

Ulo

## Rapport de mission à Montpellier du 28 au 31 mai 2007

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CIRAD-ES, UPR 37

4 juin 2007

### Déroulement de la mission

Lundi 28. *Matin*: session de travail avec Avner Bar-Hen à l'INA-PG à Paris.

*Après-midi*: trajet Paris-Montpellier en train.

Mardi 29. Comité scientifique de la convention sur les parcelles permanentes. Cf. compte-rendu en annexe B de ce rapport de mission.

Mercredi 30. *Matin*: réunion sur l'état d'avancement de la thèse de Pierrette Chagneau, avec Jean-Noël Bacro (université Montpellier 2, directeur de thèse), Frédéric Mortier, Vivien Rossi et Pierrette Chagneau. Cf. compte-rendu de la réunion fait par Pierrette Chagneau.

*Après-midi*: sessions de travail avec Vivien Rossi, Frédéric Mortier, Pierrette Chagneau.

Jeudi 31. *Matin*: point sur l'état d'avancement de mon HDR au bureau des HDR de l'université Montpellier 2; consultation de documents à la bibliothèque de Baillarguet.

*Après-midi*: sessions de travail avec Frédéric Mortier et Pierrette Chagneau; discussion avec Olivier Hamel.

### Compte-rendu des discussions

Les discussions avec Avner Bar-Hen ont porté sur les travaux que nous avons en cours, en particulier

- l'approche bootstrap pour la définition d'intervalles de confiance autour des prédictions des modèles matriciels; il serait utile à ce sujet de commander l'ouvrage suivant: A.C. Davison and D.V. Hinkley (1997) *Bootstrap Methods and Their Applications*, Cambridge University Press, Cambridge, 592 p.

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- la correction du troisième article tiré de la thèse de Mélanie Zetlaoui (accepté avec corrections mineures par *Acta Biotheoretica*).

Comme perspectives de travail en collaboration avec Avner Bar-Hen, on peut mentionner :

- la mise au point d'une méthode pour déterminer le nombre et les limites des classes de diamètre pour les modèles matriciels (on est convenu de faire un état des lieux de la bibliographie sur le sujet) ;
- la relation entre répartition spatiale des arbres et dynamique forestière *via* un processus de naissance et de morts vu comme algorithme de simulation d'un processus ponctuel marqué de Markov (cf. discussions avec Vivien Rossi et Frédéric Mortier ci-dessous).

À noter qu'Avner Bar-Hen quitte l'université Paris 13 et sera affecté comme professeur à l'université Paris 5 à la rentrée.

Les discussions avec Pierrette Chagneau et Frédéric Mortier ont surtout porté sur la thèse de Pierrette Chagneau. Nous avons également discuté de notre participation à l'atelier META2007 en Guyane et de l'article tiré du stage de M2 de Pierrette Chagneau, qui doit être re-soumis après corrections majeures à *Journal of the Royal Statistical Society, Series C (Applied Statistics)*.

Une réunion avec Frédéric Mortier et Vivien Rossi s'est tenue à propos de la relation entre répartition spatiale des arbres et processus de dynamique forestière. Cette question coïncide avec les préoccupations actuelles de Vivien Rossi dans le cadre de son travail sur le modèle Selva. On est tombé d'accord pour préparer une proposition à soumettre dans le cadre du rapprochement INRA-CIRAD. Une ébauche de proposition figure en annexe A de ce rapport.

La discussion avec Frédéric Mortier et Vivien Rossi a également porté sur la communication que nous soumettrons à l'atelier META2007. Cette communication porte sur la formation de groupes d'espèces à l'aide de modèles matriciels. Nous avons confronté nos points de vue sur la façon de faire. Il ressort que le problème de formation de groupe peut être formulé comme un problème d'optimisation discrète. Le critère à optimiser peut être

- soit la probabilité de la loi *a posteriori* du nombre de groupes et de l'affectation des espèces aux groupes, dans un contexte bayésien ;
- soit l'erreur quadratique de la prédiction des modèles matriciels, dans le contexte de la théorie de l'agrégation.

Concernant l'état d'avancement de mon HDR : après un délai d'attente de sept mois et demi, le temps pour les rapporteurs de faire leur rapport, les trois rapports sur mon mémoire de HDR sont enfin parvenus au bureau des HDR de l'université Montpellier 2. Mon dossier sera examiné par le conseil

scientifique de l'université le 4 juin 2007, qui donnera ou non son accord pour la soutenance et précisera, le cas échéant, la composition du jury.

La discussion avec Olivier Hamel a porté sur l'opportunité de choisir des sites d'étude communs, que ce soit dans le cadre de notre projet visant à installer des dispositifs permanents, ou du projet PFBC-MDP. Dans le cadre du PFBC-MDP, une liste de projets pilote a été présentée par chaque pays d'Afrique Centrale. Dans le cas du Gabon, le projet pilote qui a été classé au premier rang porte sur l'impact en termes de séquestration de carbone du passage du taux de reconstitution du stock de 60 % à 100 %. Un appui en modélisation pourra être demandé pour prédire l'impact de ce changement.

## Annexes

### A Proposition pour le fond incitatif INRA-CIRAD

**Sujet :** Relation entre la répartition spatiale des arbres et les processus de la dynamique forestière : définition d'un processus de naissance et de mort pouvant être vu comme un modèle de dynamique forestière ou comme un algorithme de simulation parfaite d'un processus ponctuel de Markov.

**Résumé :** La répartition spatiale des arbres rétro-agit sur les processus de dynamique forestière (Ford and Diggle, 1981). Ainsi la disposition des arbres dans l'espace va influencer, *via* des mécanismes de compétition densité-dépendants, la croissance, la mortalité et le recrutement des individus. Rétroactivement, la suppression des individus dominés et l'implantation de juvéniles dans les zones les moins soumises à la pression de compétition modifie la répartition spatiale des arbres. Cependant le lien entre la répartition spatiale des arbres et leur dynamique reste difficile à décrire d'un point de vue théorique ; en l'absence d'outils analytiques, le recours intensif à la simulation, avec toutes les limites de cette approche, reste la seule solution.

Dans le cadre de ce travail, la dynamique forestière est formalisée par un modèle individuel de dynamique forestière (Franc et al., 2000). Ces modèles décrivent la trajectoire de chaque arbre en termes de recrutement, croissance et mortalité. Les processus de compétition et de densité-dépendance sont pris en compte *via* des indices, dit de compétition, qui font intervenir le voisinage spatial de l'arbre (Tomé and Burkhardt, 1989; Biging and Dobbertin, 1992). Des travaux ont été entrepris dans le cadre de la théorie de l'agrégation pour simplifier ces modèles arbre dépendants des distances en modèles arbre indépendants des distances (Pacala and Deutschman, 1995). La méthode des moments, en particulier, offre un emboîtement d'approximations à des degrés

divers (Bolker et al., 2000). Au premier ordre, elle correspond à l'approximation du champ moyen, qui consiste à remplacer les indices de compétition par leur moyenne spatiale. À l'ordre suivant, l'approximation fait intervenir un moment d'ordre 2 du processus ponctuel sous-jacent à la répartition spatiale des arbres (Verzelen et al., 2006). En l'absence de méthode de calcul de ce moment d'ordre 2, la méthode des moments ne peut pas être menée à son terme. L'agrégation de modèles spatialement explicites montre comment l'étude de la dynamique débouche sur un problème de distribution spatiale.

