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THEME E:

BOTANIC GARDENS & CLIMATE CHANGE

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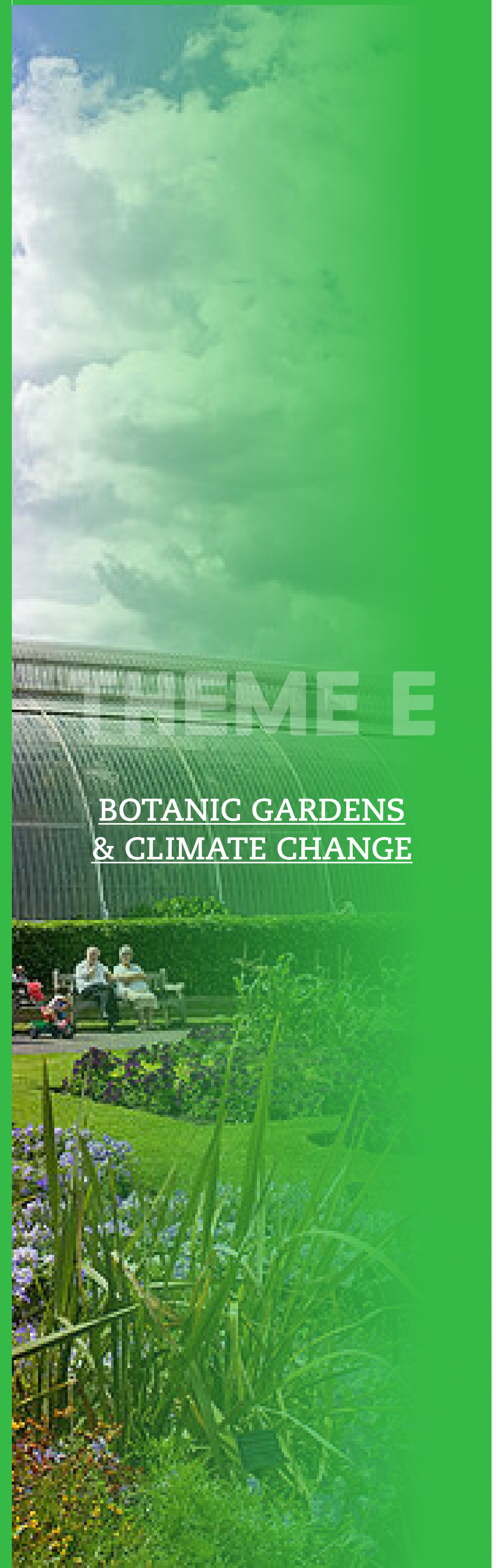
THEME E
BOTANIC GARDENS
& CLIMATE CHANGE

GESTION DIFFÉRENCIÉE AUX CONSERVATOIRE ET JARDINS BOTANIQUES DE NANCY : RÉTROSPECTIVE ET ÉVOLUTIONS

Photo credit : Gestion différenciée au jardin botanique, *Karim Benkhelifa / JBN*

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> Mots-clefs CJBN GESTION DIFFÉRENCIÉE FAUCHAGE TARDIF ARRÊT DES PESTICIDES VALORISATION DE COLLECTIONS PBI CHAUFFAGE PAR INCINÉRATION DE DÉCHETS

05. Résumé

• *Benkhelifa Karim*
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LES CONSERVATOIRE ET JARDINS BOTANIQUES DE NANCY (CJBN) ONT RÉALISÉ DE NOMBREUX EFFORTS POUR UNE ASSURER UNE GESTION DES COLLECTIONS PLUS RESPECTUEUSE DE L'ENVIRONNEMENT, AUSSI BIEN DANS LES SERRES TROPICALES QUE DANS LES COLLECTIONS TEMPÉRÉES. CELA SE TRADUIT NOTAMMENT PAR L'ÉLIMINATION DES PESTICIDES, DES ACTIONS VISANT À AUGMENTER LA BIODIVERSITÉ DANS LE JARDIN, LA MISE EN PLACE DE LA PROTECTION BIOLOGIQUE INTÉGRÉE ET MÊME UN PROJET DE PHÉNOLOGIE POUR ÉTUDIER LES CHANGEMENTS CLIMATIQUES.

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05. Collections de pleine-terre

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CONCERNANT LES COLLECTIONS DE PLEINE-TERRE, CETTE DÉMARCHE, MISE EN PLACE PROGRESSIVEMENT, A MODIFIÉ LES HABITUDES DE NOMBREUX AGENTS AINSI QUE CELLES DES VISITEURS.

Sur l'ensemble des 32 ha, certaines parcelles précédemment tondues sont maintenant gérées en fauche tardive. Les pesticides ne sont plus utilisés, le désherbage manuel s'est intensifié. Des plantes vivaces ont été plantées aux pieds des arbres et arbustes plutôt que d'épandre des désherbants sur sols nus.

Après plusieurs années, nous constatons une augmentation de la diversité faunistique et floristique locale. Les prairies et les vivaces plantées, en plus d'être ornementales, hébergent les auxiliaires de culture. Des sentiers sinueux tondus dans les hautes herbes guident et invitent les visiteurs vers les collections les plus éloignées de l'entrée du jardin. Enfin, cette démarche écologique est aussi économiquement avantageuse. Depuis quelques années, nous utilisons également de nouvelles tondeuses écologiques pour les plus grands espaces herbacés : des moutons ! Des ruches ont également été installés, afin d'introduire des pollinisateurs, de même que des nichoirs à insectes pour les espèces solitaires.

LILASCOPE : ÉTUDE DES CHANGEMENTS CLIMATIQUES

Les changements climatiques deviennent une réelle problématique des jardins botaniques. En dehors des méthodes de gestion des collections plus respectueuses de l'environnement, un nouveau projet a été mis en place en 2012 : *Lilascope*, un outil de suivi de la phénologie des lilas comme sentinelle du réchauffement climatique.

Ce projet est la traduction de la volonté affirmée par l'Université de Lorraine de mobiliser les atouts des Conservatoire et Jardins Botanique de Nancy (CJBN) sur des projets de recherches portant sur des thématiques liées aux changements globaux (climats, biodiversité, ...). Ce projet a été mis en place par le laboratoire d'Ecologie et Ecophysiologie Forestières (UMR INRA-Université de Lorraine). Il vise à caractériser la variabilité interannuelle et la variabilité génétique de la phénologie de différents cultivars de Lilas (2 cultivars suivis), une des collections emblématiques des CJBN, pour en faire un outil de monitoring à long terme des fluctuations du climat local et régional. Il s'appuie sur l'implémentation de technique moderne de capture et

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d'analyse d'image vidéo dont la retransmission en ligne sera également un outil de diffusion de culture scientifique et technique à destination du public. Le matériel utilisé est le suivant : 4 webcams de type CAM-SEC à 5 méga pixels (trois installées et une en réserve pour éviter les pertes de données en cas de panne) avec support de fixation et boitier de protection étanche, une micro station météo avec capteurs pour le rayonnement, la température de l'air et du sol, l'humidité de l'air, les précipitations et la teneur en eau du sol, une centrale d'acquisition de données avec transmission wifi et boîtier de protection étanche pour station météo type CR3000 Campbell, un mat de 10 m de haut pour supporter les caméras et le panneau solaire et un Serveur dédié. L'installation sert à repérer les différents stades phénologiques d'une plante (feuillaison, floraison, fructification, défeuillaison …) et de disposer de séries temporelles d'indices de végétation qui peuvent être confrontées aux principaux facteurs météorologiques.

Collections tropicales

Les serres tropicales des CJBN ont été parmi les premières en France à appliquer la Protection Biologique Intégrée (PBI), technique à présent courante dans les jardins botaniques. Les CJBN entament en effet la 15e année de PBI, et disposent actuellement d'un certain recul sur cette pratique. Cette durée, alliée à un volume de serres important (2 500 m²), a amené des observations pertinentes sur l'équilibre biologique et l'efficacité de l'utilisation d'auxiliaires de culture. On constate par exemple que dans la serre de grand volume (serre palmarium) il n'y a pas eu besoin d'apporter d'auxiliaires depuis plus de cinq années. En effet, les auxiliaires tels que les *Cryptolaemus montrouzieri* sont présents d'une année à l'autre et l'équilibre ravageurs/auxiliaires s'autorégule seul.

La PBI a, par ailleurs, été accompagnée dès ses débuts par une réduction non négligeable des intrants chimiques, muée à partir de 2010 par l'arrêt de l'utilisation de pesticides, démarche qu'il convient aujourd'hui d'appeler « zéro phyto ».

De plus, si l'utilisation de produits chimiques pour la culture est un aspect particulièrement visible des effets néfastes de l'horticulture sur l'environnement, la consommation de carburants pour le chauffage des serres en représente un autre. Ainsi, les serres des CJBN qui étaient chauffées à partir d'une chaufferie gaz, sont depuis 2010 chauffées par le réseau de chauffage urbain de l'agglomération de Nancy qui utilise l'incinération de déchets ménagers et une chaudière à bois. Ce système présente le double avantage de valoriser des déchets dont le recyclage est impossible, et de supprimer la consommation de carburants fossiles. Cette démarche a permis de diminuer nettement l'empreinte carbone des serres.

Les bâtiments

On peut ajouter aussi, au niveau des pratiques durables, la construction de nouveaux bâtiments plus respectueux de l'environnement. Ainsi, le pavillon d'accueil, construit en 2005, et le nouveau bâtiment technique, dont la construction vient de commencer, sont conçus dans un esprit durable, tant au niveau des matériaux que de l'utilisation énergétique.

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Les Conservatoire et jardins botaniques de Nancy ont donc réalisés de nombreux progrès dans la gestion de leurs collections, tant au niveau des collections tempérées (fauche tardive, plantation de vivaces qui abritent des auxiliaires de culture, etc.) que des collections tropicales (lutte intégrée, nouveau mode de chauffage, etc.). Ces pratiques permettent de s'inscrire dans une démarche de développement durable, qui prend en compte la problématique des changements climatiques avec un projet de recherche sur ce sujet (Lilascope).

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LES CONSERVATOIRE ET JARDIN BOTANIQUES DE LA VILLE DE GENEVE AU REGIME BIO

Photo credit : Un Jardin BIO favorise le vivant. Pollinisation de *Borago officinalis* L., ***Bernard Renaud, CJBG.***

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DEPUIS LE 1ER JANVIER 2015, LES CONSERVATOIRE ET JARDIN BOTANIQUES DE LA VILLE DE GENÈVE CULTIVENT UN JARDIN « 100% BIO ». PLUSIEURS ANNÉES D'EXPÉRIMENTATION, D'ÉTUDES ET DE RECHERCHES DE SOLUTIONS ONT ÉTÉ NÉCESSAIRES POUR RÉALISER CE PROJET AMBITIEUX ET UNIQUE EN SUISSE ROMANDE. LA RESPONSABILITÉ D'UN PATRIMOINE DE PLUS DE 9'000 TAXONS DIFFÉRENTS EN COLLECTIONS VIVANTES NE LAISSE PAS LE DROIT À L'ERREUR DANS LA MISE EN ŒUVRE DE NOUVELLES TECHNIQUES DE CULTURES. LA VOLONTÉ D'OUVRIR LA VOIE À PLUS D'ÉCOLOGIE ET DE BONNES PRATIQUES DANS L'ART DE CULTIVER LES PLANTES NOUS A POUSSÉS À FAIRE LE PAS. AUJOURD'HUI, LES VISITEURS PROFITENT D'UN JARDIN ENTRETENU SELON LES EXIGENCES DU CAHIER DES CHARGES DE BIOSUISSE, UNE GRANDE PREMIÈRE POUR UNE COLLECTIVITÉ PUBLIQUE!

