all six-inventory regions, the permanent square cluster plots produced more precise (smaller variance) estimate of the indices than temporary ones.

In addition, estimated variance of the indices using combination estimator was smaller than both permanent and temporary square cluster plots. Estimated variance of two diversity indices for permanent, temporary and combination procedures is shown in Figs. 2 and 3. In all cases, both indices were precisely estimated using permanent cluster plots and combination procedure produced smaller variance than permanent and temporary procedures.

## DISCUSSION

This study shows that national forest inventories (NFIs) in practice, can effectively contribute to perform statistically sound estimation of the landscape diversity, although they are not originally designed for such purpose.

It was found that forest inventories have potential to estimate biodiversity in terms of tree species. However, this study shows a new application of forest inventories, i.e., landscape diversity. This study has been conducted on entire landscape, but a similar study can be conducted on forest landscape through conventional forest inventories. Thus, it would be of interest to explore a relationship between tree species diversity and forest landscape diversity.

**Table 2.** Estimated Shannon' diversity index (SH), using permanent and temporary square cluster plots and for combination procedure.

Inventory regions	Permanent	Temporary	Combination procedure
	SH	SH	SH
1	0.5664	0.5446	0.5602
2 <sup>1</sup>	0.5460	0.5811	0.5560
2 <sup>2</sup>	0.5587	0.5134	0.5461
3	0.4777	0.4839	0.4793
4	0.6273	0.6180	0.6247
5	0.6275	0.6428	0.6315

**Table 3.** Estimated inverse Simpson's diversity index (D) using permanent and temporary square cluster plots and for combination procedure.

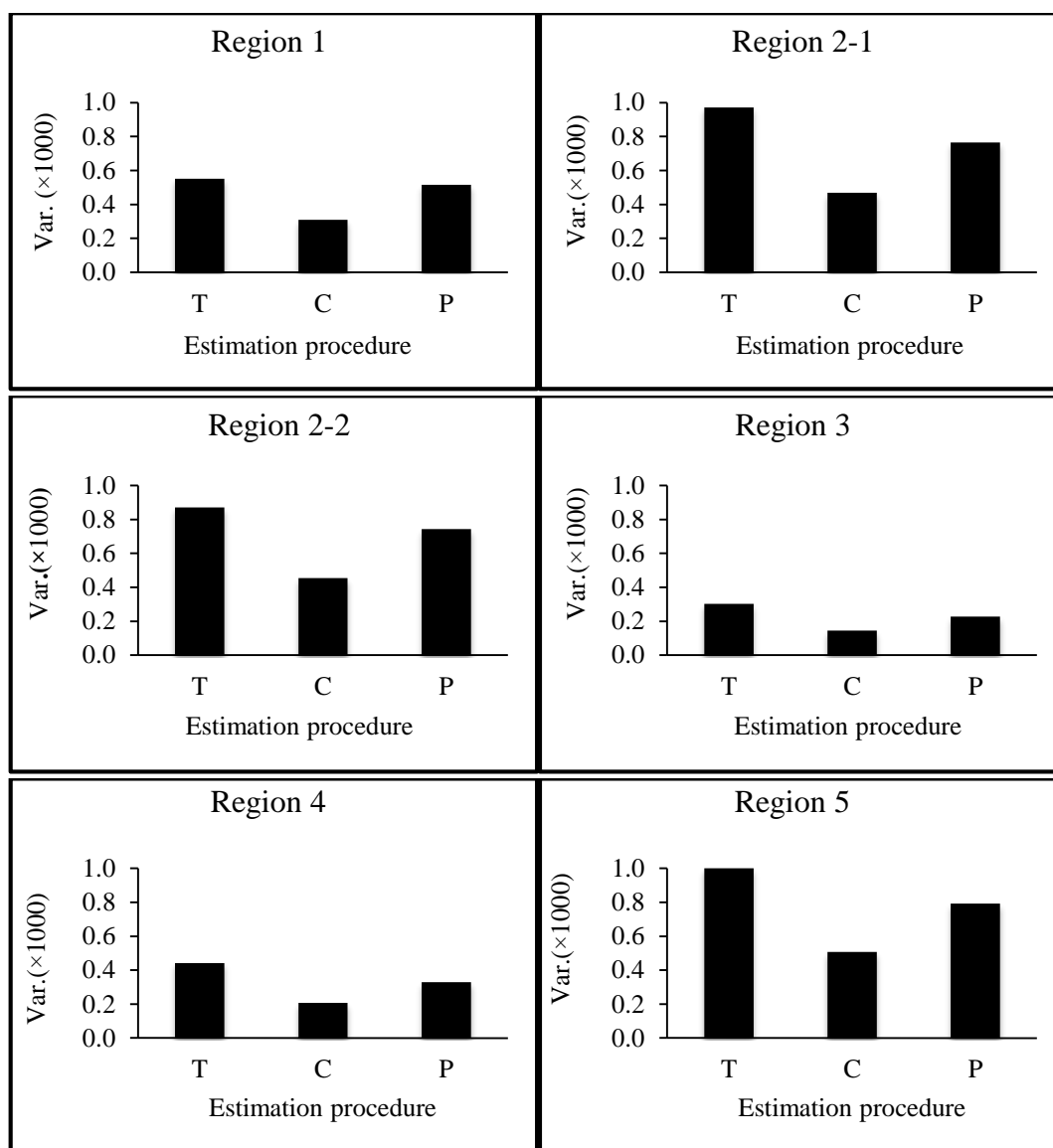
Inventory regions	Permanent	Temporary	Combination procedure
	D	D	D
1	0.9495	0.9292	0.9437
2 <sup>1</sup>	0.5233	0.6513	0.5601
2 <sup>2</sup>	0.5423	0.4146	0.5068
3	0.3615	0.3565	0.3601
4	0.9441	0.7948	0.9039
5	0.6433	0.6475	0.9039