À l'inverse, la modélisation de répartitions spatiales d'arbres peut déboucher sur un problème de description de la dynamique. La motivation de la modélisation de la répartition spatiale des arbres est de produire des peuplements virtuels réalistes (Stoyan and Penttinen, 2000; Goreaud et al., 2004). Dans ce contexte, le peuplement est vu comme la réalisation d'un processus ponctuel marqué, la marque étant le diamètre des arbres. De nombreux processus ont été proposés pour décrire la répartition spatiale des arbres (Pielou, 1960; Rathbun and Cressie, 1994; Moeur, 1997; Hanus et al., 1998). Une approche prometteuse consiste à utiliser un modèle de dynamique forestière simplifiée comme algorithme de simulation du processus ponctuel (Stoyan and Penttinen, 2000). Un parallèle peut être fait en effet entre l'indice de compétition utilisé dans les modèles de dynamique forestière et le potentiel d'interaction d'un processus de Markov, entre la convergence du modèle vers son état d'équilibre et la convergence de l'algorithme de simulation, etc. Les algorithmes de Metropolis-Hastings qui procèdent par insertion / déletion successive de points, ne sont pas sans rappeler les processus de recrutement et de mortalité mis en œuvre dans les modèles de dynamique forestière. Le parallèle s'arrête là car l'algorithme de Metropolis-Hastings fait référence à une densité de probabilité de la répartition spatiale qui n'a pas d'équivalent dans les modèles de dynamique forestière.

Dans le cadre de cette étude, nous proposons d'établir un lien théorique entre la dynamique forestière d'une part, et la répartition spatiale des arbres d'autre part. Ce lien s'effectuera *via* un processus de naissance et de mort, considéré comme un algorithme de simulation parfaite d'un processus de Markov (Møller and Waagepetersen, 2004). On identifiera un processus de Markov à la fois simple et susceptible de décrire la répartition spatiale des arbres. On construira un algorithme de naissance et de mort pour simuler ce processus. On tâchera enfin d'interpréter cet algorithme comme un modèle de dynamique forestière ; on tâchera en particulier

- d'interpréter le terme d'interaction du processus de Markov en termes d'indice de compétition ;
- de relier le recrutement annuel au bilan en termes de naissance du

- processus de naissance et de mort sur un pas de temps annuel ;
- de relier la mortalité annuelle au bilan en termes de mort du processus de naissance et de mort sur un pas de temps annuel.

## Références

- Biging, G.S., and Dobbertin, M. 1992. A comparison of distance-dependent competition measures for height and basal area growth of individual conifer trees. *Forest Science* **38**(3): 695–720.
- Bolker, B.M., Pacala, S.W., and Levin, S.A., 2000. Moment methods for stochastic processes in continuous space and time. In *The Geometry of Ecological Interactions: Simplifying Spatial Complexity*. Proceedings of Low-Dimensional Dynamics of Spatial Ecological Systems, 14-16 November 1996, Laxenburg, Austria. Edited by U. Dieckmann, R. Law, and J.A.J. Metz. Cambridge University Press, Cambridge, pp. 388–411.
- Ford, E.D., and Diggle, P.J. 1981. Competition for light in a plant monoculture modelled as a spatial stochastic process. *Annals of Botany* **48**(4): 481–500.
- Franc, A., Gourlet-Fleury, S., and Picard, N. 2000. Introduction à la modélisation des forêts hétérogènes. ENGREF, Nancy.
- Goreaud, F., Loussier, B., Ngo Bieng, M.A., and Allain, R., 2004. Simulating realistic spatial structure for forest stands: a mimetic point process. In *Proceedings of the Interdisciplinary Spatial Statistics Workshop 2004*, December 2-3, 2004, Paris, France. ENGREF and University of Paris I Panthéon-Sorbonne, Paris, France. Available from <http://team.univ-paris1.fr/jiss2004/index.php>.
- Hanus, M.L., Hann, D.W., and Marshall, D.D. 1998. Reconstructing the spatial pattern of trees from routine stand examination measurements. *Forest Science* **44**(1): 125–133.
- Moeur, M. 1997. Spatial models of competition and gap dynamics in old-growth *Tsuga heterophylla* / *Thuja plicata* forests. *Forest Ecology and Management* **94**(1-3): 175–186.
- Møller, J., and Waagepetersen, R.P. 2004. Statistical Inference and Simulation for Spatial Point Processes. Chapman & Hall/CRC, Boca Raton.
- Pacala, S.W., and Deutschman, D.H. 1995. Details that matter: The spatial distribution of individual trees maintains forest ecosystem function. *Oikos* **74**(3): 357–365.
- Pielou, E.C. 1960. A single mechanism to account for regular, random and aggregated populations. *Journal of Ecology* **48**: 575–584.

- Rathbun, S.L., and Cressie, N. 1994. A space-time survival point process for a longleaf pine forest in southern Georgia. *Journal of the American Statistical Association* **89**(428): 1164–1174.
- Stoyan, D., and Penttinen, A. 2000. Recent applications of point process methods in forestry statistics. *Statistical Science* **15**(1): 61–78.
- Tomé, M., and Burkhart, H.E. 1989. Distance-dependent competition measures for predicting growth of individual trees. *Forest Science* **35**(3): 816–831.
- Verzelen, N., Picard, N., and Gourlet-Fleury, S. 2006. Approximating spatial interactions in a model of forest dynamics as a means of understanding spatial patterns. *Ecological Complexity* **3**(3): 209–218.

## B Report on the scientific committee on PSP

The scientific committee on permanent sample plots (PSP) was held on Tuesday 29 May 2007 in the CIRAD office in Montpellier. Participants were Alain Billand (CIRAD), François Goreaud (CEMAGREF, France), Sylvie Gourlet-Fleury (CIRAD), David Newbery (University of Bern, Switzerland), Nicolas Picard (CIRAD) and Mike D. Swaine (University of Aberdeen, UK). Jean-Louis Doucet (FUSAGx, Belgique) was absent for health reasons.

We thank again the participants outside CIRAD for giving us their time and thoughts on the best way to set up PSP.

### B.1 Introduction

Setting up PSP may be broken down into three steps: (i) planning, (ii) implementation on the field, and (iii) post-measurement operations. The planning step raises questions such as: What kind of device should be set up? If the device is made of several replications of a base unit, how many replications should be set up and, most importantly, what should be the size of the base unit? These questions may be summarized as: What should be the size of the device? Other questions are listed in slides 14, 16, 17 of the oral presentation (see Appendix B.3).

We developed a statistical approach to answer the question about the size of the device. It is based on a target quantity to be predicted using the data from the PSP, namely the stock recovery rate. The number of trees to be monitored is computed to get a prescribed precision of estimation of the stock recovery rate at level  $\alpha$ . This reasoning has some pros and cons. The objective of this committee was to discuss the solutions that we proposed to solve the questions and, when we were hesitating between several options, to choose

the most relevant one. It should be kept in mind that the technical rules that will result from this work are directed to forest managers. In particular, one question was to know whether we proposed some recipes to be applied locally, or whether we proposed a standard device (resulting for these recipes) to be set up everywhere in the same manner.

## B.2 List of recommendations of the committee

Questions to  
be addressed

- The first question to be asked should be: Why set up PSP? Are PSP directed to concessioners alone, or is there a regional vision implying a regional network of PSP?
- Mutualizing PSP through a network at the regional scale would require an amendment of forest regulations: the base unit for setting up PSP could no longer be the forest management unit (FMU); agreements between forest concessioners to mutualize PSP should be made possible.
- Objectives behind PSP should be identified: are they designed to fit complex models (with a research purpose) or simply to estimate the annual allowable cut? The device should be adapted to the question addressed and different protocols may be proposed depending on the objectives.
- Different protocols should be proposed for logged over forests and for primary forests.
- Three options could be proposed to concessioners to set up PSP: a minimum option, that corresponds to the minimum that should be available everywhere; a middle-way option; and a full option. The three options should be mutually consistent so that one could shift from a level to another at any time.
- Additional questions to be addressed are:
  - Where to set up PSP?
  - How much does it cost?
  - What should the temporal prospect? Do we expect the PSP to give answers after 3, 5, 10 years or more?
- A preliminary answer to this latter question is that PSP are designed for the next generation of management plans, thus giving a prospect of about 10 years.
- What human training should be foreseen to implement the protocol in the coming 10 years?