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05. Introduction

• *Freyre Nicolas*
• *Loizeau Pierre-André*

Photo credit : Un Jardin BIO favorise le vivant. Pollinisation de *Borago officinalis* L., ***Bernard Renaud, CJBG.***

BIOSUISSE EST L'ORGANISATION FAÎTIÈRE DES PRODUCTEURS BIO DE NOTRE PAYS DEPUIS 1981. ELLE EST PROPRIÉTAIRE DU LABEL BOURGEON, LE PLUS LARGEMENT RÉPANDU ET RECONNU PAR LES CONSOMMATEURS SUISSES.

À ce jour, plus de 5700 exploitants agricoles et horticoles travaillent dans le respect des directives de BIOSUISSE, une des normes les plus exigeantes au monde en matière d'agriculture biologique. Le Jardin botanique de la Ville de Genève bénéficiera de ce label de qualité après une période dite de reconversion, d'une durée de 2 ans, durant laquelle les règles de BIOSUISSE sont strictement identiques à celles qui prévaudront ensuite.

Ce projet répond à plusieurs objectifs. Le premier et le plus important est bien sûr l'enjeu écologique. En abandonnant complètement et strictement tous les produits chimiques de synthèse utilisés dans l'entretien des espaces verts, nous respectons d'autant mieux l'écosystème qui nous entoure. Travailler en BIO, c'est respecter les cycles de la vie. C'est assumer la finitude de nos ressources naturelles et agir en conséquence, à notre échelle. Le deuxième enjeu est celui de la santé. Se conformer aux exigences du BIO améliore nettement les conditions de travail des jardiniers. Les pratiques écologiques sont en effet bien plus favorables et respectueuses de la santé humaine que les méthodes conventionnelles utilisées jusqu'à aujourd'hui. Le troisième objectif est de faire évoluer la pratique de l'horticulture et de le faire reconnaître. En effet, le cahier des charges de BIOSUISSE s'adresse principalement à l'agriculture, soit la production de denrées alimentaires animales ou végétales. La démarche des Conservatoire et Jardin botaniques de la Ville de Genève est pionnière en ce sens qu'elle s'applique à des collections de plantes et des espaces verts publics.

BIOSUISSE

> IMAGE 1

Logo BIOSUISSE

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05. Matériel et méthodes

• *Freyre Nicolas*
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La démarche de reconversion vers des techniques de culture biologique est le résultat de plus d'une année d'étude de faisabilité. Il y a d'abord un constat de départ : en 2014, le Jardin botanique de la Ville de Genève est « presque » BIO. Pour mesurer avec rigueur et précision le vide à combler vers la certification BIO, nous avons rédigé et soumis un sujet de travail de bachelor à la Haute école du paysage, d'ingénierie et d'architecture de Genève (hepia). Un étudiant de la filière Gestion de la Nature s'est saisi du sujet et a travaillé pendant 3 mois au contact du terrain et des jardiniers. L'objectif était de clarifier la procédure administrative vers la certification, et de mesurer l'impact technique et financier d'une telle opération (Irschingler, 2014).

L'étude a consisté à faire un inventaire le plus exhaustif possible de tous les intrants utilisés au Jardin (engrais, produits phytosanitaires, semences, substrats de culture, alimentation et soins aux animaux, etc…) et de vérifier la compatibilité avec les règles de BIOSUISSE. Pour tous les produits non autorisés, l'objectif était de proposer une ou plusieurs solutions techniques alternatives, de manière à pouvoir assurer une transition vers le BIO sans prétériter la santé des plantes et des animaux. Toutes les pratiques de culture ont également fait l'objet d'une évaluation relative au cahier des charges de BIOSUISSE. La deuxième partie de l'étude a porté sur l'évaluation des coûts et la charge administrative engendrés par un tel processus. La procédure à suivre pour une reconversion BIO a également été clarifiée.

À la suite des résultats de cette étude, nous avons pris toutes les mesures nécessaires pour nous mettre en conformité avec les exigences de BIOSUISSE avant le 1er janvier 2015. Techniquement, la méthode a consisté à faire un tri complet des intrants du Jardin, acquérir des fournitures nouvelles, et mettre en place des procédures pour assurer une traçabilité parfaite de toutes les opérations liées à l'utilisation de ces intrants (traitements phytosanitaires, soins animaliers, travaux d'apiculture, etc…). Administrativement, la démarche a consisté à affilier l'institution à BIOSUISSE ainsi qu'aux différents organismes de contrôle et de représentation professionnelle. Après cette étape importante, nous nous sommes soumis à un contrôle à blanc de l'ensemble du Jardin botanique effectué par un organisme indépendant de certification.

La dernière étape, et probablement la plus sensible, a été de convaincre l'ensemble du personnel du secteur Jardin (42 collaborateurs) du bienfondé de cette démarche vers le BIO. En effet, la réussite de ce projet tient beaucoup dans la capacité des jardiniers à accepter le changement et à s'y adapter.

Résultats

Une des principales difficultés a été de se familiariser avec la liste contraignante des intrants de l'Institut de recherche de l'agriculture biologique (FiBL,2014). La règle veut que tous les intrants de l'exploitation doivent figurer dans cette liste; nous avons dû ainsi bouleverser de nombreuses habitudes et rechercher des nouveaux fournisseurs à qualité de produits égale, voire supérieure. Par exemple, la fumure minérale des plantes a été complètement revue et remplacée par des engrais organiques. Avec des temps de réaction parfois plus longs, l'utilisation de ces engrais nécessite une adaptation des pratiques culturales de la part des jardiniers. Les substrats de culture ont été également reconsidérés, avec pour objectif de travailler sans tourbe pour la production, ce qui correspond à une exigence supplémentaire par rapport aux normes de BIOSUISSE. C'est peut-être l'aspect phytosanitaire qui nous

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a posé le moins de problème, dans la mesure où nous utilisions déjà la lutte BIO (auxiliaires de culture) depuis plusieurs années. Le fait de travailler avec des plantes sauvages et de cultiver une extraordinaire biodiversité (plus de 9000 taxons différents) est en soit une grande aide pour limiter les attaques qui restent très localisées. L'alimentation des animaux d'élevage (ovins et caprins) ainsi que les protocoles de soins vétérinaires ont été par contre entièrement revus et corrigés pour se conformer au cahier des charges de l'agriculture biologique. Des solutions alternatives ont finalement été trouvées pour l'ensemble des produits non autorisés par BIOSUISSE (voir annexe). L'intégralité de ces résultats est présentée dans le travail de bachelor de V. Irschlinger (2014).

En plus des restrictions concernant les intrants, certaines mesures contraignantes relatives aux pratiques de culture sont décrites dans le cahier des charges de BIOSUISSE. Il est dit par exemple que « la régulation des mauvaises herbes doit être effectuée uniquement par les techniques de culture et par des moyens mécaniques. Le désherbage thermique est autorisé. [...] La stérilisation du sol à la vapeur est interdite en plein air » (BIOSUISSE, 2014). L'unique solution et la plus efficace reste donc le désherbage manuel, qui était déjà largement pratiqué au Jardin botanique compte tenu de la spécificité et de la diversité des cultures. De manière générale, une très grande importance est donnée au respect de la vie du sol. « À long terme, seuls les sols vivants continueront de fournir des récoltes » (BIOSUISSE, 2014). C'est pourquoi la conservation et l'amélioration de la fertilité naturelle des sols revêt une importance centrale en agriculture biologique et doit être obtenue par des techniques de culture adéquates. Tout ce qui contredit cet objectif primordial doit être abandonné. Il est en particulier « formellement interdit d'utiliser des engrais chimiques de synthèse et des produits phytosanitaires chimiques de synthèse ou fabriqués à l'aide de l'ingénierie génétique » (BIOSUISSE, 2014). Au-delà de l'interdiction, c'est le principe de respect de la vie qui est mis en avant, comme postulat central de l'agriculture biologique.

Le cahier des charges de BIOSUISSE prévoit également des mesures obligatoires d'encouragement de la biodiversité. « Les producteurs Bourgeon cultivent l'ensemble de leur domaine de manière à ménager le plus possible l'environnement et les plantes, animaux et microorganismes présents. Ils s'efforcent d'avoir un domaine aussi diversifié que possible qui laisse de la place à divers êtres vivants et habitats aussi bien dans les surfaces cultivées qu'à leurs abords. Les producteurs Bourgeon complètent avec des mesures supplémentaires les déjà grandes prestations systémiques de l'agriculture biologique pour la biodiversité » (BIOSUISSE, 2014). De par sa diversité en terme de nombre d'espèces cultivées, mais aussi paysagère, le Jardin botanique respecte déjà ces principes sans mesure supplémentaire. Il est toutefois intéressant de noter que les principes de BIOSUISSE ne s'arrêtent pas uniquement à la culture elle-même, et accordent une place importante à la notion de services écosystémiques.

Les principaux problèmes que nous avons rencontré sont liés à l'acquisition de matériel végétal de multiplication (semences, boutures, plants, etc...), l'offre en qualité BIO étant très faible en production ornementale. Il y a aujourd'hui en Suisse très peu de fournisseurs qui proposent des semences de plantes ornementales (annuelles, bisannuelles et bulbes) certifiées BIO. Le choix et la diversité sont ainsi très faibles, et la qualité germinative n'est pas toujours optimale. Il paraît évident que si la demande émanant des professionnels de l'horticulture augmente, le nombre de fournisseurs, la qualité et la disponibilité des produits, ainsi que la diversité de formes et de couleurs

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augmentera en conséquence. Conscient de cette réalité, BIOSUISSE n'exige pas, pour le moment, des semences certifiées, pour autant que le producteur prouve l'absence de disponibilité sur le marché. Tout prétraitement phytosanitaire (graines enrobées) est par contre bien évidemment proscrit.

Administrativement, nous avons dû mettre en place plusieurs actions pour se mettre en conformité. D'abord, toutes les opérations techniques (traitements phytosanitaires, traitements vétérinaires, achats d'intrants, opérations d'apiculture et d'élevage, etc…) doivent être strictement documentées et archivées pour assurer un suivi complet de l'exploitation. « Les exploitations doivent rendre compte de leurs achats d'engrais, d'amendements, de fourrages, d'additifs fourragers et de produits phytosanitaires, et de l'emploi qui en est fait. La présence de tout intrant non autorisé par le présent Cahier des charges est formellement interdite dans toute l'exploitation » (BIOSUISSE, 2014). Ces exigences de traçabilité demandent la tenue à jour d'un certain nombre de registres consultables en tout temps sur l'exploitation.

Ensuite, le Jardin botanique de la Ville de Genève a formellement signé un contrat de production avec BIOSUISSE, l'organe fédérateur des agriculteurs BIO. Nous avons également mandaté la société indépendante BioInspecta, qui est l'organisme de contrôle des exploitants BIO. Enfin, nous sommes devenus membres de BioGenève, l'association cantonale des producteurs BIO. L'ensemble des cotisations obligatoires et des émoluments de contrôle s'élève aux alentours de 1000.-CHF par année. Le Jardinier-chef a également dû suivre une formation obligatoire de 2 jours sur les principes de l'Agriculture biologique.