So that, it is needed to modify sampling protocol which are employing in forest management. Findings of this study has shown that further information of a given parameter results in a precise estimate of the parameter. It can be performed by combination of different data sources like the present study or to combine point sampling and line intersect sampling (virtual line between circular plots) in a conventional inventory which is conducted in regional level. The applied procedure in this study is simple where classes of land cover are usually determined and recorded by field surveyor. Indeed, the main advantage of employing NFIs is that there is no need for land cover/ use maps for large area (e.g., national and regional levels). Furthermore, quality of the landscape diversity assessment through remotely-sensed data is still highly dependent on the availability and quality of field data. The use of diversity measures in community ecology has been heavily criticized, because diversity conveys no information on the actual species composition of a community.

The same critics are equally valid when diversity measures are applied to land cover classes instead of species (Turner 1990). In the other words, an unbiased sample-based estimator of landscape diversity is not possible (Good 1953), although its component (area proportion of land cover class) can be estimated without bias.

Forest manager can use forest landscape diversity as useful tool in monitoring the tree species diversity over time, because direct measurement of biodiversity is often difficult or impossible. However, notably, sample size should be the same because the indices values are sample size-dependent and the magnitude of bias of the indices estimators tends to decrease with increasing sampling size (Ramezani *et al.* 2010).

The statistical performance (in terms of precision) of the diversity indices estimators is independent on classification system (Hunsaker *et al.* 1994). In the other words, the precision of the estimator is not much affected by spatial distribution of land cover classes within a landscape. Thus, in forest landscape where a more detailed classification system is often used a larger sample size is needed or it is possible to combine point and line intersect sampling (virtual line between sample plots) to achieve a reasonable precision.