- What should be the role of forest services in the setting up and monitoring of PSP?
- The access to data coming from PSP is major question that should be addressed. Who is the owner of the data? Should a copy of the data be automatically given to national forest services?

#### Planning

- The choice of 10 cm as the minimum diameter for inventory is acceptable. Alder & Synnott (1992) recommended 20 cm because this threshold permitted to set up one plot in one day. On the other hand, very few species blossom before 20 cm in diameter.
- If forest managers presently have no data to apply the reasoning that comes out into the design of PSP, there is no use of giving them the reasoning alone. What should be given is the result of the reasoning when applied to M'Baïki data.
- Species measured on trails should include not only commercial species, but also species that are common in the whole Congo Bassin, to get a common baseline for dynamics at the regional scale.
- Trails would be devoted to the estimation of the stock recovery rate for target species. Permanent plots would be devoted to the assessment of stand global dynamics and to the recruitment of priority species.
- How to deal with phenology? There seems to be no satisfactory way of assessing phenology.

#### Environmental

##### variability

- Environmental variability is a key point to design PSP. It includes spatial (e.g. gap size) and temporal variability. Environmental variability is presently taken into account in the computation of the sample size required to get a prescribed precision, but not in the resolution of the SLOSS trade-off. A suggestion is to work with simulated data to see the impact of the CV value of the result. Another suggestion is to propose different scenarios corresponding to different ranges of values on the CV.
- A solution to address the issue of environmental variability would be to set up preliminary PSP to measure the environmental variability (the same as pre-inventory in forest inventory) and then to design the final PSP. But then we would lose 5 years of measurement.
- ☞ The protocol that will be proposed will correspond to a first generation of PSP. They will be used to assess the environmental variability. Then the protocol will evolve using collected data on environmental variability to get successive generations of PSP.

## Computation of $X$

- The impact of the initial diameter distribution  $\mathbf{N}(0)$  on the precision of estimation of the stock recovery rate should be documented, as forest managers will use their own values for  $\mathbf{N}(0)$ .
- The influence of  $\mathbf{N}(0)$  on the sensitivity analysis of the stock recovery rate with respect to demographic parameters should be documented (computation of  $\partial\varphi/\partial\theta$ ). In particular, if we use trails with a controlled diameter distribution for the sample, a uniform diameter distribution  $\mathbf{N}(0)$  should be used.
- Disregarding the reaction of the forest stand to canopy opening after logging may generate a bias in the estimation of the stock recovery rate (underestimation of growth after opening).

## Time

- Choice of the time step between two successive measurements:  $\Delta t$  should be large enough to smooth bad and good years. Ideally, temporal variability should be taken into account.  $\Delta t = 2$  years can generate a bias.
- Analyse using M'Baïki data the variations of diameter increments depending on  $\Delta t$ . This may be taken as a proxy for measurement errors, even if measurement errors are difficult to asses in practice.
- All computations regarding the stock recovery rate should be done again at M'Baïki using  $\Delta t = 4$  years (far from 1985 to handle the impact of silvicultural treatments).
- The timing of the measurement period within the year should be addressed (see Baker et al., 2002, *Forest Ecology & management*, **171**(3):261–274). The rainy season seems to be the best period as regards phenology but is also the most difficult for field work. As measurement itself may take time, plots and trees inside plots should measured always in the same order.
- The influence of the length of the temporal projection on the sensitivity analysis of the stock recovery rate with respect to demographic parameters should be documented (computation of  $\partial\varphi/\partial\theta$ ). If the stock recovery rate is computed at the end of several felling cycles, we expect  $\partial\varphi/\partial f$  to increase (where  $f$  is the average recruitment rate).

## Recruitment

- How to estimate the recruitment rate? For common species, there is no problem with permanent plots, but for rare species it may require to monitor large areas. An alternative would be to inventory seedlings

or saplings (but what is the link between the recruitment rate and the density of seedlings or saplings?), or to add another diameter class just below 10 cm.

- The inventory of newly recruited trees could be done on a large buffer area of 400 ha every 5 years. Or recruitment could be inventoried in circular plots of radius 20 m centred on those trees that are monitored along trails.

#### Field operations

- How to set up trails on the field to connect identified trees? This *a priori* requires a pre-inventory to locate target trees.
- To mark plot corners, an alternative to PVC stakes or to ditches is to use concrete boundary stones.
- To mark trees, it is also possible to used a metal label tied to the trunk with a string and a slipknot. Nails should not be used.
- For the usefulness of RFID chips, contact ONF.
- The number of trees should not be too long to prevent reading errors. On the other hand, longer numbers permit to bring information (such as the year of first measurement, for instance).
- Using two rings of paint to mark the height of measurement seems to be an unnecessarily complicated operation. If the ring of paint is too wide, a convention would be to locate the tape at the top of the ring.
- Pocket computer or paper to write down measurements in the field have similar performances in terms of ease of use, reliability, or risk of data loss. However the pocket computer permits to save time. On the other, it should be checked that forest managers will provide a sufficient training so that field workers know how to use it.

#### Buttresses

- Diameter for buttressed trees can be measured in an accurate way using a relascope with a constant distance to the tree, a constant angle view, and two perpendicular sighting directions.
- When a tree has buttresses, diameter measurement should be initiated well above buttress (2 m above). Then, as buttresses grow and measurement has to be raised, overlapping measurements should be done: one measurement at the old measurement height and one measurement at the new measurement height.