Au 1er janvier 2015, le Jardin botanique a ainsi officiellement commencé une période de 2 ans de reconversion dans l'objectif d'obtenir le label BIO en 2017. Nous nous sommes soumis avec succès au premier contrôle de BioInspecta en mars 2016, ce qui est loin d'être anodin dans l'approche de notre métier. Accepter de faire contrôler son travail par une entreprise extérieure, c'est une manière de s'exposer à un jugement. C'est pourtant l'outil incontournable qui permet de certifier la qualité des exploitations BIO en Suisse. Le contrôle a lieu chaque année entre mars et septembre. En plus de cet exercice obligatoire (et annoncé), 10% des exploitations suisses sont visitées une deuxième fois de manière aléatoire.

Discussion

Toutes les solutions techniques trouvées dans le cadre de cette recherche ont été proposées aux jardiniers comme une alternative positive. Cette approche « solution » a été la clé de la réussite du processus vers le BIO. Il est en effet nécessaire d'accompagner le changement au lieu de l'imposer. Un agriculteur peut prendre seul la décision d'une reconversion BIO. Par contre, une institution aussi complexe que la Jardin botanique de Genève, qui compte 42 collaborateurs et plus de 9000 taxons, doit nécessairement passer par un processus d'acceptation. Pour les jardiniers, il s'agit de réinventer son métier, d'oser expérimenter, déconstruire des principes établis depuis de nombreuses années.

Dans le contexte actuel de l'agriculture biologique, le chemin pris par le Jardin botanique de Genève est bien évidemment une exception. Cette démarche est pionnière, puisqu'à priori, le cahier des charges de BIOSUISSE

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s'adresse au secteur agricole, et principalement à la production alimentaire. Le processus de reconversion BIO du Jardin botanique a été possible, il faut le reconnaître, grâce au bon sens des instances de certification. Plusieurs aspects de notre métier si spécifique ne sont en effet pas décrits dans les règles du jeu, personne jusque-là n'ayant soulevé la problématique. Est-il possible de recevoir des plantes rares de collection d'autres Instituts botaniques qui ne sont pas certifiés BIO ? Comment nourrir des animaux d'ornement si l'aliment n'existe pas en qualité BIO ? Faut-il renoncer aux traditions d'échanges de graines à travers les *Index seminum* ? Autant de questions qui ont été soulevées et résolues par des compromis, grâce à la bienveillance de BIOSUISSE qui est conscient de ses limites, et qui a souhaité encourager notre démarche.

La suite logique serait de faire évoluer le cahier des charges de BIOSUISSE, vers la prise en considération des spécificités des métiers de l'horticulture, de la botanique et des espaces verts. Il semble nécessaire d'avoir une masse critique d'entreprises et de jardins botaniques assez importante pour pouvoir stimuler ce changement.

Conclusion

Au niveau national, le Jardin botanique de la Ville de Genève est la première collectivité publique à respecter formellement les normes de BIOSUISSE. Les espaces verts urbains en Suisse étant majoritairement gérés et entretenus par le secteur public, l'objectif est d'inciter et d'encourager d'autres municipalités à faire de même en s'appuyant sur cette expérience. La portée de ce projet prendrait alors une dimension supplémentaire avec un impact démultiplié.

La réussite de ce projet tient essentiellement dans la capacité des jardiniers à accepter le changement. Concrètement, le passage en BIO ne demande pas nécessairement plus de travail, mais oblige à réaliser plusieurs adaptations. L'enjeu a été de trouver ensemble des solutions techniques (engrais, traitements, substrats, etc…) qui soient favorables et parfois même meilleures qu'auparavant. La responsabilité des collections vivantes du Jardin botanique de la Ville de Genève (plus de 15 000 plantes de collections) ne laisse en effet pas le droit à l'erreur ou à l'approximation !

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SIBERIAN FIR SEED PRODUCTIVITY IN V.N. SUKACHEV INSTITUTE OF FOREST ARBORETUM, RUSSIA

Photo credit : Siberian firs at Forest Arboretum, *R.I. Loskutov*

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> Keywords
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SEED FORMATION
SEEDS PRODUCTIVITY

05. Abstract

• *Bazhina Elena*

THE DEVELOPMENTAL ASPECTS OF SEXUAL REPRODUCTION OF SIBERIAN FIR (*ABIES SIBIRICA* LEDEB.) GROWING AT THE SUKACHEV INSTITUTE OF FOREST ARBORETUM WERE ANALYZED. SIBERIAN FIR SEED-CONE BUD, PRE-FERTILIZATION OVULE DEVELOPMENT, POLLINATION, FERTILIZATION AND EMBRYO DEVELOPMENT WERE HISTOLOGICALLY INVESTIGATED. SEED PRODUCTIVITY OF CONES AND SEEDS IS VERY LOW AT THE ARBORETUM. THE RESULTS OBTAINED IN THIS STUDY CONTRIBUTE TO UNDERSTANDING THE EFFECTS OF CLIMATE CHANGE ON THE REPRODUCTION OF *A. SIBIRICA*; SUCH INFORMATION MAY CONSTITUTE THE BASIS FOR THE CONSERVATION OF THIS PLANT.

> Keywords *EX SITU* CONSERVATION
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05. Introduction

• *Bazhina Elena*

Photo credit : Siberian firs at Forest Arboretum, ***R.I. Loskutov***

IN A MODERN ERA OF ENVIRONMENTAL CHANGE, THE DETERMINATION OF PLANTS HARVESTING IS IMPORTANT FOR THE DEVELOPMENT OF MODELS WITH PROTOCOLS FOR PLANT CONSERVATION.

However, gaps in fundamental biological information for threatened plants are one of the challenges for global plant conservation. *Ex situ* plant collections provide valuable means for researching of climate change (Firsov, 2012; Shaw & Hird, 2014). When forest plants are grown artificially in arboreta, botanical gardens and on plantations, they have to, like in the case of climatic changes, and adapt themselves to new environmental conditions. Target 8 of the Global Strategy for Plant Conservation (GSPC) is directly aimed using *ex situ* collections to support conservation, and enabling supply of *ex situ* material for recovery and restoration programs (Secretariat of the Convention on Biological Diversity, 2009). Botanical gardens and arboreta are important in terms of improving our understanding of *ex situ* conservation of plants, climatic change effects on plants and of mechanisms of their adaptation to these changes (Owens & Blake, 1985; Westwood & Cavender, 2015).

Plant conservation requires broadening our knowledge of plant reproductive biology, especially of how seeds develop in the plants being grown. It was shown that climatic changes at introduction induce reproductive phenology shift and different types of disturbances in planted trees (Owens *et al.*, 1991; Beuker *et al.*, 1998; Skrøppa *et al.*, 2007; Bazhina, 2014; Bazhina *et al.*, 2011). And viewed in that light, studying the characteristics of the seed production of the fir trees (*Abies sibirica* Ledeb.) growing in the arboretum may contribute significantly to our understanding of how to conserve woody species.

The purpose of this study was to investigate female gametophyte and seed development in the Siberian fir (*Abies sibirica* Ledeb.) cultures in the Arboretum of the V.N. Sukachev Institute of Forest (Krasnoyarsk, Russia).

Materials & methods

GENERAL INFORMATION

V.N. Sukachev's Forest Arboretum was originally established in 1977, in the wildland/Krasnoyarsk interface (Akademgorodok) in an area of 15.15 ha.

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The aims of the arboretum are conservation, investigations of introduction and acclimatization and education. The arboretum displays many elements of the Siberian- and Far-Eastern-type ecosystems. This is essentially an islet of mountain steppe with soil characterized by thick sod layer and ground vegetation dominated by tall grasses (Mamaev *et al.*, 1993). Notwithstanding its proximity to Krasnoyarsk, the arboretum is almost not polluted, because it is situated outside the zone of the prevalent industrial emission transfer (Varpholomeev & Maltsev, 2006). The arboretum is a member of the Botanic Gardens Conservation International (BGCI).

GEOGRAPHICAL AND TOPOGRAPHICAL CHARACTERISTICS

The arboretum is situated on a terrace (275m a.s.l.) of the left bank of Yenisei River (Lat. 55°59', Long. 92°45').

CLIMATIC AND SOIL CHARACTERISTICS

The arboretum is considered to be an East-Siberian version of the Southern taiga subzone. The climatic conditions of the arboretum according to Spravochnik po klimatu (1967) are the following: extremely continental climate with cold winter (up to -53°C in January) and short hot summer (up to +38°C in July). The mean annual precipitation is 485mm. The length of the vegetation is 154 days; the period of freeze-free is 120 days and the period with snowpack is 165 days. The arboretum is supported by sod-carbonate, weakly alkaline (pH is close to neutral 7.01±0.08) soil containing little humus (2.55±0.13%) and mobile nitrogen (Loskutov, 1991).

DATASET

Siberian fir saplings were grown from seeds collected in natural fir stands of Altai region found in moderately continental climate and were brought to the arboretum from the nursery of the Research Siberian Institute of Fruit Growing (Barnaul, Altai) in 1977 (Loskutov, 1993).

Developing seed buds and cones were collected every 1 or 2 weeks from late April through August from several 50-year-old Siberian fir trees growing at the arboretum. They were collected in the upper parts of crowns of trees, brought to the laboratory, and fixed. Ovuliferous scales or separate ovules were removed from large cones. The ovulate cones were fixed in Navashin's solution or in alcohol mixed with acetic acid to a ratio of 3 : 1 for one day, dehydrated through the tertiary ethyl alcohol series (Pausheva, 1988) and embedded to paraffin. Serial sections were cut at 8µm, stained for anatomical study by iron-hematoxilin and procion red and blue dyes (Ivanov, 1982).

DATA ANALYSIS

A 10-15 ovule and developing seeds per stage were analyzed using a Micromed-2 microscope. Seed productivity was measured as a quantity of seed scales producing seeds during 2010-2012. Since, under each seed scale 2 ovules developed, then the seed productivity was calculated according to the formula: $A=n/2N100$ (%), where n- seed number is, N- total number of seed scales is (Minina & Tretyakova, 1983). Seed quality was tested by X-rays method (Scherbakova, 1965). Quantity of full, empty and damaged by insect's seeds was calculated (in %). Results were statistically analyzed using standard statistical methods STATISTICA 7.0 (StatSoft, Inc. STATISTICA, 2001).

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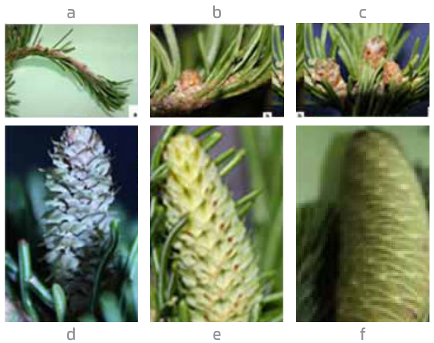
SEED-CONE BUD DEVELOPMENT

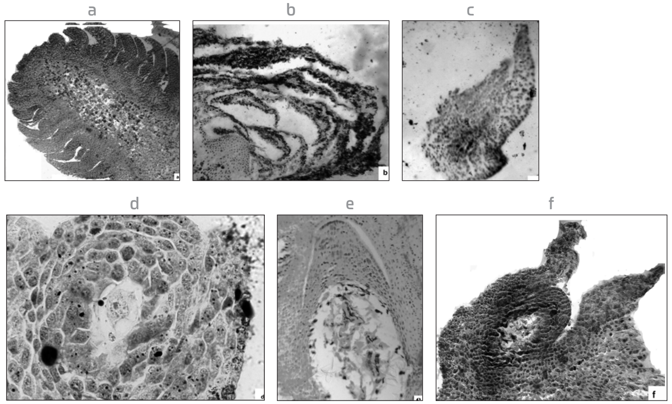
The developmental aspects of sexual reproduction of the Siberian fir growing at the arboretum and in natural populations are essentially the same. Seed-cone buds develop only on shoots in the upper region of the crown. They differentiated nearly all axillary primordia on the upper surface of twigs in early-July (**Fig. 1a**). In late July, a differentiation begins in macrostrobiles: bract scale primordia become notable on the apex flanks. In mid-to-late August, swellings occur at the bract scale bases that later develop into a small ovuliferous scale (**Fig. 2a**). Only bracts at the very base and tip of the cone do not develop ovuliferous scales. Part of buds will become latent or form small vegetative buds (**Fig. 2b**). When conditions are unfavorable for seed-cone differentiation, part of latent buds makes up to 80-90%.

