Which indicators for monitoring genetic diversity in cultivated plants?

//////////////// a case study of common wheat ////// cultivated in France during the 20th century

A robust system of evaluation of the state of and changes in biodiversity, including domestic biodiversity, with appropriate indicators, is needed by many international and national organisations (CBD, FAO, French National Strategy for Biodiversity...). The application of indicators which are comprehensive, up to date and simple to use, is a central issue for the FRB. Its Conseil d'Orientation Strategique (COS) created a working group in 2009 to address this issue and its Scientific Committee (CS) has highlighted this goal in its strategic plan, published at the request of the Ministère de l'Enseignement Supérieur et de la Recherche. Such indicators and monitoring systems need to be developed for the genetic diversity of cultivated plants.

The FRB, through an expert group, has reviewed the available indicators which are relevant for monitoring changes in the genetic diversity of cultivated plants. This has resulted in a table of indicators covering different aspects of the genetic diversity of cultivated plants, with different kinds of data: the number of cultivated varieties, the distribution of these varieties in the agricultural landscape and their genetic diversity.

This table has been used to assess changes in the genetic diversity of a crop: common wheat cultivated in France during the 20th century.

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A TABLE BASED ON A SET OF INDICATORS

INDICATORS	INDICES	DIVERSITY MEASURES	INCORPORATED INFORMATION			
			Number of varieties	Areas	Between varieties genetic data	Within varieties genetic data
Varietal richness	Number of varieties	Number of varieties	✓			
Spatial diversity of the varieties	SW (Shannon)	Spatial heterogeneity of varieties	✓	✓		
	Es (Simpson)	Dominance of varieties	✓	✓		
	J (Piélou)	Uniformity of distribution of varieties in a cultivated area	✓	✓		
Genetic diversity between varieties	H (Nei)	Allelic frequencies within varieties	✓		✓	
Spatial genetic diversity, between varieties	H*(Bonneuil et al.[1])	Allelic frequencies within the area cultivated	✓	✓	✓	
Spatial genetic diversity, within and between varieties	Ht*(Bonneuil et al.[1])	Genetic diversity between and within varieties in the area cultivated	✓	✓	✓	✓

1. Bonneuil, C., et al., A new integrative indicator to assess crop genetic diversity. Ecol. Indicat. (2012)

RESULTS

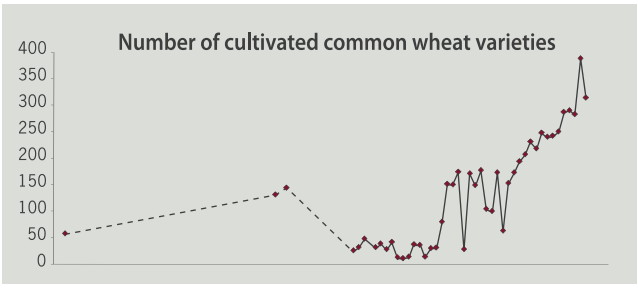
NATIONAL CHANGES IN GENETIC DIVERSITY DURING THE 20TH CENTURY

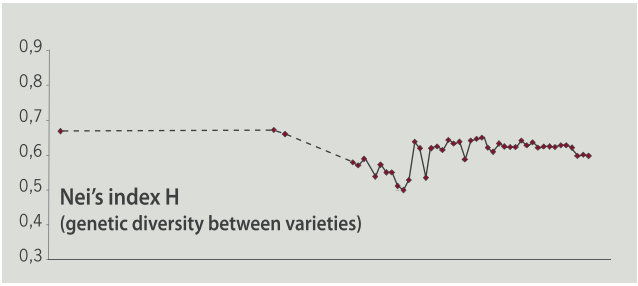
- **From 1912 to 2006, the number of cultivated varieties has increased** through the development of plant breeding. The number of varieties cultivated fell between the late 1950s and the early 1970s. This decrease coincided with a period of strong intensification of French agriculture and simplification of farming systems, with fewer varieties cultivated. Almost all indicators show minimum values of diversity during this period.
- In contrast with the number of varieties, the H index did not increase from 1912 to 2006, indicating that **cultivated varieties kept the same level of genetic diversity through the century.**
- The index which integrates the most information (Ht*) shows **a very strong genetic homogenization of common wheat in France**. This homogenization **occurred principally as a result of the decrease in genetic diversity within the varieties cultivated** from 1912 to 1964. Landraces, **genetically very diverse**, have been progressively replaced by «old lines», far more genetically homogeneous, which were themselves replaced by genetically pure varieties (see green box). Since 1964, these «modern pure lines» have become the only varieties that can be sold commercially and are the only ones cultivated.