#### Botanical identification

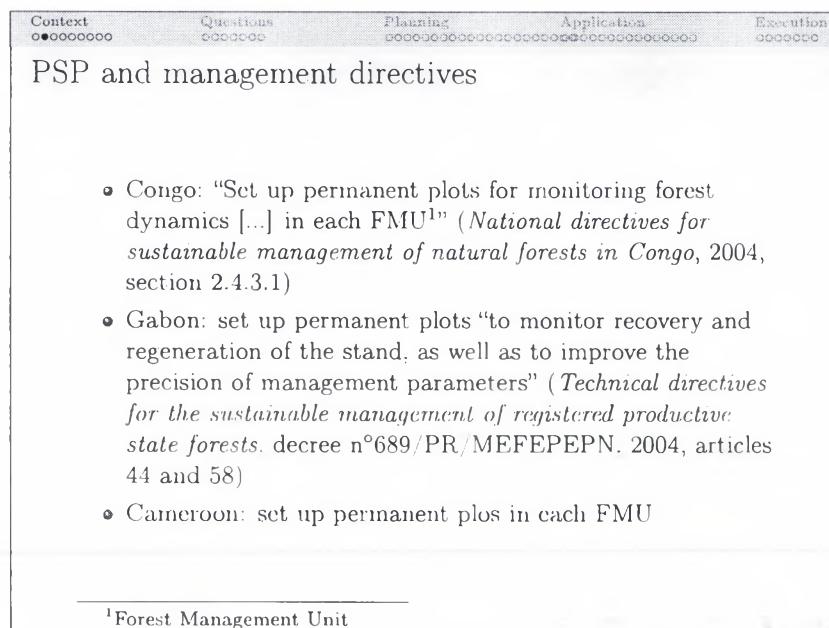
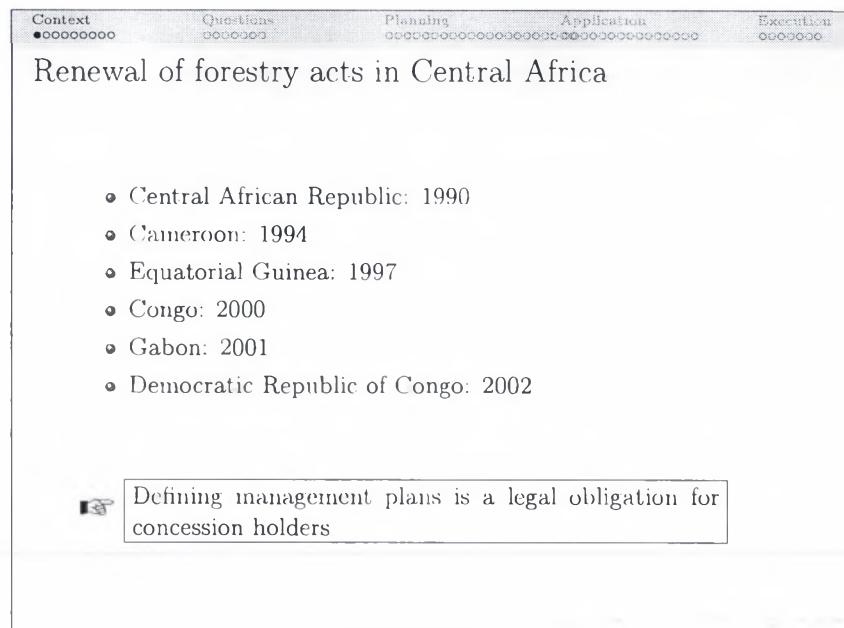
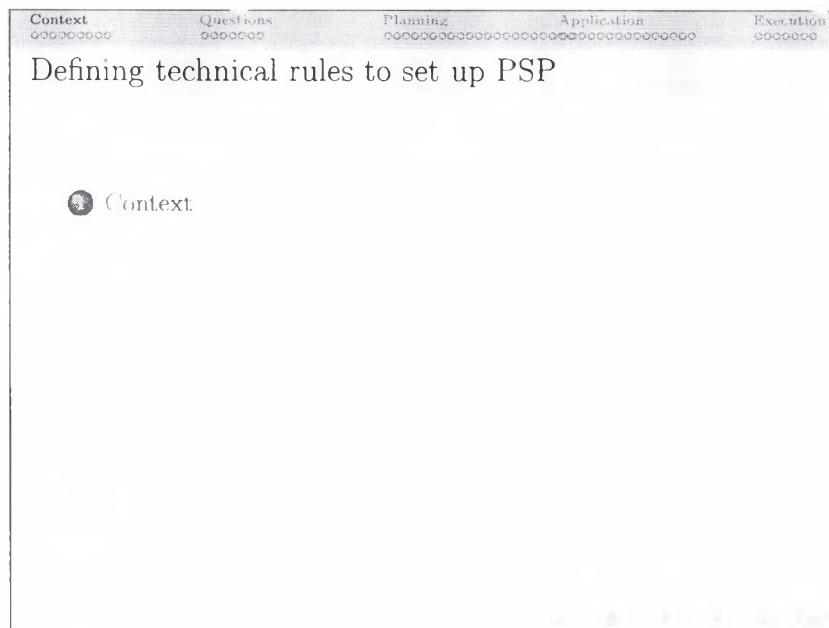
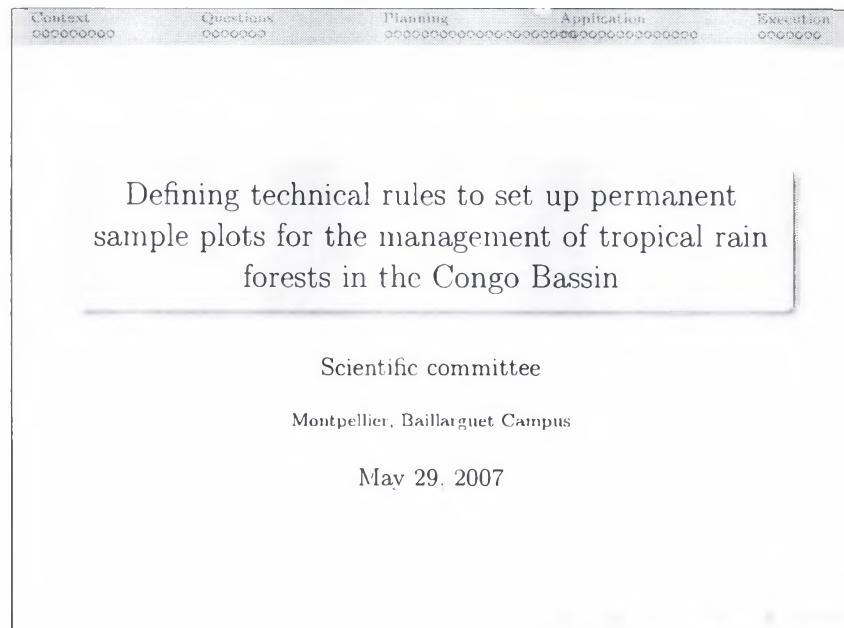
- A precise botanical identification is a prerequisite to get usable data.

- The majority of trees can be determined by sight. For the others, a specimen has to be collected (or the tree is classified as "unknown").

Three  
options

- The three proposed options for designing PSP are as follows:
  1. Minimum option: the permanent device is composed of trails within a buffer area.
    - Measurements along trails are used to estimate the stock recovery rate.
    - The buffer area is inventoried every 5 years to estimate the recruitment rate.
    - Target species are the commercial species.
    - Prescribed precision of estimation of the stock recovery rate is 20% at level 95%.
    - The size of the buffer area depends on long-term prediction of the stock recovery rate.
  2. Middle-way option = minimum option +
    - Target species also include potentially commercial species
    - Permanent plots are set up to assess stand dynamics. As no pre-inventory is available to assess the variability of stand dynamics, an empirical size is used (say  $6 \times 3$  ha).
  3. Full option = middle-way option +
    - Prescribed precision of estimation of the stock recovery rate is 10% at level 95%.
    - The site is open to research activities (with its own funding).

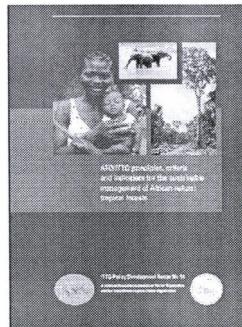
### B.3 Slides of the oral presentation



Context oooo●oooo	Questions ooooooo	Planning oooooooooooo	Application oooooooooooo	Execution oooooo
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## Forest certification

*Indicator 2.3.2. The felling rotation and yield are clearly determined and respected in accordance with the principles of sustainable production.*



- Sub-indicator 2.3.2.1. The calculation of yield and the determination of the rotation are verifiable from the forest management document.
- Sub-indicator 2.3.2.2. The rotation is based on the growth rates and minimum diameter of trees to be harvested, and on data obtained from the forest management inventory.
- Sub-indicator 2.3.2.3. The forest management document provides management options beyond the first rotation.

Context oooo●oooo	Questions ooooooo	Planning oooooooooooo	Application oooooooooooo	Execution oooooo
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## A new “demand” for setting up PSP

- Either because they anticipate the application of management directives
  - Or because they aim at forest certification
- concession holders in the Congo Basin are interested in setting up PSP

Presently, no technical norm to set up PSP

- ☒ everyone follows its own recipe
- ☒ COMIFAC initiative to propose a technical standard

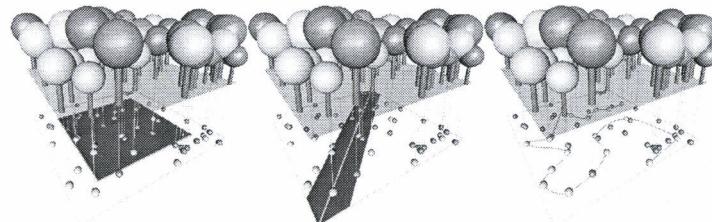
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## Definitions

- Permanent sample plot (PSP): any device (no necessarily a plot!) where trees are individually marked in a permanent way, thus permitting to pass again and remeasure identified trees.
- Natural tropical rain forests: the renewal of the wood stock after logging occurs in a natural way: in particular regeneration is not assisted ( $\neq$  plantations)
- Congo Basin: Cameroun, Central African Republic, Congo, Democratic Republic of Congo, Equatorial Guinea, Gabon