Fertile ovuliferous scales initiate two ovule primordia before winter dormancy. Ovules are on the upper surface of ovuliferous scale and consist of a megasporangium (nucellus). At the late-August ovuliferous scale increased up to 254x296mkm, nucellus increased up to 128x85mkm. A ring of meristematic cells develops around the nucellus. Seed-cone buds overwinter at this stage.



> FIGURE 1

Seed cones development: a – seed-cone buds initiation (mid-July); b – dormant seed-cone bud (early September); c - seed-cone after dormancy (late April); d – seed cone at pollination (May) showing pointed bracts; e, f – branch and matured cone (late August)



> FIGURE 2

Median longitudinal sections of: a - a dormant seed cone bud: bracts have a broad base and point tip, a small ovuliferous scale forms in its axil (late August); b – a latent bud in spring; c - a post dormant seed cone: developing bracts and ovuliferous scale demonstrate mitotic divisions (late April); d – an ovule from seed cone after dormancy showing one large megaspore mother cell in the nucellus; e,f – ovule at pollination: free-nuclear female gametophyte, integument is already funnel-shaped and female gametophyte show free nuclei

PRE-FERTILIZATION OVULE DEVELOPMENT

In dormant seed cones the ovular areas showed a discrete epidermis and one or two isodiametric hypodermal archesporial cells and subjacent cells were aligned in concentric arcs. In the post dormancy stages seed-cone buds become very long, bracts, ovuliferous scale and ovules developed rapidly (Fig. 2c), the ring meristematic cells formed the integument. Each archesporial cell divided to form an inner sporogenous cell and an outer primary parietal cell, which further divided periclinally to form the parietal tissue. One of the sporogenous cells elongated considerably, became prominent, and functioned as the megaspore mother cell (MMC) (**Fig. 2d**). After the MMC formed (late-May), the cells of the nucellar epidermis divided periclinally forming a thick nucellar cap and integument differentiated. Meiosis of MMC was not followed by wall formation and megaspore went through free-nuclear divisions. Tapetal cell became more irregular and flattened on the inner surface of the nucellus as the nucellar cavity enlarged and became spherical (**Fig. 2e**). At pollination time integument overgrew the nucellus, extended beyond the edge of the ovuliferous scale, and developed a wide flangelike structure and a wide open micropyle (**Fig. 2f**).

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The haploid female gametophyte cells divided, except for several cells at the micropylar end, each of which elongated, formed a large basal vacuole and functioned as an archegonial initial. At the arboretum usually two to four initials per ovule formed as in a natural population. Cells around each archegonial initial divided, forming small isodiameric archegonial jacket cells with densely staining cytoplasm and large nuclei. Then archegonial initials divided unequally and form a small primary neck cell to the outside and a large, vacuolated central cell to the inside, which enlarged and developed many clear vacuoles (**Fig. 3a**). Archegonial jacket cells remained small, isodiametric, and densely staining. Female gametophyte cells continued to divided, forming a large egg nucleus (**Fig 3b, c**). The matured gametophyte was slightly irregular and nearly filled the nucellar cavity; the 2 archegonia were surrounded by a single layer of jacket cells, which were smaller than the surrounding gametophytic cells.

POLLINATION AND FERTILIZATION

The period of pollination varies with the location and the weather. Pollination is usually occurring earlier at the arboretum (in the second decade of May) than in natural populations growing in vicinity of Krasnoyarsk where pollination usually occurs in late May but may occur a week later - early June depending on weather conditions. At the time of pollination the scales of the female cones become slightly separated from each other, thus allowing easy access for the pollen to the micropyles (**Fig. 1d**). However, no germinating pollen grains were found on the nucellar tip of ovules at the arboretum. Because of the failure of cones to be pollinated, many stages from fertilization through the early embryonic stage were represented by few specimens and are not illustrated photographically. However, a few adequate specimens were available to describe embryo development.

EMBRYO DEVELOPMENT

The 16-celled pro-embryo was formed 1-2 week after fertilization, by mid-July (**Fig. 3d**). It was a very transient phase before suspensor elongation which lasts in true fir only a few days (Owens & Molder, 1977; Singh & Owens 1981, 1982). During the next stage, cells of the embryo tier divide to form distal apical cells and basal embryonal tubes, which elongated and force the apical cells further into the female gametophyte. The apical cells divided to form a club-shaped embryonal mass (**Fig. 3e**). The proximal cells of the embryonal mass elongated unequally to form a massive secondary suspensor, which pushed the embryonal cells into the corrosion cavity of gametophyte (**Fig. 3f**).

In some ovules occurs “cleavage polyembryony” when the suspensor tier elongates and embryonal tubes form. Cleavage refers to the separation of the apical cells into four files of cell. One of these embryos resulting from cleavage are more vigorous and other soon degenerate (**Fig. 3g**). Matured *Abies* seeds seldom have more than one matured embryo. All other embryos stop development at a very early stage, degenerate and are reabsorbed.

Cells at the distal end of the embryo formed several cotyledons (embryonal leaves) around small shoot apical meristem (**Fig. 4a, b**), cells of central portion of the embryo formed root apical meristem and the basal cells formed a thick secondary suspensor. During the next week embryos and seed matured, the remaining female gametophyte cells contain stored food in the form of starch and lipo-protein (Owens & Molder, 1977; Singh & Owens 1981, 1982). Differentiation in the club-shaped embryonal mass to initiate root meristem and a ring of cotyledon primordial occurred in the 4th week of July and embryo matured by the 1th week of September. Seed development

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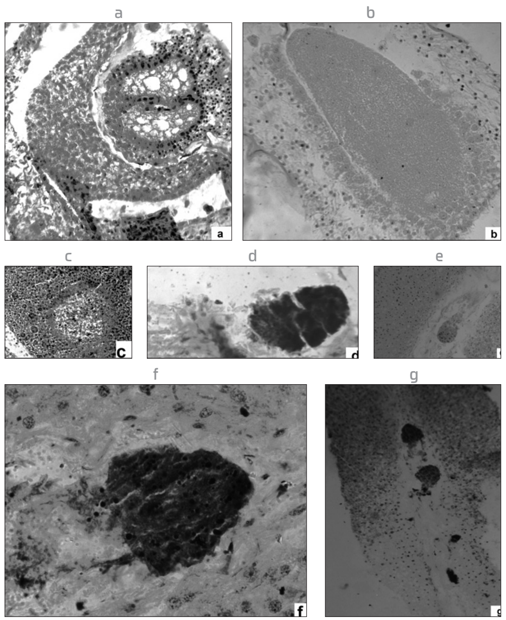
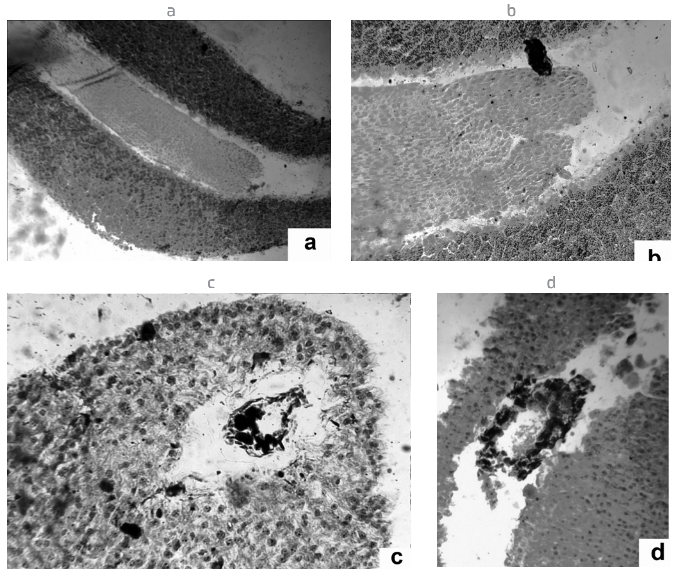
is completed in late-August - early-September. This is about three months after pollination as in alpine (*Abies lasiocarpa* (Hook.) Nutt.) and *amabilis* (*A. amabilis* (Dougl.) Forbes) firs (Owens & Molder, 1985).

In most ovules there is absence of pollination, no further seed development was possible and female gametophytes were finally aborted (**Fig. 4c**). We noted that gametophytes wereaborted only if, five to six weeks after pollination, fertilization had not occurred. In this case, gametophytes collapsed and their contents became absorbed by the surrounding tissues. Lack of fertilization is very common in true firs and female gametophyte will degenerate leaving a normal-appearing but empty seed.



> FIGURE 3

Longisections of ovules to show the development of the archegonium and embryo: a – young archegonia surrounded by a layer of a jacket cells; the central cells are highly vacuolated; b, c – later stage: b - central cell cytoplasm is dense and nucleoli of jacket cells are hypertrophied; c – matured archegonium showing dense cytoplasm with numerous large and small inclusions and large egg nucleus; d – 16-celled proembryo consisting of four ties of cell: apical, suspensor, rosette and open (mid-July); e – club-shaped embryo in corrosion cavity just before meristematic zone appear. The suspensor cells and embryonal tubes elongate and become coiled as they push the distal embryo tier through the archegonial jacket into the female gametophyte tissue; f – torpedo-shaped embryo. Inner female gametophyte cells are collapsing next to corrosion cavity; g – cleavage polyembryony: one embryo (torpedo-shaped) is more vigorous and the others soon degenerate



> FIGURE 4

Longisections of an ovule in mid-summer: a, b - the embryo within corrosion cavity at time of cotyledon initiation and formation (late-July); c - collapsed female gametophyte; d - *Megastigmus* egg in corrosion cavity

SEED PRODUCTIVITY OF CONES

The Siberian fir trees growing in the Institute of Forest Arboretum have generally low production of cones and seeds, with cone amounts varying from none to twenty in a tree. Generally seed productivity of cones ranged 45% to 87% during the years covered by our studies. However, these seeds showed an extremely low viability, containing developed embryos making up only 1-9.8%. Empty seeds were morphologically similar to full ones.

Unlike the natural populations of the species found in the low-mountain areas of Eastern Siberia, in which the seed buds damaged by seed chalcids (*Megastigmus*) amounted to a considerable number, the insect larval infestations were negligible (less than 1% of the seeds were damaged) at the arboretum. Few *Megastigmus* eggs observed during archegonium formation. The eggs were located at the embryo sac ends opposite that where archegonia are, as well as between the nucellus tips and embryo sacs (**Fig. 4d**).

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05. Discussion

• *Bazhina Elena*

According to the 2009 Assessment Report on Climate Change and Its Impacts (IPCC), Eastern Siberia is a region where air temperature has been observed to increase remarkably over the past several decades. The most considerable air temperature changes have occurred in the montane ecosystems dominated by mixed fir-Siberian pine forest stands. For conservation and reforestation in new environmental conditions, woody species have to adapt their reproductive systems to these changes. The main and sometimes the only way of reproduction of Siberian fir are by seeds (Hekrasova & Ryabinkov 1978). Understanding of the mechanisms of seed development in moved Siberian fir trees, as well as research of the mechanism disturbances, are crucially important to succeed in controlling the species cone and seed production during its adaptation to new microclimatic conditions.

