Basic concepts in phenotypic plasticity of forest trees

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Phenotypic plasticity

• Ability of a *genotype* to form distinct phenotypes when exposed to different environmental conditions.



 More strictly applied to irreversible developmental changes rather than to transient physiological adjustments

Phenotypic plasticity, a scientific trend

- Trending topic in biological research for the last decades.
 - 28,600 entries in Google Scholar (1992-2012)
 - X plant 17,700 X tree 14,400 X tree X adaptive 8,780
- Uncertainties due to climate change have driven increasing attention on Phen.Plast.
 - possible adaptive response of plant populations to too rapid changes for genetic change or migration.

ARTICLE IN PRESS

Review

Essay

Biol Invasions (2015) 17:1109-1122 DOI 10.1007/s10530-014-0781-3

Plant phenotypic plasticit changing climate

A.B. Nicotra¹, O.K. Atkin¹, S.P. Bonser², A.M. Davidson¹, P. Poot⁴, M.D. Purugganan⁵, C.L. Richards⁶, F. Valladare

Genetic differentiation and phenotypic plasticity in life-history traits between native and introduced populations of invasive maple trees

'joelker1, Paxton R. Payton4 & David T. Tissue1

OPEN O ACCESS Freely available online

Laurent J. Lamarque · Christopher J. Lortie · Annabel J. Porté · Sylvain Delzon

Adaptation, Plasticity, and Extinction in a Changing Environment: Towards a Predictive Theory

Luis-Miguel Chevin¹*, Russell Lande¹, Georgina



SYNTHESIS

Adaptation, migration or extirpation: climate change outcomes for tree populations

Sally N. Aitken,¹ Sam Yeaman,² Jason A. Holliday,¹ Tongli Wang,¹ and Sierra Curtis-McLane¹

ORIGINAL PAPER

Plant. Cell &

Phenotypic plasticity, a scientific trend

- Scientific literature has dealt with virtually all aspects and levels of plasticity in plants:
 - from morphological/developmental down to physiological or metabolic and molecular (DNA methylation)
 - from species or populations down to gene expression.
- However, we are still far from understanding the nature and utility of plasticity in tree breeding and genetic conservation; in particular:
 - frequent confusion between stability (breeding sense) and canalization (lack of plasticity)
 - should we search for plastic or less plastic phenotypes?
 - form or amplitude of plastic response? genetic basis?
 syndromes (relationships between traits)?

Plasticity is trait-specific



Santos-del-Blanco et al. (2013) J Evol Biol

Plasticity is environment-specific



Schlichting (2008)

Plasticity is not all that glitters (Ontogenetic allometric effects)

Pinus pinaster, 1 yr seedlings destructive greenhouse test



Considering size effect (allometry-ontogeny) may change our perception of developmental plasticity

Own data, unpublished

Plasticity is not necessarily adaptive

Types and causes of phenotypic variation (Alpert & Simms 2002)

Type of variation	Cause	Type x cause
Explained by environment or G x E interaction	Selection for phenotypic variation	Adaptive plasticity
	Inability to prevent variation despite fitness reduction	Injurious plasticity
	Lack of selection against phenotypic variation	Neutral plasticity

A higher sensitivity to environmental stimuli does not necessarily imply higher total fitness

Dissecting genetic and environmental effects



- Different genetic effect among environments
- Different phenotypic plasticity among genotypes

Plasticity versus stability

- Genetic trials (common gardens) are available over wide ranges of environments, permitting the estimation of genetic components of plasticity
 - time-related for all experiments
 - site- or time-related for clonal experiments
- Numerous methods have been implemented by breeders to dissect G x E, searching for stability of performance (low G x E) (Leo's yesterday class)

Yield: stable or plastic?



Pliura (2008) TBX workshop

C: too reactive to low fertility environments

E , D: low plasticity but too low trait value

Biologically stable

Unstable under a breeding perspective

Yield: stable or plastic?

Pinus pinaster Field experiment Joint Regression Analysis



Stable genotypes (breeding sense) combine high yield values with low G x E: plasticity close to the average

Dissecting G x E: specific vs. general adaptation



Chambel (2006) PhD Thesis

Yield: stable or plastic?



Consistency of performance, a simple non-parametric method for assessing stability of yield traits (Ketata 1989)

Is G x E and plasticity related?

Yes, indeed!