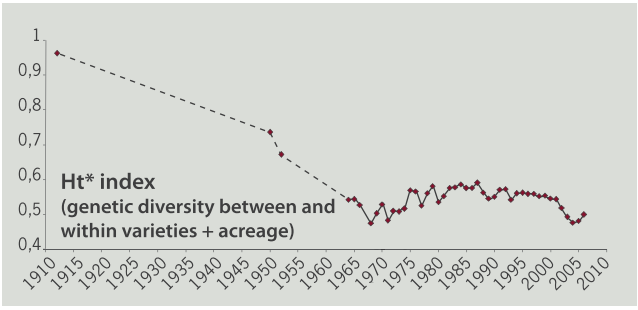
The Ht* index brings together the different types of homogenization highlighted in the table including:

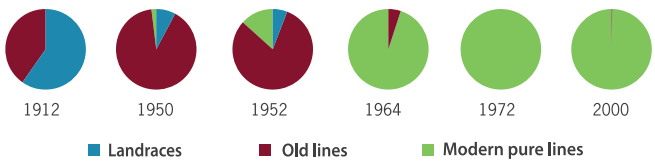
- **genetic homogenization caused by the disappearance of diversity within varieties**
- **spatial homogenization with the different *départements* (French administrative territories) progressively cultivating the same varieties.**

Increasing number of information









While they complement each other, the different indicators focus on different questions: breeding of new varieties, the area covered by the varieties, genetic proximity between varieties, genetic variability within varieties and the distribution of genetic diversity between regions.

Several key sources of data have contributed to the indicators:

- number of varieties and the areas cultivated: monographs, agricultural surveys,
- diversity between varieties: allelic composition of 1,104 varieties according to 35 microsatellite sequences,
- diversity within varieties: previous studies which evaluated the levels of diversity within varieties of wheat populations maintained on farms.

These indicators have been used to monitor the changes in the genetic diversity of a major crop, common wheat, in relation to the significant agricultural changes which occurred in France during the 20th century.

A HISTORY OF VARIETAL INNOVATION FOR COMMON WHEAT, AND ITS REGULATION IN FRANCE

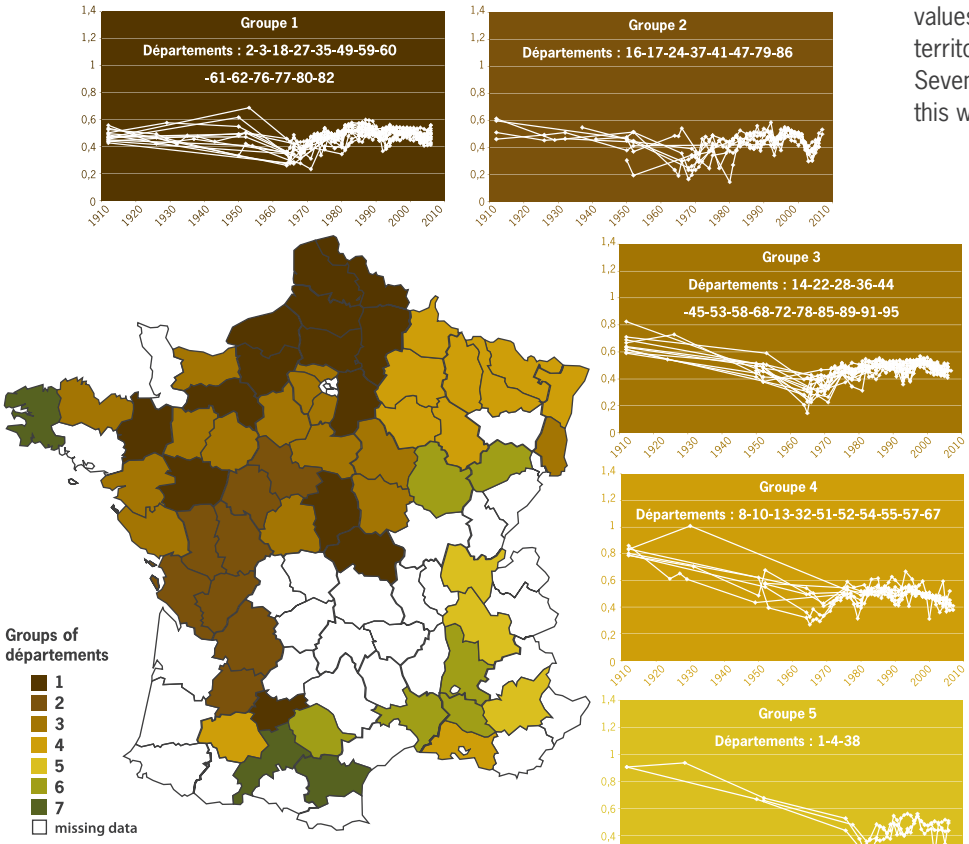
During the 19th century, **"landraces"** were traditionally selected and cultivated by farmers. They are genetically heterogeneous; plants of the same variety have similar characteristics, but different genes.