Abies sibirica shows a 1-year type of reproductive cycle similar to the other true fir (Powell, 1970; Singh & Owens, 1982; Arista & Talavera, 1994; Politi *et al.*, 2011). The seed cones show only rudimentary ovules containing archesporial cells during winter dormancy, and their differentiation are post-dormance phenomena. A considerable part of seed buds aborted before or during dormancy, and became dry hard, and pitched. Cones abortion can seriously reduce potential crop at the arboretum.

The phenology of events occurring during spring and summer differs at the arboretum and in natural populations. Climatic changes appeared to be responsible for physiological disturbances in the planted fir individuals, which disturbances were particularly evident during meiosis or during pollen formation (Bazhina *et al.,* 2011; Bazhina, 2014). Because of inadequate pollination is the low number of filled seeds found at the arboretum. The development of the pollen tube and ovule is more highly synchronized in true fir than in most other conifers and the brief period of pollen tube development happens during the few days while female gametophyte is maturing (Owens & Molder, 1985). Any asynchrony in development or frequent low pollen production may then prevent fertilization and reduce the number of filled seed.

The Siberian fir trees growing in Forest Arboretum have generally low production of cones and seeds. The cone development might be blocked at certain stages by a number of factors (Colangeli *et. al.*, 1989; Owens & Morris, 1998), and in particular climatic conditions, which probably caused abortion of buds before their bursting or of cones at early stages of their development. Siberian fir cone morphogenesis is remarkable for the fact that the processes of both megasporogenesis and female gametophyte development do not depend on seed pollination (Nekrasova & Ryabinkov, 1978). However, the major factors accounting for sterile seed occurrence are insufficiency and low quality of pollen. It is due to certain specificity of fir sexual reproduction that the fir trees at the arboretum are unable to realize their high reproduction potential. In other words, this specificity causes such a low adaptation of the fir reproduction system to the environmental conditions found in the arboretum.

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Thus, acquiring understanding of how Siberian fir seed formation occurs and what disturbs this process in plantations is an important step towards effective control and management of cone and seed production of the fir trees during their adaptation to new microclimatic conditions. In the context of ongoing climate changes, these disturbances have become research priorities. For artificial forest growth to be successful, it is crucial to carefully select parent trees. *Ex situ* collections must involve enough material (the number of individuals) to be suitable for reproduction and reintroduction (Anonymous, 1995). Besides, for effective *ex situ* conservation of woody species, seeds should be collected from local natural populations, and subsequently tested for quality using cytological and genetic techniques prior to planting.

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STUDY OF THE ADAPTABILITY OF TREES TO DROUGHT: PHENOLOGICAL MONITORING OF ASSISTED GROWTH SENSORS, IN THE BOTANICAL GARDEN OF VILLA THURET

Photo credit : PepiPiaf sensor on Eucalyptus dorrigoensis tree, *Inra PACA Villa Thuret*

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05. Abstract

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THE ADAPTING OF TREES TO CLIMATE CHANGE IS ONE OF THE BIGGEST CHALLENGES WE FACE PRESENTLY. THE GOAL OF THE PHENOTOOLS PROGRAMME IS TO MEASURE THE IMPACT OF CLIMATE ON THE PHENOLOGY OF GROWTH OF A SAMPLE OF EXOTIC TREES INTRODUCED AT THE VILLA THURET BOTANICAL GARDEN IN A MEDITERRANEAN CLIMATE.

These trees are from very diverse taxonomic groups, biogeographic origins and have different growth patterns. They are deciduous or conifer species, with rhythmic or perennial growth. The method used lets us observe and compare their primary growth and their secondary growth simultaneously. The approach requires the use of autonomous micro-dendrometers to record and continuously monitor micro-variations in trunk or branch diameter. The initial results highlight contrasted growth and drought-adaptation strategies at the same site.

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05. Introduction

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Photo credit : PepiPiaf sensor on Eucalyptus dorrigoensis tree, *Inra PACA Villa Thuret*

THE ADAPTING OF TREES TO CLIMATE CHANGE IS ONE OF THE BIGGEST CHALLENGES WE FACE PRESENTLY. IN ORDER TO SURVIVE, THESE LIVING ORGANISMS, THAT GENERALLY HAVE A LONG LIFESPAN, MUST BE ABLE TO WITHSTAND INCREASINGLY FREQUENT AND MORE INTENSE CLIMATIC EVENTS.

Climate changes affect the phenology of species and have consequences on the growth and reproduction of trees. The question of which species to plant is one faced by forestry, orchard and urban landscape managers.

In the Mediterranean climate, water resources are highly fluctuating, with a variation coefficient of 30% (Rambal, 2002). Over the decades to come, we will see an increase in more intense droughts around the Mediterranean and a reduction in rainfall events, which will become more unpredictable and violent. Will the flora be able to withstand more and more pronounced drought conditions? Some species are able to limit water loss by reducing their leaf surfaces, the number of stomata or conditions for transpiration from stomata (leaf hairs, waxes, etc.). Others have greater capacity to access groundwater, i.e. deep root systems. On a physiological level, transpiration, which is a vital process for tree growth and its temperature regulation, is heavily affected by the water shortages linked to edaphic drought. The higher the deficit, the slower growth. In an extreme drought, even if the stomata are fully closed, dehydration continues and can cause xylem vessel embolism and eventually death of the tree (Cruiziat *et al.,* 2001, 2003).

One of the findings we made at the Villa Thuret, located in southeast France, is that many exotic trees can withstand the excesses of the Mediterranean climate (proven in the fact that they have continued to thrive in the garden for several decades, some for a century or more), apparently irrespective of their phylogenetic positioning or biogeographic origin. However, they demonstrate diverse –indeed contradictory – phenologies: some grow while others are "paused", they flow once or several times depending on year, stop growing in some winters or some summers but not others, etc. Some retain their original phenology (e.g. southern hemisphere) while others adapt to the seasons in the host country, according to conditions that have yet to be explained.

Due to the influence of climate on phenology, the plants' exposure to environmental fluctuations and the taking into account of global chang-

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es, studies on phenology have increased in number over the last ten years (Gordo & Sanz, 2010). In 2005, Rathgeber et al. put forward a hypothesis on the influence of global change (climate and CO_2 increases) on forest ecosystem production. Some studies have demonstrated a correlation between the earlier appearance of the first phenological stages in spring and rising temperatures over recent years (Cleland *et al.*, 2007), which is consistent with an increase in the length of the vegetation period. Current changes lead to modifications in plant phenology and, due to high temperatures and drought conditions in summer (Cleland *et al.*, 2007), this can lead to a reduction in radial growth and hence in forest productivity (Michelot *et al.*, 2012). Among the studies into the impact of climate on plant phenology, some focus on primary meristem events that lead to longer stems (Cleland *et al.* 2007; Gordo & Sanz, 2010), while others deal with the modulation of secondary meristem functioning and the consequences on thickness growth (Rathgeber *et al.*, 2000; Rossi *et al.*, 2011; Cuny *et al.*, 2012; Klein *et al.*, 2013; Michelot *et al.*, 2012). These results may appear contradictory and raise the question of the relationship between these types of growth. Furthermore, in the Mediterranean region, the climate creates growth conditions that alternate frequently between two winter dormancy phases and two vegetation phases: we refer to this as bimodal growth (Camarero *et al.*, 2010).

The methods currently applied in studies into the impact of climate change on phenology come up against some methodological limitations. For example, knowledge about the development and growth of some species, in particular Mediterranean and/or exotic species in a Mediterranean climate, which varies from one year to another, remains underdeveloped at this stage and lacks hindsight (some permanent sites exist in the natural environment: Puechabon, Fontblanche, St Michel de l'Observatoire). To benefit from historical data and diverse situations, it is therefore necessary to set up robust, automated methodological tools to supply the databases and phenological models, and also help us understand the development phases of these species and assess their capacity for adaptation in relation to this characteristic (phenology), which has not been the subject of extensive study so far.

Since 2013, in the framework of the "Perpheclim" (Perennial fruit crops and forest phenology evolution facing climatic change - Database, Modelling and Observatory network) project of the ACCAF metaprogramme (Adaptation of agriculture and forest to climate change) run by INRA (French national institute for agricultural research), we have set up a primary and secondary growth phenology monitoring system at Jardin Thuret, on a diversified sample of trees to highlight and characterise the underlying physiological and morphological processes. What is the impact of climate and its excesses on growth and what are the long-term effects. What morphological, phenological and physiological determiners can we observe and monitor? Can we pinpoint growth strategies when faced with the risk of edaphic drought for these species? These are some of the questions that our study will endeavour to answer.

Materials & methods

The sample currently comprises 68 adult trees belonging to 17 taxa with forestry potential. The selection criteria are as follows: taxonomic and biogeographic diversity, primary growth mode diversity, growth phenology diversity, exoticism and acclimatisation (the trees are all adult and have well accommodated to the pedoclimatic conditions at Jardin Thuret), presence of control

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species (native taxa, some of which belong to the same genus as the exotic taxa), trees enabling testing of a new phenological criterion: sudden bark shedding. The exotic species belong to the *Arbutus*, *Corymbia*, *Eucalyptus* and *Quercus* genera and the native species to the *Arbutus*, *Ostrya* and *Quercus* genera. The trees form three groups: deciduous species with rhythmic growth and evergreen species with rhythmic or perennial growth.

1. PRIMARY GROWTH MONITORING

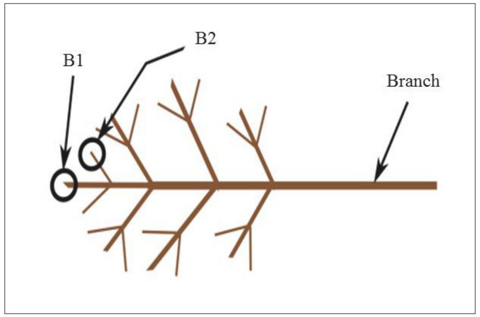
The weekly monitoring is inspired by the BBCH scale, with a universal decimal code for the phenological stages of the plants grown (**Table 1**) (Meier, 2001).

> TABLE 1.

Phenological stages

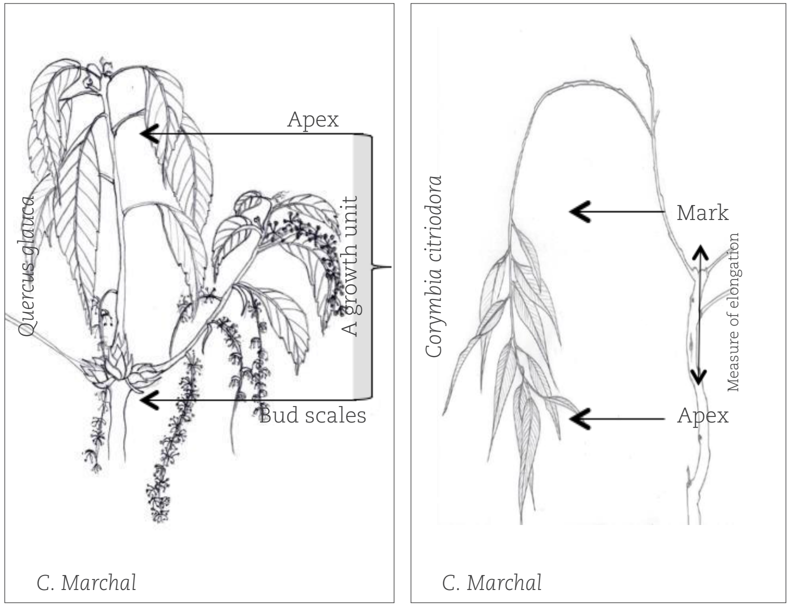
Code	Stage	Stage description
9	Leaves	The end of the first leaves extends beyond the end of bud scales
11	Leaves	The first leaves are plated on about 10% of the crown
15	Leaves	The first leaves are plated on about 50% of the crown
51	Flowers	The majority of flower buds began to swell
52	Flowers	The majority of flower buds began to open
61	Flowers	10% of the flowers or kittens are anthesis
65	Flowers	50% of the flowers or kittens are anthesis
69	Flowers	90% of the flowers or kittens are anthesis
71	Fruits	10% of fruit have reached their maximum size
85	Fruits	50% of fruit is ripe (changed color, or are dried and dehiscent, or fell)
91	Senescence	10% of the leaves have turned color or fell
95	Senescence	50% of the leaves have turned color or fell

The elongation of branches is also measured weekly along at least two axes per tree: a main B1 axis and a secondary B2 axis (**fig. 1** and **2**).