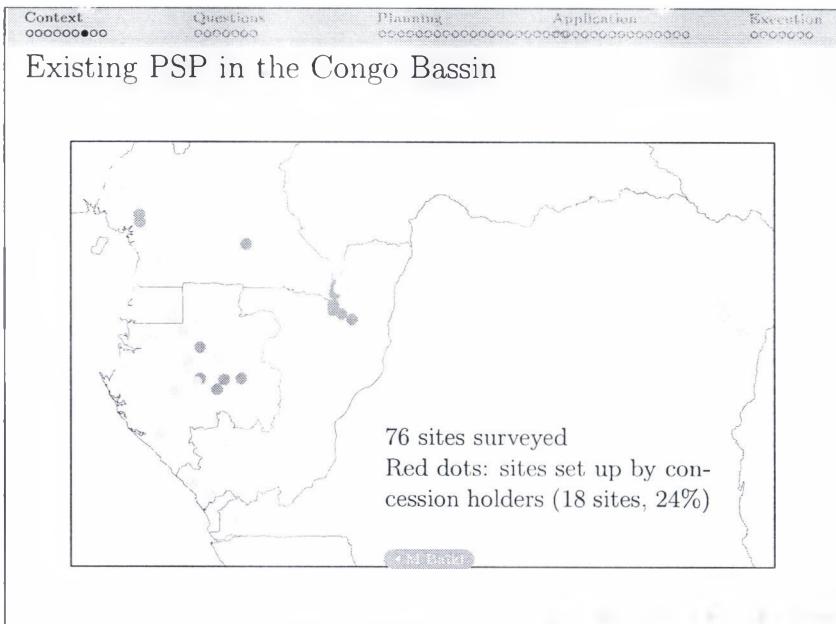
Context oooo●oooo	Questions ooooooo	Planning oooooooooooo	Application oooooooooooo	Execution oooooo
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## Types of device



Three types of permanent devices:

- plots
- transects
- paths



- | Context    | Questions | Planning     | Application          | Execution    |
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- Existing protocols
- ➊ Smithsonian Institute, Program MAB (Dallmeier, 1992)
    - 1 ha plots, starting from 10 cm DBH
    - 38 replications in the Congo Bassin
  - ➋ Smithsonian Institute, CTFS
    - huge plots (10–50 ha), starting from 1 cm DBH
    - 5 replications in the Congo Bassin (+ other replications in the world: Barro Colorado Island...)
  - ➌ Missouri Botanical Garden (Gentry, 1992)
    - plots 5 m × 200 m, starting from 2.5 cm DBH
    - many replications (all over the world)
  - ➍ ECOFAC (White & Edwards, 2000)
    - transects 5 km long and 5 m (DBH ≥ 10 cm) or 50 m (DBH ≥ 70 cm) wide

- | Context      | Questions | Planning             | Application          | Execution    |
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| oooooooooooo | ooooooo○  | oooooooooooooooooooo | oooooooooooooooooooo | oooooooooooo |
- Existing protocols (continuing)
- ➎ CIRAD
    - plots 4–6 ha in size, starting from 10 cm DBH
    - 3 sites in the Congo Bassin (+ other replications in Ivory Coast, French Guiana, Brazil, Indonesia)
  - ➏ As regards concession holders
    - Plots or paths
    - Plot size: 0.25, 0.5, 1, 9 or 25 ha
    - Minimum diameter: 10 or 40 cm

- | Context      | Questions | Planning     | Application          | Execution    |
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- Defining technical rules to set up PSP
- ➐ Questions to be addressed

Context oooooooo	Questions ●ooooo	Planning oooooooooooooooooooo	Application oooooooooooooooooooo	Execution oooooo
How to set up and monitor PSP?				
<p>Three steps:</p> <ul style="list-style-type: none"> <li>● Planning</li> <li>● Field implementation</li> <li>● Data treatment and post-measurement operations</li> </ul>				

Context oooooooo	Questions oo●ooo	Planning oooooooooooooooooooo	Application oooooooooooooooooooo	Execution oooooo
What is meant by planning?				
<ul style="list-style-type: none"> <li>● Forest managers expect a field guide or set of field instructions: plot sizes are given, number of replications is given, etc.</li> <li>● precise but not general</li> <li>● Alternative: write a source book from which a field guide of PSP procedures can be developed at a local level (specify the methods but not the results)</li> <li>● no local ability to develop field procedures if reasoning too complex</li> </ul>				
Questions related to planning				
<ul style="list-style-type: none"> <li>● What type of device? (plot / transect / path)</li> <li>● What size?</li> <li>● If main device broken down into base units: How many replications? What size for the base unit?</li> <li>● Minimum diameter for inventory?</li> <li>● Should all species be treated in the same way? Selection of species?</li> <li>● Time between two consecutive census?</li> <li>● Life span of a device?</li> </ul>				
Questions related to field implementation				
<ul style="list-style-type: none"> <li>● How to delineate plots?</li> <li>● How to mark trees permanently?</li> <li>● How to measure diameters with buttresses?</li> <li>● How to determine species?</li> <li>● How to manage data on the field?</li> </ul>				

Context	Questions	Planning	Application	Execution
Questions related to data treatment and post-measurement operations				
<ul style="list-style-type: none"> <li>• How to store data?</li> <li>• How to detect abnormal data?</li> </ul>				

Context	Questions	Planning	Application	Execution
Questions that will not be addressed (unless you think they should)				
<ul style="list-style-type: none"> <li>• Where to locate permanent devices?           <ul style="list-style-type: none"> <li>• Forest stratification  How to stratify?</li> <li>• Legal constraints (one device in each FMU)</li> </ul> </li> <li>• How to integrate PSP in the management process? (as defined by management directives)           <ul style="list-style-type: none"> <li>• Temporal constraints due to other forest operations (e.g. logging)</li> <li>• How to manage human and material needs to set up PSP? (training...)</li> </ul> </li> <li>• How to maintain PSP on the long-term?           <ul style="list-style-type: none"> <li>• Which funding?</li> <li>• What should be the role of the state, what should be the role of private concession holders?</li> <li>• How to harmonize practices at the national or regional scale?</li> </ul> </li> </ul>				

Context	Questions	Planning	Application	Execution
Quick answer to some questions (or does this deserve to be further investigated?)				
<ul style="list-style-type: none"> <li>• Minimum diameter for inventory: 10 cm DBH</li> <li>• To handle species diversity:           <ul style="list-style-type: none"> <li>• Planning based on a restricted set of priority species</li> <li>• Same field measurement for all species (no selection) </li> <li>• forest dynamics as a whole</li> </ul> </li> <li>• Post-measurement operations: standard techniques for data storage (e.g. Access) and outlier detection</li> </ul>				

Context	Questions	Planning	Application	Execution
Defining technical rules to set up PSP				
 Planning				

Context	Questions	Planning	Application	Execution
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## Principle

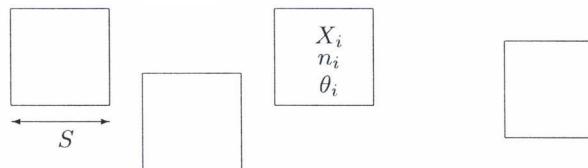
- Same reasoning as in forest inventory
- A quantity  $X$  to be predicted with a given precision  $\varepsilon_\alpha$  at level  $1 - \alpha$
- $X$  predicted from sample  $s_n$  of  $n$  observations
- Super-population approach: observations are i.i.d.  $\sim F$
- ☒ distribution of  $X$  depends on  $F$  and  $n$
- ☒ relationship between  $\varepsilon_\alpha$  and  $n$

Context	Questions	Planning	Application	Execution
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## More precisely

4 variables:

- $p$ : number of replications of base device
- $S$ : size of base device
- $n$ : sample size ( $= n_1 + n_2 + \dots + n_p$ )
- VC: variation coefficient of  $X$  between replications



Context	Questions	Planning	Application	Execution
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## Optimization problem as in forest inventory