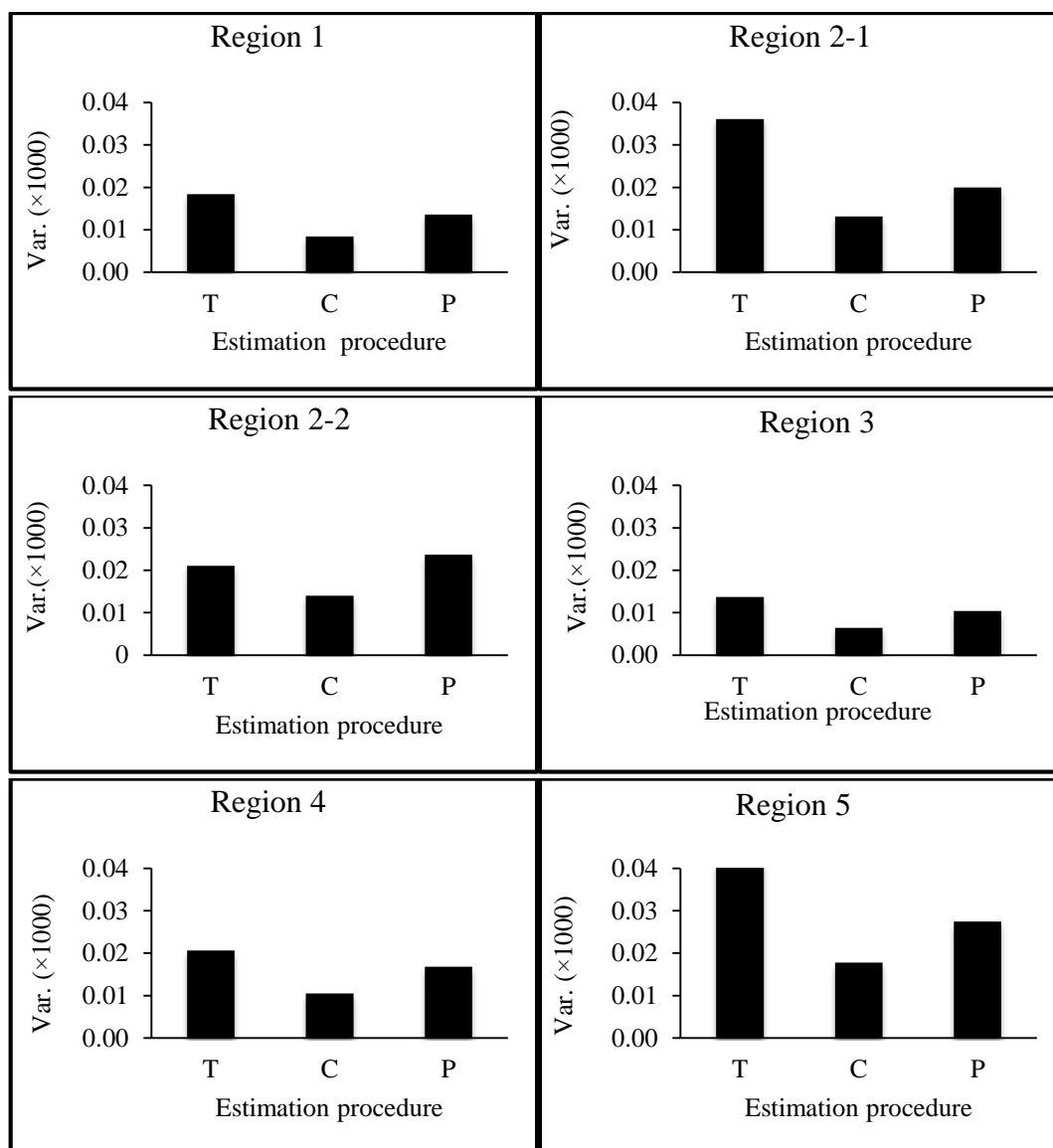
**Fig. 2.** Estimated variance of Shannon's diversity index (SH) for temporary (T), combination (C) and permanent (P) procedures and for six inventory regions.