> FIGURE 1

Measured up branches



> FIGURE 2

Elongation measurement techniques for rhythmic or aperiodic growth

2. SECONDARY GROWTH MONITORING

Dendrochronology has been used for several decades to analyse year-on-year variations in tree diameter growth and the effects of age, cultural practices and climate variations. Variations in the diameter of a trunk, branch or fruit are continuously monitored with LVDT (Linear Variable Differential

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> PHOTO 1 & 2

Left: PepiPIAF sensor
Right: Micro dendrometer

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Transformer) type sensors of sufficient resolution (1 µm), and reflect the action of four factors: 1) irreversible cell growth, reversible swelling or contracting of the organ in relation to 2) the moisture level and 3) thermal expansion of the organ (Kozlowski, 1971; Klepper *et al.*, 1971; McBurney & Costigan, 1984; Améglio & Cruiziat, 1992; Simonneau *et al.*, 1993; Zweifel *et al.*, 2000; Cochard *et al.*, 2001; Daudet *et al.*, 2005) and 4) the contraction or expansion of conductive elements under the impact of internal pressure related to water status of those conductive parts (Irvine & Grace, 1997; Offenthaler *et al.*, 2001; Sevanto *et al.*, 2002). We have used PépiPIAF sensors (Améglio *et al.*, 2010) which give very accurate (sensitivity to microns) continuous measurements of the diameter of an organ and memorise the data (diameter and temperature) without disrupting its functioning, using wireless technology (**Photo 1**).

Micro-dendrometers are used for twice-weekly trunk diameter measurements (**Photo 2**). We have taken weekly micro-core samples to track cambium/cork cambium activity. Finally, we monitored bark shedding in the species concerned, the objective being to explore a new simple phenological character for use in looking at cork cambium functioning (Ducatillion *et al.*, 2013). The entire device is on the **Table 2**.

Latin name	Family	Native	Primary growth	Fall leaves	Fall bark	Flowers season	Place of flowering	Trees number	Sensors PépiPiaf number	Growth measure	BBCH stages	Micro-coring	Microwave dendrometers	Followed bark fall
Aesculus californica	Hippocastanaceae	California	R	D	PG	P	T	2	1	2	2	1	2	0
Arbutus andrachne	Ericaceae	Eastern Mediterranean	R	E	S	H	T	4	0	2	3	1	1	4
Arbutus canariensis	Ericaceae	Canary Islands	R	E	S	W	T	1	1	1	1	1	1	1
Arbutus glandulosa	Ericaceae	Central America	R	E	S	W	T	1	0	0	0	0	0	
Arbutus menziesii	Ericaceae	South of North America	R	E	S	W	T	1	0	1	1	0	1	0
Arbutus unedo	Ericaceae	Western Mediterranean	R	E	PG	W	T	2	1	2	2	0	2	2
Arbutus x andrachnoides	Ericaceae	Greece	R	E	PG	W	T	3	0	2	3	1	2	3
Arbutus x thuretiana	Ericaceae	Hybrid	R	E	S	W	T	2	2	2	2	2	2	2
Corymbia citriodora	Myrtaceae	North East Australia	A	E	S	S, E	T	2	2		2	2	2	2
Corymbia maculata	Myrtaceae	Australia : Q, NSW, V	A	E	S	E	T	1	0	0	0	1	1	1
Eucalyptus dorrigoensis	Myrtaceae	Eastern Australia	A	E	S	E	T	2	1	1	1	1	1	1
Ostrya carpinifolia	Betulaceae	Mediterranean	R	D	P	S	A	3	0	1	3	1	1	0
Quercus glauca	Fagaceae	East and South Asia	R	E	P	S	A	4	0	2	4	0	2	0
Quercus ilex	Fagaceae	Mediterranean	R	E	P	S	A	10	2	2	10	2	6	0

> TABLE 2

Synthesis device.

Primary growth: rhythmic (R), aperiodic (A). Fall leaves: deciduous (D), evergreen (E). Fall bark: progressive (PG), sudden (S), persistent (P). Flower season: spring (S), summer (E), autumn (A), winter (W). Place of flowering: terminal (T), axillary (A)

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For each of these species, measurements in diameter variations have been set against climate data, elongation periods, different phenophases and bark shedding. We now have eight years' worth of phenophase observations for several species, but only two and a half years with the use of sensors and bark shed observation. The initial results nonetheless reveal some significant trends. The effect of climate on the growth of the three initial tree categories is compared in **Table 3**.

Group 1, illustrated by *Arbutus* x *thuretiana* (a hybrid between A. *canariensis* and A. *andrachne* naturalised at Jardin Thuret), reveal a number of axes in the growth or flowering phase, between autumn and early summer. Normal winter temperatures do not affect growth. However, environmental conditions affect the phenophase dates. Growth stops during the summer period.

Trees in group 2, illustrated by *Eucalyptus dorrigoensis*, show pretty regular, opportunist growth throughout the year. In the *Aesculus californica* (group 3), budburst is very early (February) with brief primary growth. Leaves cease their activity earlier at the end of spring and fall in summer middle while it normally should shed in autumn for deciduous trees.

Under the same Mediterranean climate, the trees measured in the Botanical Garden in Villa Thuret demonstrate very contrasted primary and secondary growth depending on species, with variable sensitivity to climate factors (i.e. winter temperatures: e.g. *Eucalyptus dorrigoensis* vs. *Aesculus californica* or summer rainfall and drought; *Aesculus californica* vs. *Quercus ilex*)). Some species as *Aesculus californica* seem to avoid potential summer drought, regardless of the year's rainfall, with early leaf fall with no apparent link to

Climate action on 3 tree types. Some examples

Type of growth	Species example	Bud break and primary growth	Secondary growth	Climate action on growth
1 - Evergreen. Rhythmic growth	*Arbutus x thuretiana*	All the time except in summer.	Spring and beginning of summer	Impact on the phenophases and impact of extreme events
	Quercus ilex	Short and rapid growth in spring. Sometimes growth in autumn	Spring and summer	Impact of temperature on bud break
2 - Evergreen. Aperiodic growth	*Eucalyptus dorrigoensis*	Long growing with at least two short stops (winter and summer)	Only a stop in summer	Impact of extreme events
3 - Deciduous. Rhythmic growth	*Aesculus californica*	From late winter to late spring	Spring and summer	Slight impact on phenophases

> TABLE 3

Climate action on three tree types. Some examples

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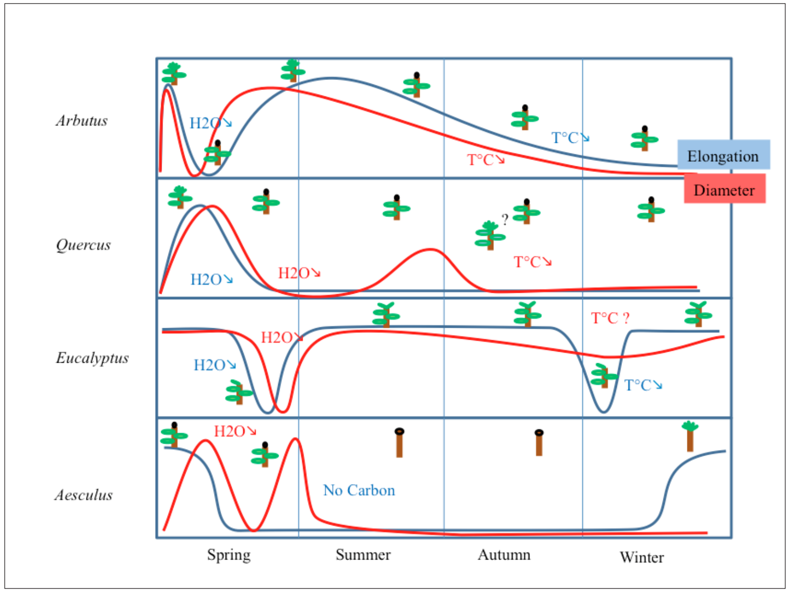
a climatic factor (no marked water stress). The physiology of these species in terms of phenophases, water flows and carbon management may thus be approached through the continual analysis of diameter variations and shows high diversity in functioning under the same climate. The annual phenological cycles of the four species groups are shown in **Fig. 3.**



> FIGURE 3

Diagram of the phenological cycles of 4 groups of species, according to the seasons. The curve in blue gives the average elongation for the 4 group of species independently of the climate. The red curve gives the same average for the diameter growth. For each season, we indicated the effect of the main climatic factor on elongation (in blue) or diameter growth (in red). For example, the diameter growth of the Eucalyptus is greatly attenuated by water stress (H2O) in late spring and early summer in comparison with the average diameter growth for this site at this period. For this species, diameter growth was also impacted in winter in response to the colder temperatures (T°C) of one year in comparison to the average temperature during winter for this site.

For example for *Eucalyptus*, when you measure diameter growth, you can observe an almost constant rate of growth decreased in late spring and early summer only by the soil water reserve (rainfall during this period) and during winter if the temperature decreased below +10°C. For *Aesculus californica*, the pattern of growth diameter appears the same as that measured in its original area in California (Mooney & Hays, 1973) but our continuous diameter measurements indicate that the fall of the leaves in this species is not related to water stress (no more shrinkage during the day indicated no strong mobilization of water reserves in the bark). Here we have a typical adaptation to the Mediterranean climate by an avoidance of drought stress by leaves fall with no stress and a drastic reduction of transpiration.

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05. Conclusion

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By monitoring both primary growth and secondary growth, we can obtain an overall view of the effect of climate on a plant's functioning. At the same site, the three groups of trees show contrasting growth modes, responding or not to climate conditions. The choice and positioning of the axes monitored, within the tree's architecture, provides more realistic information on the tree's behaviour in response to climate variations.

Thus, the study over a few years on the same site of primary or secondary growth dynamics can quickly permits to extract the phenophase of these growths for different species, but also to conclude on climatic factors (water or temperature) affecting them.

Thus observation of the bark phenology through the continuous acquisition of micrometric variations of branch or trunk diameter measurements using the PépiPIAF sensors therefore makes it possible to track not only secondary growth (resumption of cambial activity, growth rhythm) but also leaf phenology (budburst, leaf growth and senescence) by providing new information on the physiology of species which are little or so far unknown. This new tool therefore allows for the acquisition of phenology measurements in numerous situations (isolated tree, arboretum, acclimatisation gardens, orchards, forests, vines, trees in towns, etc.) while contextualising the different phenophases observed in the climatic environment (e.g. heat conditions), but also the physiological environment (e.g. water constraints), both of which can be addressed using the same measurement.