A new approach to breeding appeared with industrialization. As milling became more mechanized and centralised as new agricultural practices were adopted, more homogeneous varieties which were less prone to "lodging" and more homogeneous were required. This change can be dated to 1884, when the Vilmorin Company created the first pure French line by controlled cross-breeding. Landraces were maintained in the southern half of France, Brittany and mountainous regions, but disappeared at the beginning of the 20th century in the Parisian Basin, Picardy and Nord-Pas de Calais regions. The new varieties for these fertile regions were selected to be adapted to intensive farming practices. These varieties which are referred to here as **"old lines"** were obtained from a single seed by 5 to 10 years of self-fertilization, and were genetically far more homogeneous than landraces.

With the creation of the "Comité technique permanent de la selection" in 1942, a new period of plant breeding and varietal regulation started at the end of the Second World War. National authorization was required before a variety could be commercialized. Tests of "Distinction, Uniformity and Stability" and a "Technological and Agronomic Value" were defined and became increasingly strict. In this study these are referred to as **"modern pure lines"**. These varieties are more homogeneous than "old lines" and became the major varieties cultivated in French farmers' fields.

RESULTS

MAJOR REGIONAL DIFFERENCES IDENTIFIED



The color gradient indicates the place of agriculture modernization showed by Ht* values: from the earliest brown to the latest green

Using a multivariate method of analysis of the Ht* values, *départements* (French administrative territories) which show similar trends were pooled. Seven groups of *départements* were identified in this way.

- The map shows that agricultural modernization, involving the replacement of landraces by professional breeders' varieties, did not happen simultaneously across the whole country. Already by 1912, the major regions of cereal production in the North, the Centre, the West and the Paris region (groups 1, 2 and 3), had lower diversity than the other *départements*.

- The regions where diversity was still high in 1912 cultivated a relatively high number of landraces on the majority of their territories. For the South-West and at the periphery of the major wheat production regions, 85% of the area under common wheat was planted with numerous landraces at this time (groups 4, 5, 6 and 7). In these areas, agricultural modernization occurred later but by the early 1960s there was complete replacement of landraces and «old lines» by «modern pure lines».

This study concerns common wheat, a major crop in France. The changes in genetic diversity shown here reflect principally homogenization of genetic diversity in situ, essentially due to the loss of diversity within varieties during the 20th century. This homogenization raises the issue of the sensitivity of wheat crops with respect to current and future environmental changes (pathogens, drought, sustainable agricultural practices...). The methodology used in this study: indicators, genetic markers, inventories of cultivated areas is applicable to other species. The methodology could allow evaluation of changes in genetic diversity to other important crops of a region. However, the use of this methodology should be adapted to each species according to:

- its biological and genetic characteristics
- the region concerned
- the key events in the history of breeding and commercialization of the crop studied, in order to identify the relevant time scale to consider.

The approach could focus on particular segments of DNA which carry genes of interest or on phenotypic data (size, shape, resistance to diseases, etc.) in order to assess the functional diversity of cultivated varieties or to compensate for a lack of data on genetic markers.

The results could provide useful information for the optimization of methods in varietal surveys and the monitoring of the genetic diversity of cultivated plants by those studying biodiversity. The proposed indicators could be used in the RG-Scope system[1]. The use of these results could also be considered by the "Stratégie Nationale pour la Biodiversité" and by organisations concerned with agricultural biodiversity.

Finally, this study illustrates the consequences of the evolution of agriculture and the associated professional sector on cultivated plant diversity. The use of these indicators provides a powerful tool to assist decision-makers in taking action to maintain the diversity of cultivated genetic resources at national and regional levels. These resources are needed to deal with the social and environmental challenges of tomorrow's agriculture and food production.

1. Labelled SOERE (Système d'observation et d'experimentation pour la recherché sur l'environnement) in 2011 as part of the ECOSCOPE system, the project RG-SCOPE, led by the FRB, aims at federating national systems for the observation of genetic resources by networking structures and their databases via a national internet gateway.

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The FRB, Fondation pour la Recherche sur la Biodiversité was officially established in 2008 by the French Ministry for Research and the Ministry of the Environment. It was founded by eight public research organisations (BRGM, IRSTEA, CIRAD, CNRS, IFREMER, INRA, IRD, MNHN) and is a platform for coordinating and promoting research on biodiversity, involving the scientific community and civil society. To date, more than 110 organisations, including environmental NGOs, business, natural resources managers and local authorities have joined the FRB.

The founder members of the FRB