- 4 variables
- 2 parameters:  $\varepsilon_\alpha$  and cost (or effort)  $C$
- 4 equations:
  - $n$  related to  $pS$
  - $\varepsilon_\alpha$  related to  $n$  and VC
  - VC related to  $p$  and  $S$
  - $C$  related to  $p$  and  $S$
- ☒ Optimization problem under constraints:
  - Minimize  $C$  given  $\varepsilon_\alpha$
  - Or maximize precision (= minimize  $\varepsilon_\alpha$ ) given  $C$

Context	Questions	Planning	Application	Execution
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## SLOSS trade-off "Single Large Or Several Small"

- $n = f(pS)$
- VC =  $g(p, S)$
- ☒  $\varepsilon_\alpha = h(p, S)$ , or  $p = \phi(S, \varepsilon_\alpha)$
- ☒  $C = \psi(S, p) = \psi[S, \phi(S, \varepsilon_\alpha)]$

$$S_{\text{solution}} = \underset{S}{\operatorname{argmin}} \psi[S, \phi(S, \varepsilon_\alpha)]$$

Context	Questions	Planning	Application	Execution
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## Disregarding environmental variability

$$\varepsilon_\alpha = \frac{q_\alpha}{\sqrt{p}} \left[ \frac{\text{E}[g_{\theta_i}(n/p)]}{\text{E}(X_i)^2} + \text{CV}^2 \right]^{\frac{1}{2}}$$

where  $g_{\theta_i}(n_i) = \text{Var}(X_i|n_i, \theta_i)$

- VC,  $\theta_i$  describe environmental variability
- present knowledge does ~~not~~ permit to model it

- Simplifying assumption of homogeneous environment  
Then,

- $\varepsilon_\alpha$  depends only on  $n$  (or  $pS$ ), not on SLOSS trade-off
- Optimization problem broken down into two independent problems:

- $\varepsilon_\alpha = f(n)$  to be solved for  $n$ , for a given  $\varepsilon_\alpha$
- SLOSS problem:

$$\begin{cases} pS = g(n) \\ \underset{p.S}{\operatorname{argmin}} C(p.S) \end{cases}$$

Context	Questions	Planning	Application	Execution
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## What are PSP set up for?

*Management directives for sustainable management of natural forests in Congo, 2004, § 2.4.3.1:* "PSP are to be set up to collect precise data on:

- specific growth
- forest productivity
- recovery rates
- species ecology
- species phenology
- ecosystem and regeneration dynamics
- specific age of sexual maturity
- response of forest stand to silvicultural treatments
- etc."

- How to quantify all this? How to satisfy multiple criteria?

Context	Questions	Planning	Application	Execution
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## Application of this principle

- What is the quantity  $X$  to be predicted?
- What is an observation?
- What is the distribution  $F$  of observations?

Each choice may bring a different result!

Context	Questions	Planning	Application	Execution
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## Predicting the stock recovery rate

Our choice for  $X$ , the quantity to be predicted

$$= \frac{\text{initial stock recovery rate}}{\text{initial exploitable stock}} = \frac{\text{exploitable stock at the end of a felling cycle}}{\text{exploitable stock at the end of a felling cycle}}$$

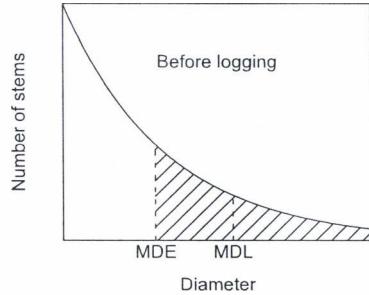
- because it is a key parameter used in management plans
- because it integrates growth rates, mortality rates and recruitment rates

Same reasoning applicable to other quantity, if required!

Context Questions Planning Application Execution

## Management of natural forests in the Congo Basin

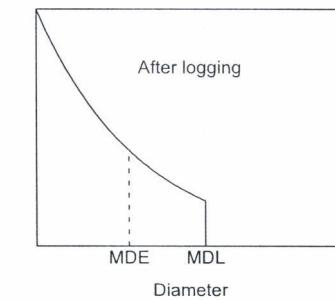
- for each species
- possibility = logging intensity that ensures a given recovery rate of the wood resource
- determined by tuning three management parameters:
  - MDL: minimum diameter for logging ( $\geq$  MDE)
  - length of felling cycle (or rotation)
  - stock recovery rate



Context Questions Planning Application Execution

## Management of natural forests in the Congo Basin

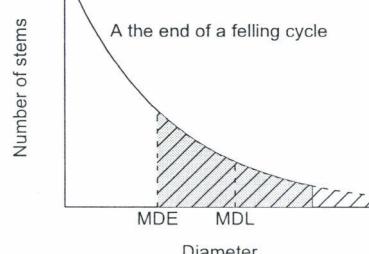
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Context Questions Planning Application Execution

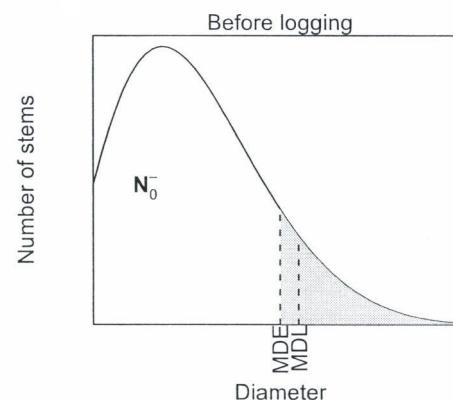
## Management of natural forests in the Congo Basin