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INTRODUCTION OF EXOTIC TREE SPECIES IN FRENCH ELIMINATION ARBORETA: LESSONS OF THE PAST AND IDENTIFICATION OF VALUABLE FOREST REPRODUCTIVE MATERIALS FOR THE FUTURE

Photo credit : *Abies procera* à l'arboretum de Sainte Anastasie, *T. Lamant*

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> Keywords ARBORETUM EXOTIC FOREST TREES CLIMATIC CHANGE

05. Abstract

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ADAPTING FRENCH FOREST TO CLIMATIC CHANGES IS ONE OF THE IMPORTANT CHALLENGES THAT INRA[1] AND ONF[2] HAVE TO RAISE. IN ORDER TO REACH PART OF THIS GOAL, BOTH INSTITUTES HAVE REVISITED 6 ARBORETA PLANTED, FOR MOST OF THEM, FORTY YEARS AGO.

Their initial goal was to identify species, able to resist to pollution or to be an alternative to species endangered by pathogen problems. These arboreta are located in three different climates: oceanic, mountainous and Mediterranean. Numerous species are present at least in two different arboreta enabling comparison of their behavior under contrasted climates. In this project, we have measured survival and diameter on 254 taxa (17835 individuals). Moreover, total height of the three biggest trees per plots has also been measured. Thus, we can compare oldest results obtained in these arboreta in terms of growth and survival with those after several climatic accidents (drought, heat). We also have recorded the temperature and precipitations in order to identify years which are the most different from the average. We lastly began a study of chronodendrometry in view to determine the reactions (in terms of radial growth) of different species under climate stresses. The ultimate goal of the project is to identify species offering the best compromise between overall growth and growth to stress during extreme years. These studies have showed that species which were the best thirty years ago are not the best nowadays. For example, in 1989, in the Mediterranean arboreta, the best choice for broadleaves was, species of genus *Fraxinus*, *Alnus* or *Arbutus*. Presently, the best species belong to the genus *Eucalyptus* spp. in spite of 1985's intensive frost. Arboreta also provide information on the invasive character of non-native species such as *Hakea* spp. Moreover, native species are not always better adapted in terms of growth and climate adaptation. It is for example the case in the arboreta under oceanic climate for *Pinus sylvestris* L., worse than *Sequoia sempervirens* (D. Don) Endl. or *Abies grandis* (Douglas ex D. Don) Lindl.. We have also shown that arboreta could be very interesting places to educate forest managers on the interest of new species under climatic changes. Indeed, in managed forest the number of species is low, and generally forest manager badly know or ignore non-native species' autecology. Arboreta are suitable places where they could increase their knowledge and thus discover the potentiality for forest purposes of more than hundred species in real forest conditions like *Alnus rubra* or *Nothofagus* or still *Chamaecyparis* and *Thuya* spp.

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> Keywords ARBORETUM EXOTIC FOREST TREES CLIMATIC CHANGE

05. Introduction

• *Lamant Thierry*
• *Bastien Jean-Charles*
• *Bellanger Richard*
• *Ducatillion Catherine*
• *Musch Brigitte*

Photo credit : *Abies procera* à l'arboretum de Sainte Anastasie, ***T. Lamant***

IN APRIL 1967, INRA PUBLISHED A REPORT ENTITLED "EXPERIMENTATION ON ECOLOGICAL ARBORETUMS" PROPOSING THE FOUNDATION FOR A PROGRAM TO PREDICT THE BEHAVIOR OF A SPECIES OR A PROVENANCE IN A GIVEN ENVIRONMENT (LACAZE, 1967).

This report led to the establishment of experimentation sites of a new genre and unique concept in the world of dendrology and forestry: "the elimination arboreta". The two main questions addressed by these experiments were:

(1) to find species able to grow in areas without forest vegetation (e.g. Massif Central's high moors, wetlands) generally considered as "forest production deserts",

(2) to provide alternative to species traditionally used in reforestation; but being unsuitable for various causes (insect attacks, air pollution, potential problems inherent in large-scale monocultures, etc.). These arboreta were established in public forests between 1969 and 1982 and almost all in national forests. Several reports have been published on the arboreta (Pestour, 1984; Imbert, 1988; Allemand, 1989; Blandin & Steiner, 1996; Mons, 1993). Today, trees planted in these arboreta have been selected by local conditions, that are sometimes very stressful (drought heat, short vegetation period, extreme frosts, etc.) and could be considered as adapted to their environment. The question now is: are some species known enough to be promoted as potential productive forest reproductive material? To try to answer that question, INRA and ONF, merged their inventories and data tables. The important results and conclusions of this study are presented here after.

Materials & methods

GEOGRAPHY

The six arboreta used to support this study were created by INRA. They are now managed by ONF as arboreta of scientific interest (Lamant *et al.*, in press) and are also included in the French multipartner public arboretum network (Ducatillion *et al.*, in press).

These arboreta are located in 3 different climates as oceanic (Basse Seine), mountainous (Sainte Anastasie and Col des 3 soeurs) and Mediterranean (Caneiret, Plan Esterel, and Treps) (see location in **fig. 1** and metadata in **fig. 2**).

> Keywords ARBORETUM EXOTIC FOREST TREES CLIMATIC CHANGE

05. Materials & methods

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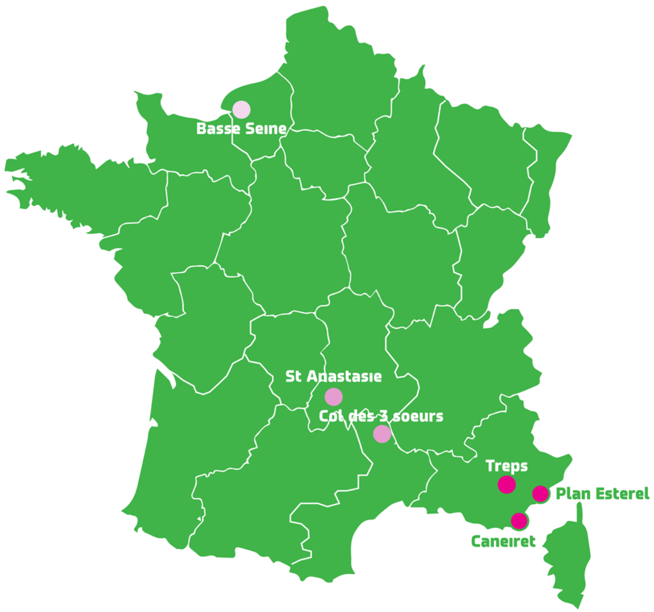

> FIGURE 1

Map of the six scientific arboreta

Despite their geo-climatic distribution, and although some sources are common to several of them, these arboreta were not installed with the aim to build a network.

TREE SPECIES

At the beginning, 779 taxa (species and subspecies) belonging to 64 botanic families and 188 genera have been introduced in the 1970s. A significant proportion (43%) of the conifers taxa is present in two different climates and 2% only in 3 different climates. Moreover, 6% of the hardwoods taxa are present in two different climates. The main genera are *Abies* (19 species), *Betula* (7 species), *Cupressus* (20 species), *Eucalyptus* (58 species), *Fraxinus* (8 species), *Picea* (12 species), *Pinus* (45 species) and *Quercus* (11 species).

PROVENANCES

Most seed lots come from wild collection in the natural range of the species, and rarely from planted forests or botanic gardens. Most species are represented by several origins (see as an example in **fig. 3** below the distribution of the provenances representative of *Abies procera* Rehder in the species' native range).

As a result of an easy seed supply and a good bioclimatic match, arboreta include a high proportion of species native from the western part of the United States and Southwestern Canada.

> FIGURE 2

Synthetic characteristics of the 6 scientific arboreta

Arboretum name	Location	Year birth	Area (ha)	Elevation (m)	Soil	Climate	Average rainfall (mm/yr)	Extremes (°C.)	Previous nbr of taxa	Current nbr of taxa	Previous nbr of provenances	Current nbr of provenances
Canereit	Var, SE	1973	4	260-320	Ryolith	Mediterranean	820	-12 to 38	398	151	587	230
Plan Estérel	Var, SE	1974	3	400-420	Ryolith	Mediterranean	820	-12 to 38	327	111	512	191
Treps	Var, SE	1975	1,8	600	Gneiss	Mediterranean	690	-14 to 38,7	108	48	139	74
Col des 3 Sœurs	Lozère, center mountain	1973	5	1390-1480	Granitic sand	Mountain	980	-30 to 34	71	47	339	330
Sainte Anastasie	Lozère, center mountain	1969	5,3	1200	Silt	Mountain	1300	-30 to 30	44	39	130	118
Basse Seine	Seine-Maritime, NW	1975	15	100-140	Silt & flint clay	Oceanic	800	-17 to 38	101	93	253	249

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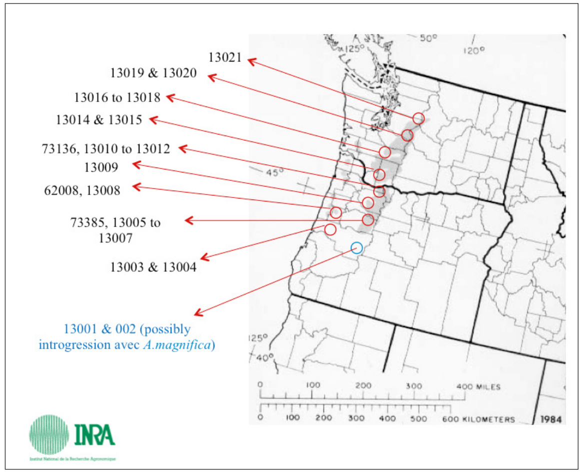


> FIGURE 3

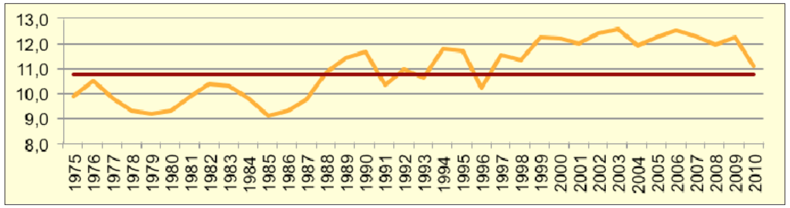
Noble fir's (*Abies procera*) native range in the USA and planted provenances (with their access number): most seed lots are characterized with the geographic coordinates of their harvesting site (latitude, longitude, elevation)

DESIGN

Each arboretum consists of several hundred rectangular plots of 90 m² each (for most of them), consisting of 30 trees of the same provenance, at a planting spacing of 2 m x 1 m.

OBSERVATIONS AND MEASUREMENTS

Depending of the arboreta, observations and measurements were carried out at different periodicities: e.g. 10 and 15 years after plantations in Mediterranean area, after 15 and 20 years in Massif Central and after 20 years in Normandy. Each subsequent report proposed a selection of interesting species, which resulted in other experimental plantations with more provenances and plants per species in order to explore their quality performances on a larger number of trees.



> FIGURE 4

Average annual temperature collected on 5 different weather stations around Basse Seine arboretum

About 20 years after the first studies (between 2010 and 2012) we undertook a new series of measurements and observations (health rating). The current objective was to find productive forest species. Therefore the 56 shrubs taxa have not been considered. Survival and circumference of 17835 trees (254 taxa from 68 genera) have been recorded. In order to compare species on the basis of dominant tree performances, total height of the three biggest trees per plot has also been measured.