Is the relationship straightforward from G x E analysis methods

Not at all

If we want to progress in our understanding / use of plasticity in breeding, we must find new, specific methods for assessing plasticity for each genotype

Plasticity indexes (Pls)

ESSAY REVIEW

Journal of Ecology 2006 94, 1103–1116

Quantitative estimation of phenotypic plasticity: bridging the gap between the evolutionary concept and its ecological applications

FERNANDO VALLADARES, DAVID SANCHEZ-GOMEZ and MIGUEL A. ZAVALA[†]

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Plasticity indexes (PIs)

- Two environments (sites, time)
 - Max min (Valladares et al. 2006)



- Slope of adjusted reaction norm
- Parameters from non-linear regressions / random regression
- (Max min) / Max not necessarily the same environments among genotypes



environment

Plasticity indexes (Pls)

- Given a design with family structure, per individual PIs allow dissecting the genetic architecture for plasticity (h², Q_{st}, QTLs...), but this requires:
 - Repeated phenotypic measures across time applying an index to an individual (e.g. dendrochronological assessments)
 - Across sites or time by using clonal replicates (clones within families design)
 - Extremely uncommon, normally numerous clones within a fem families or provenances

PhenoPlastFor network

- A thematic network is being implemented in Trees4Future project:
 - Expert group
 - Conceptual discussion
 - State-of-the-art synthesis
 - Experiments
 - Methods
- A short list of case studies has been selected to address different questions related to Phen Plast linked to breeding

PhenoPlastFor network

• Study case of temporal plasticity of height growth in a half-sib trial of Scots pine (INIA)

Regina Chambel, Anäis Denardou, Eduardo Notivol, Jose Climent

- Retrospective height increment from 1994 and 2004, plus total height in 2014.
- Individual Plasticity Index calculated with maximum and minimum annual increments.
- Heritability with and without block effects

F21RIA Scots pine case study

193	194	195	196	197	198	199	100	I01	102	103	Imax	YMax	Imin	YMin	VPlasIndex
18	40	12	15	21	. 51	47	42	35	46	53	53	2003	12	95	0,77
34	41	8	16	35	52	45	48	52	42	50	52	98 y 2001	8	95	0,85
.Z	.Z	.Z	.Z	.Z	.Z.	.Z	.Z	.Z	.Z.	.Z	.Z	.Z	.Z	.Z	.Z
24	20	8	20	32	. 54	49	55	38	37	30	55	2000	8	95	0,85
35	21	4	16	24	55	52	54	33	54	52	55	98	4	95	0,93
23	22	9	15	31	. 65	62	63	72	62	37	72	2001	9	95	0,88
25	21	12	27	47	63	62	59	56	50	68	68	2003	12	95	0,82
12	15	8	4	27	29	24	46	51	58	49	58	2002	4	96	0,93
36	31	12	33	46	43	52	44	41	39	51	52	99	12	95	0,77
25	11	10	18	36	53	58	50	52	66	52	66	2002	10	95	0,85
29	30	20	35	41	. 43	51	46	51	55	43	55	2002	20	95	0,64
39	30	11	17	28	41	43	54	45	52	48	54	2000	11	95	0,80
10	22	10	16	27	64	56	64	47	65	51	65	2002	10	95	0,85
32	24	10	14	29	39	50	50	37	47	46	50	99	10	95	0,80
20	27	6	16	42	51	60	33	39	58	40	60	99	6	95	0,90
.Q	.Q	.Q	.Q	27	41	51	65	59	63	60	.Q	.Q	.Q	.Q	.Q
28	28	15	22	30	49	53	42	39	43	57	57	2003	15	95	0,74

F21RIA Scots pine case study

REG	COL	ROW	Х	Y	FAM	REP	H03	QPI	VPI	VPI2
1	12	1	1	36	VAL30	1	416	9.14	0.89	0.7921
2	12	1	1	35	VAL30	1	501	3.71	0.73	0.5329
3	12	1	1	34	VAL30	1	515	8.38	0.88	0.7744
4	11	1	1	33	VAL41	1	375	11	0.91	0.8281
5	11	1	1	32	VAL41	1	555	4	0.75	0.5625
6	11	1	1	31	VAL41	1	605	3.39	0.71	0.5041
7	10	1	1	30	VAL63	2	570	3.55	0.72	0.5184
8	10	1	1	29	VAL63	2	515	11.8	0.92	0.8464
9	10	1	1	28	VAL63	2	531	5.27	0.81	0.6561
10	9	1	1	27	VAL68	2	562	4.46	0.78	0.6084
11	9	1	1	26	VAL68	2	490	3.56	0.72	0.5184
12	9	1	1	25	VAL68	2	NA	NA	NA	NA
13	8	1	1	24	VAL48	3	424	5.78	0.83	0.6889
14	8	1	1	23	VAL48	3	496	4	0.75	0.5625

Objectives

- Is plasticity for annual height growth increment a heritable trait for the conditions of the experiment?
- Is heritability for plasticity of AHGI of similar magnitude than that for total height?
- Did more plastic families attain a bigger total height?)

Results

• Is plasticity for annual height growth increment a heritable trait for the conditions of the experiment?

• h²= 0,268 (nb) ; 0,285 (b, b x f)

- Is heritability for plasticity of AHGI of similar magnitude than that for total height? (considering blocks)
 - 0,285 vs 0,338 for H03
- Did more plastic families attain a bigger total height?)
 - See plot

Results



Perspectives

- Spatial analysis and competition may increase the percentage of explained variance
- Standard errors of heritabilities
- Genetic (additive) correlations with other fitness traits

Thanks to T4F, BreedR team and you all for your attention