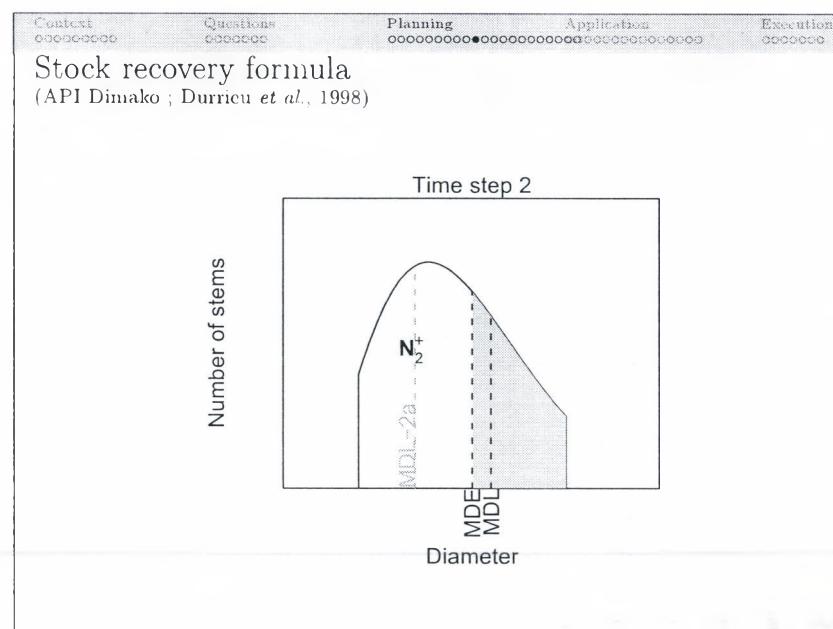
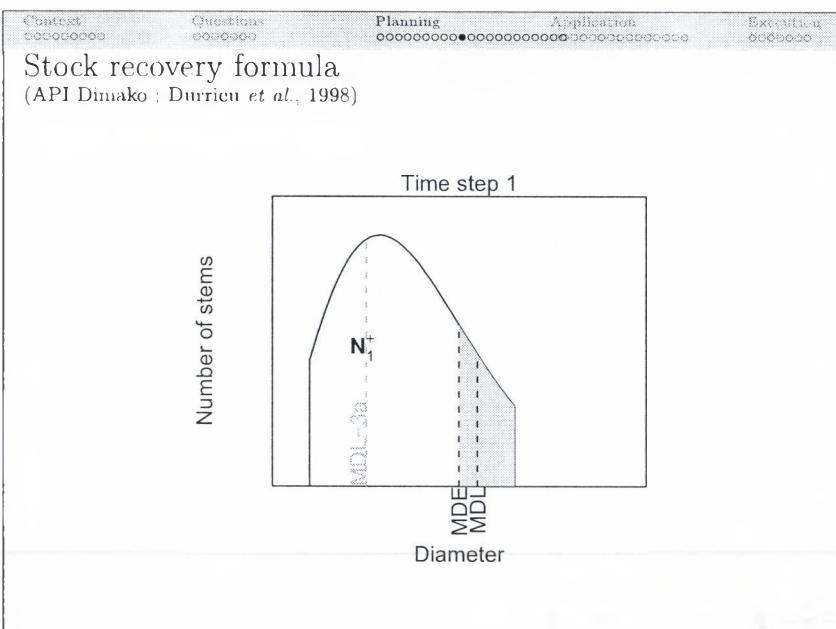
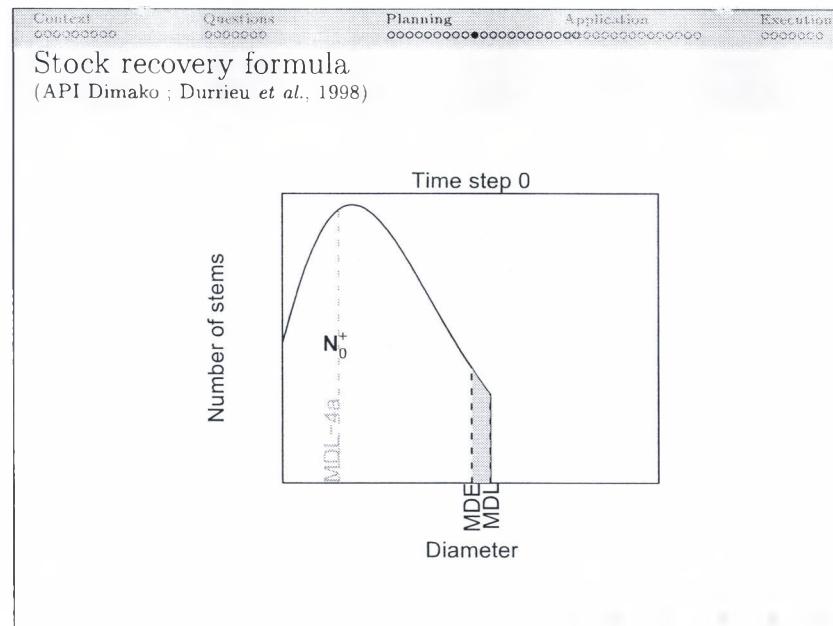
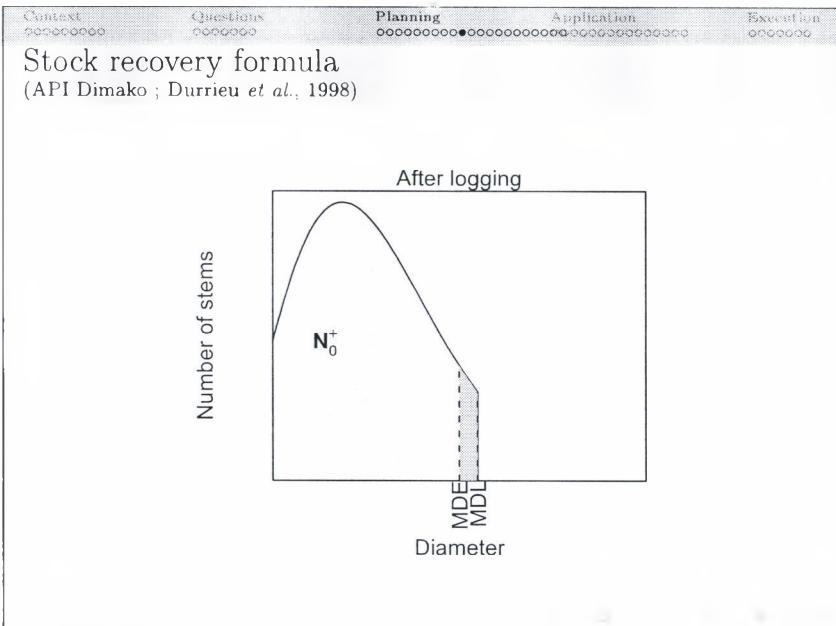
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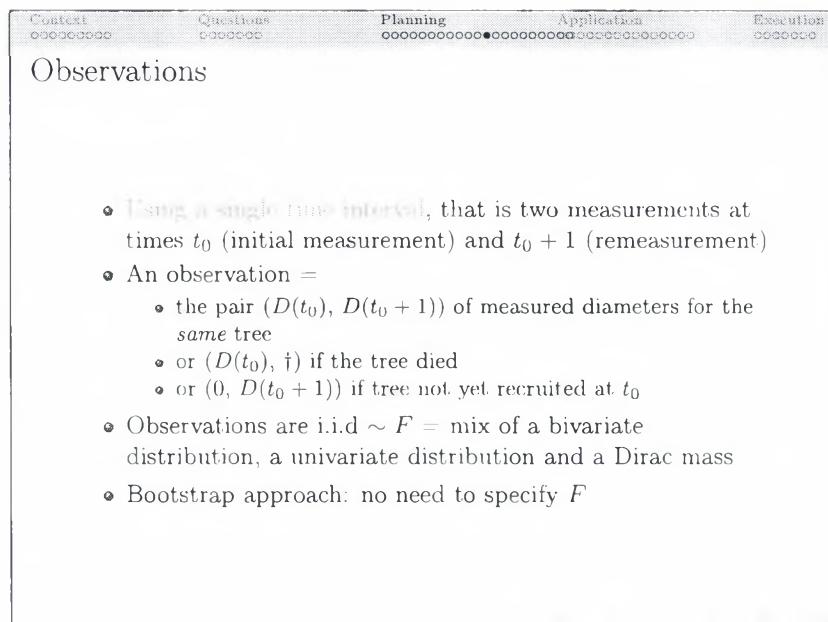
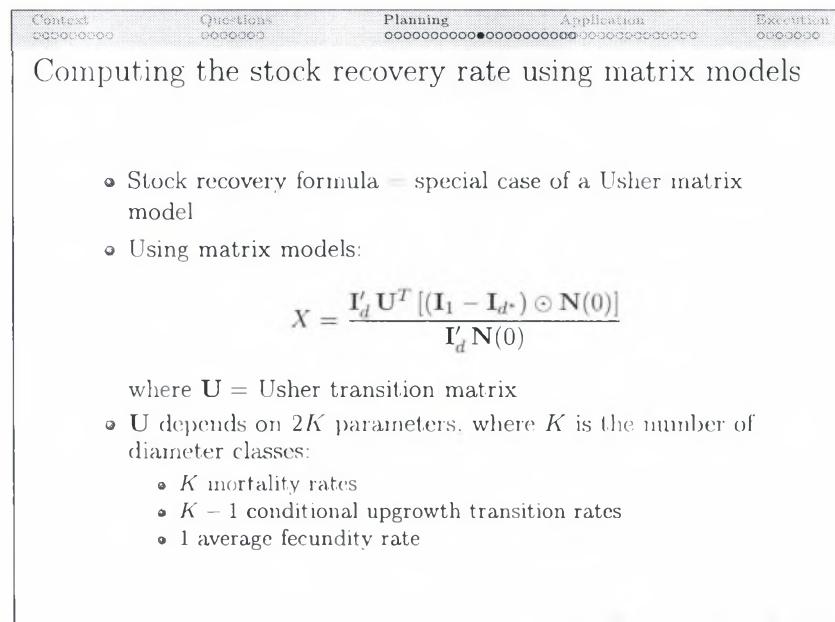
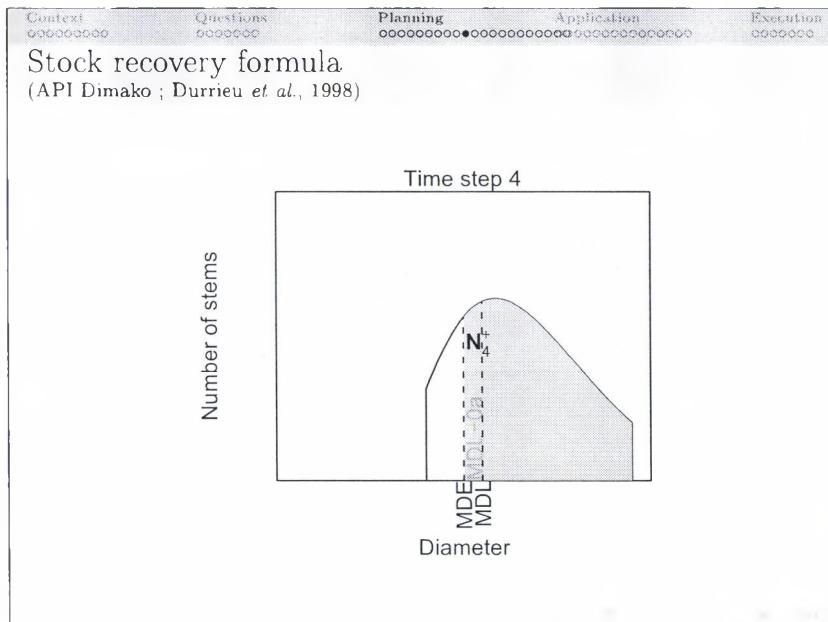
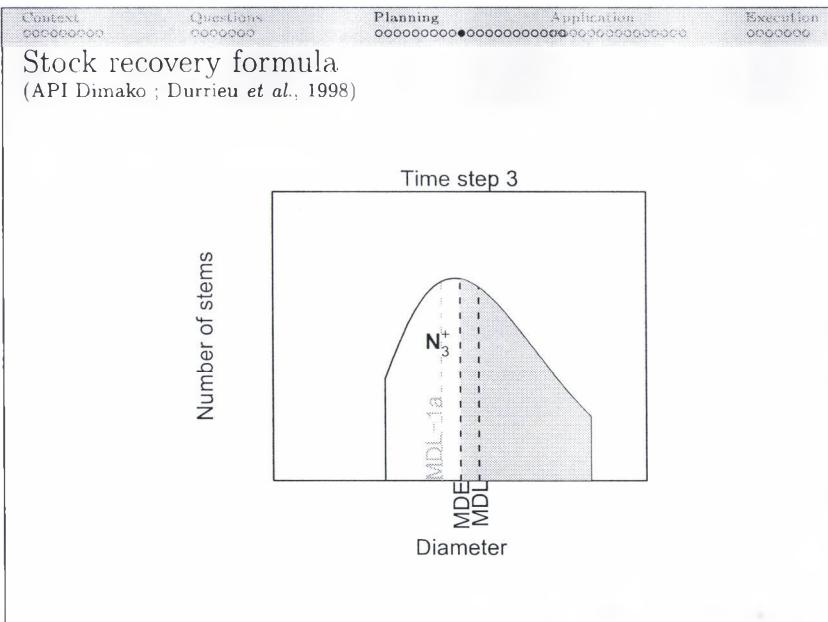