Furthermore, we have also collected wood increment cores to check the possible impact on ring width of exceptional climatic years (for temperature and rainfall). As an example **fig. 4** below shows that, between 1978 and 2006, the Basse Seine arboretum experienced a temperature rise of 3 °C and the average temperature rise of 1° in 35 years.

Finally, we began an inventory of species able to naturalize in the Caneiret and Plan Esterel arboreta (south of France).

First results

Data are heterogeneous and complex. Nearly 40 years after their installation, the objectives of these arboreta have changed to shift towards the species adaptation to climate change. Currently and under the influence of climate changes (for example the scenario A2A shows the extension of thermo-Mediterranean climate and especially the meso-Mediterranean) we are trying to find solutions

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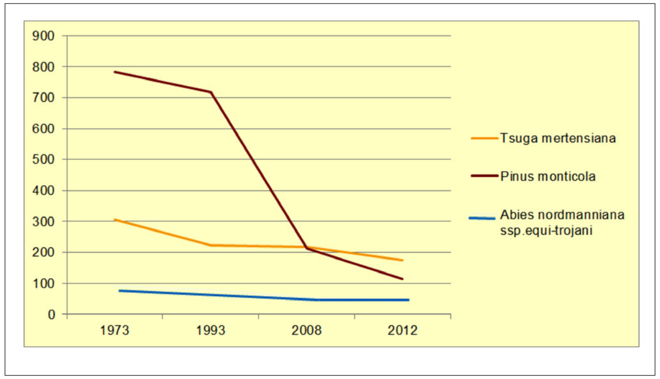
from these arboreta or at least proposals for new adapted species to complete the indigenous species. First synthetic results drawn from the survival growth measurement are given here as an example.

SURVIVAL

Arbitrarily, the raw survival is given here as the number of species of which at least one tree is still alive. Out of 3719 initial plots, there are 2365 plots where at least one tree is surviving. Out of 779 initial taxa, 355 present at least one survivor (hence 424 taxa are completely dead).

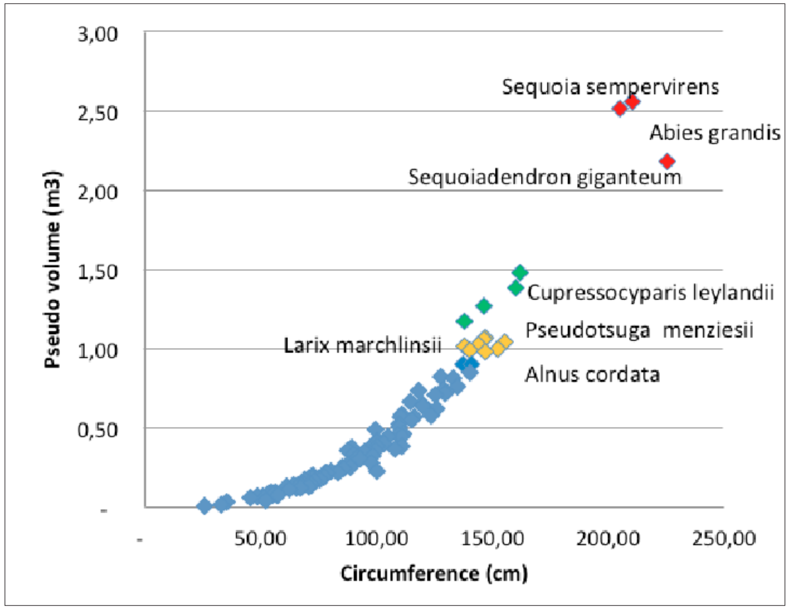
On the basis of successive inventories, we observed that survival of some species gradually decreases, which would demonstrate their total inadequacy. Others species suddenly disappeared in the first few years following their installation, which may be explained by uncommon factors, incidental, or humans (frost, drought, wild animals and lack of adequate maintenance). We also observe trees whose numbers even if they decline, remain relatively constant since planting (example of 3 species in **fig. 5**).



> FIGURE 5

Survival evolution according to time in number of trees. Example of 3 species at the Col des 3 Sœurs arboretum (*Tsuga mertensiana* (Bong.) Carrière, *Pinus monticola* Douglas ex D. Don, *Abies nordmanniana* subsp. *equi-trojani* (Asch. & Sint. ex Boiss.) Coode & Cullen)

GROWTH AND DENDROCHRONOLOGY



> FIGURE 6

Basse Seine arboretum (35 years old). Regression circumference – pseudo volume (m_3) of trunk of the 3 biggest trees per plot

EVOLUTION OF SPECIES GROWTH RANKING ALONG TIME

One of the most striking teachings of these arboreta is that species recommendations evolved significantly with time. In 1993 (20 years after plantation) in the Massif Central arboreta (mountain climate), one of the best conifers was *Pinus monticola* Douglas ex D. Don. Since 2000, the presence of *Cronartium ribicola* J.C. Fisch on American 5 needles-pines killed most of the *Pinus monticola* trees. Today, *Pinus peuce* Griseb. is one of the best performing pine species and *Abies homolepis* Siebold & Zucc. is the best fir species.

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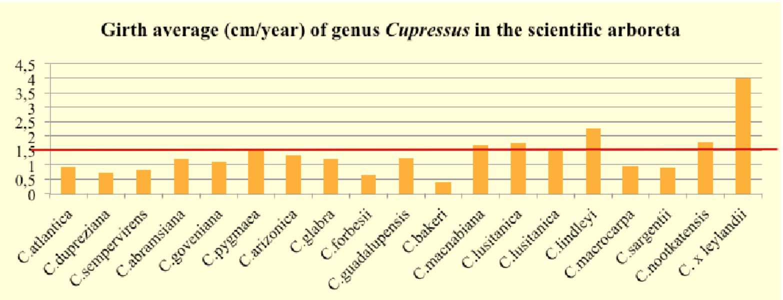
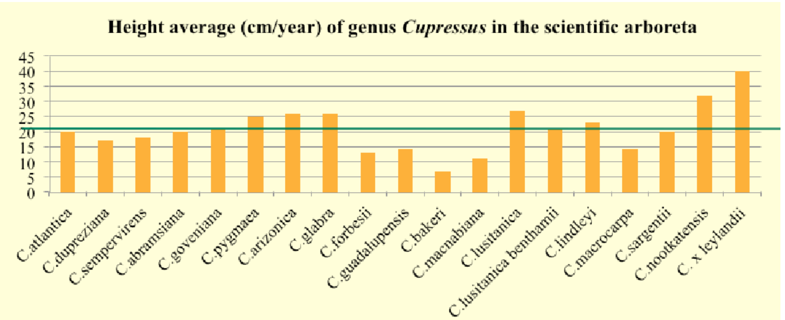
Under Mediterranean climate, in 1989 (16 years after plantation), in the Mediterranean arboreta, the best broadleaves were species of genus *Alnus*, *Arbutus* or *Fraxinus* because most of the *Eucalyptus* spp. froze. Now *Eucalyptus* spp. sprouts are taller than all the other species in spite of 1985's intensive winter frost.

The second teaching is that native species are not always best suited in terms of growth and adaptation to climate as in Basse Seine arboretum (under oceanic climate) with *Pinus sylvestris* L. (native) vs. *Sequoia sempervirens* (D. Don) Endl. or *Abies grandis* (Douglas ex D. Don) Lindl. and *Fagus sylvatica* L. (native) vs. *Nothofagus obliqua* (Mirb.) Blume.





> FIGURE 7

Compared growth of the species of *Cupressus* spp. in the whole of arboreta in cm a year, between 1973 and 2012.

Average circumference is 1,1 cm/year. Average height is 21 cm/year

DENDROCHRONOLOGY

We have made a selection of the best trade-off between growth and their reaction during difficult years. One of these studies was conducted in the arboretum of Basse Seine: *Cedrus atlantica* (Endl.) G. Manetti ex Carrière, *Cryptomeria japonica* (L. f.) D. Don, *Pinus sylvestris* L. and *Nothofagus obliqua* (Mirb.) Blume have greatly reduced their annual ring width during both dry and hot years and then normally grows the following years. This reaction suggests they are able to withstand water shortages without suffering the consequences in the long term. This should means that the lack of water does not affect (or a little) the growth of these taxa.

NATURALIZATION AND INVASIVE SPECIES

In Mediterranean arboreta, we find some invasive species to be eliminated such as *Hakea sericea* Schrad. and *Hakea salicifolia* (Vent.) B. L. Burtt. (Ducatillion *et al.*, 2015).

GENERAL RESULTS

Non exhaustive list of tree species with good potentialities of survival and growth, according to the climate:

- Mediterranean climate : *Genera Cupressus* and *Eucalyptus*
- Mountain climate: *Abies homolepis* Siebold & Zucc. and *Pinus peuce* Griseb.
- Oceanic climate: *Sequoia sempervirens* (D. Don) Endl. and *Nothofagus obliqua*, (Mirb.) Blume.
- *Abies nordmanniana* subsp. *equi-trojani* (Asch. & Sint. ex Boiss.) Coode & Cullen resists as well to the cold as the relative summer drought and could adapt to a wide climatic range, except the Mediterranean region.

> Keywords ARBORETUM EXOTIC FOREST TREES CLIMATIC CHANGE

05. Discussion

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SURVIVAL

The survival is a complex criterion: we know how many species are still represented by at least some individuals today, but we do not still know the cause of the mortality of others: biotic, abiotic or accidental factors? The tree accommodation can depend on constraints other than the climate. The survival expresses in a different way in time according to the species. The current result does not augur future results. Certain trees (species–provenance) can present a low rate of survival in a given time, but some surviving trees present a good quality potential. On the contrary, certain species present a high survival, but trees are in poor condition, or weakly productive. Three types of climate are representative of the French climate, except the continental climate, which gives a wide range of possibilities. On the other hand, it is not possible to define a wide gradient of survival, the species common to these three kinds of climatic arboreta being practically non-existent.

GROWTH

Growth varies over time and according to the species (example of fir trees with usually slow early growth, then faster). We need some growth observations along a good proportion of trees life before choosing an appropriate species. The environmental conditions of certain arboreta do not represent the usual forest area: the environment of Lower Seine is exceptionally fertile; on the contrary the ground in Caneiret is so poor and draining (dry) that even the native species have difficulty to develop. Even survival is an accomplishment.

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Conclusion & perspectives

Six elimination arboreta were planted in the 1970s, in 3 French climatic regions. 779 exotic taxa were introduced, represented by often several provenances. A large number of tree species comes from North America, but also from Australia, South America, South Africa or Mediterranean Basin. Every couple species-provenance is represented by several plots (about 30 trees per plot). Since their plantation in arboreta, these trees were selected by severe environmental conditions. The living trees are today more than 40-year-old and are regularly inventoried and measured (height and trunk circumference). First results give 355 living taxa.

But survival is heterogeneous: in some species all the trees are alive; in some another only one tree is alive. Besides, their growth is not always representative of forest potentialities, because of excessive constraints of local environment, or because the measurement age, or because biotic or abiotic accidents are not identified. It is thus necessary to refine analyses, in particular to cross all the methods of measure and analysis illustrated here, completed by thorough qualitative site's analysis to identify causes of tree death. Nevertheless the performance of some species seems already promising, according to sites and expectations, and for the current climate. We can include for example *Cupressus* spp. and *Eucalyptus* spp. such as *Eucalyptus cephalocarpa* Blakely in the Southeast of France, *Sequoia sempervirens* (D. Don) Endl. in the West, *Abies homolepis* Siebold & Zucc. in mountain or *Abies nordmanniana* subsp. *equi-trojani* (Asch. & Sint. ex Boiss.) Coode & Cullen in the 3 regions.

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05. References

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