According to our results, both indices can be employed to quantify landscape diversity through field-based forest inventory. However, inverse Simpson's index gives more weight to the common land cover class (i.e., large land cover class in size) in a sample. On the other hand, the rare land covers class (i.e., small in size) causes only small changes in the value of  $D$ , whereas such a class causes a significant change in the value of  $SH$ . Thus, the question remains as which diversity index and under which situations should be used. It is recommended to use two indices together to cover drawback. In the present study, point sampling (circular subplot centers) is used for estimating two diversity indices. However, the indices can also be estimated using line intersect sampling (LIS) method as demonstrated by Ramezani & Holm (2011) on aerial photos.

In such procedure, virtual line between subplots can be served as sampling line transect (see Fig. 1). With LIS, the indices component, i.e., area proportions of different land cover classes and thus diversity indices, are estimated based on proportion of intersection length of a given land cover class with one sampling line to the total length of all line transects. In the present study, it has been impossible to estimate the diversity indices using LIS because information on the proportion of intersection length of land cover class with sampling lines is not available in the Swedish NFI. However, diversity indices might be estimated more precisely using LIS than point sampling because by LIS more information can be captured, particularly in the estimation of Shannon's diversity where rare land cover class causes a significant change in the value of  $SH$ .

In this study, I demonstrated that the estimates could be improved using a combination estimator of permanent and temporary cluster plots from the Swedish NFI.

It is also possible to combine NFI datasets with other data sources, for instance, some ongoing environmental monitoring programs such as national inventory of landscape in Sweden (NILS, Ståhl *et al.* 2011). Note that before the combination, the datasets should be harmonized because different classification schemes might be used in different surveys.



**Fig. 3.** Estimated variance of inverse Simpson's diversity index (D) for temporary (T), combination (C) and permanent (P) procedures and for six inventory regions.

## CONCLUSION

In a sample survey, a given metric can be estimated in different ways, but the statistical efficiency of a given sampling method depends on selected metric. In this study and with NFI datasets, it is impossible to determine the best sampling method to estimate the diversity indices in terms of accuracy because of the lack of true value of the landscape diversity. So that, there is a need for a sampling simulation survey where sampling is conducted in large time and then the statistical properties of the indices estimators would be compared.

Another further application, which should be investigated, is the ability to determine change of these diversity indices over time. Fortunately, time series of NFI datasets are available in many developed countries (e.g., Norway, Finland, Germany, and USA). The obtained results show that the method can be used in developing countries where conventional forest inventory is in use.

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## ارزیابی تنوع پوشش گیاهی با استفاده از آماربرداری میدانی در مقیاس مکانی بزرگ

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### چکیده

برای برآورد تنوع پوشش گیاهی یا تنوع کاربری زمین در مقیاس مکانی بزرگ برای مثال در سطح ملی یا منطقه‌ای اغلب از نقشه‌های حاصل از تصاویر ماهواره‌ای یا عکس‌های هوایی استفاده می‌گردد. اما هدف این تحقیق ارائه یک روش جدید، یعنی استفاده از آماربرداری جنگل سراسری در سطح ملی است. در این تحقیق شاخص‌های سیمسون و شانون برآورد شدند. یکی از اهداف این تحقیق بررسی تاثیر استفاده از برآورد کننده ترکیبی در دقت برآورد شاخص‌های فوق الذکر بود. برآورد شاخصها با استفاده از پلات‌های نمونه‌برداری دائمی نسبت به پلات‌های موقت با دقت بیشتری همراه بود. به علاوه، استفاده از برآورد کننده ترکیبی منجر به دقت بیشتر خواهد شد. کاربرد روش به کار گرفته شده در این تحقیق بسیار آسان است. یکی از فواید عمده این روش آن است که نیازی به نقشه پوشش گیاهی نیست و اینکه شاخص‌های برآورد شده با صحت بیشتری همراه خواهند بود. از آنجا که اطلاعات تاریخی آماربرداری جنگل در بسیاری از کشورها موجود است، بنابراین امکان بررسی تغییر کاربری زمین در طول زمان نیز وجود دارد.

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