Context Questions Planning Application Execution

## Stock recovery formula (API Dimako ; Durrieu *et al.*, 1998)







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## Sampling variability

- It relates the quantity of information brought by the sample  $s_n$  of  $n$  observations to the variability of any prediction of the matrix model
- Estimator of the Usher matrix:

$$\hat{\mathbf{U}} = U(s_n)$$

Estimator of the stock recovery rate:

$$\hat{X} = \frac{\mathbf{I}'_d \hat{\mathbf{U}}^T [(\mathbf{I}_1 - \mathbf{I}_{d^*}) \odot \mathbf{N}(0)]}{\mathbf{I}'_d \mathbf{N}(0)}$$

- The distribution of  $\hat{X}$  follows from  $F$

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## Which estimator should be taken?

- There exists a functional  $g$  such that

$$\mathbf{U} = g(F)$$

- Classical approach: plug-in estimator
- It is obtained by replacing  $F$  by its empirical distribution:

$$\hat{\mathbf{U}}_{\text{plug-in}} = g(\hat{F}_n)$$

where

$$\hat{F}_n = \sum_{k=1}^n \delta_{o_k}$$

and  $\delta_o$  = Dirac mass at observation  $o$

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## Plug-in estimator

- Plug-in estimator of  $\mathbf{U}$  identifies with classical proportion estimator:

$$\hat{f}_{\text{plug-in}} = \frac{\#\text{recruited}}{n - \#\text{recruited}}$$

$$\hat{m}_{i,\text{plug-in}} = \frac{\#\text{dead trees in class } i}{\#\text{trees in class } i \text{ at } t_0}$$

$$\hat{p}_{i,\text{plug-in}}^* = \frac{\#\text{trees moving up from class } i \text{ to } i+1}{\#\text{trees in class } i \text{ at } t_0 \text{ excluding dead trees}}$$

- Plug-in estimator not efficient for small samples:

- Low bias ( $\mathbf{U}_{\text{plug-in}}$  unbiased but  $\hat{X}_{\text{plug-in}}$  biased)
- Huge variance

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## Increment estimator

- Definition:

$$\hat{f} = \hat{f}_{\text{plug-in}}$$

$$\forall i, \quad \hat{m}_i \equiv \hat{m} = (\#\text{dead trees}) / (n - \#\text{recruited})$$

$$\hat{p}_i^* = 1 - \hat{G}_i(u_{i+1} - \hat{a}_i)$$

where  $G_i$  = conditional diameter distribution knowing that the tree is in class  $i$ ,  $u_{i+1}$  = lower bound of class  $i+1$  = upper bound of class  $i$ , and  $a_i$  = average diameter increment in class  $i$

$$\hat{a}_i = \frac{\sum_{\text{class } i} D(t_0 + 1) - D(t_0)}{\#\text{trees not dead in class } i \text{ at } t_0}$$

- Increment estimator much more efficient for small samples (much lower variance, small bias)

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## Bootstrap techniques

- Permits to compute any statistical property of  $X$
- Consider that the unknown distribution  $F$  of observations is  $\hat{F}_n$
- Bootstrap algorithm:
  - Select  $B$  independent bootstrap samples  $s_1^*, s_2^*, \dots, s_B^*$ , each consisting of  $n$  observations drawn with replacement from  $s_n$ .
  - Evaluate the bootstrap replication corresponding to each bootstrap sample,

$$\hat{X}_b^* = X(\hat{\theta}(s_b^*)) \quad (b = 1, \dots, B)$$

- Estimate the expected value of  $X(\hat{\theta})$  by the empirical mean of the  $B$  replications:

$$\hat{X}_\bullet^* = \frac{1}{B} \sum_{b=1}^B \hat{X}_b^*$$

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## Bootstrap algorithms (continued)

- Bias:
  - Estimate the bias of  $X(\hat{\theta})$  by:
$$\widehat{\text{bias}} = \hat{X}_\bullet^* - X(\hat{\theta}_{\text{plug-in}})$$
- Standard deviation:
  - Estimate the standard error of  $X$  by the sample standard deviation of the  $B$  replications:
$$\hat{\sigma}_B = \left\{ \frac{1}{B-1} \sum_{b=1}^B [\hat{X}_b^* - \hat{X}_\bullet^*]^2 \right\}^{1/2}$$
- Precision of estimation:
  - The lower bound  $\hat{X}_{\alpha,\text{lo}}$  of the confidence interval at level  $1 - \alpha$  is the  $(\alpha/2)$ th empirical percentile of the  $\hat{X}_b^*$  values, whereas its upper bound  $\hat{X}_{\alpha,\text{up}}$  is the  $(1 - \alpha/2)$ th empirical percentile of the  $\hat{X}_b^*$  values.
$$\hat{\varepsilon}_\alpha = (\hat{X}_{\alpha,\text{up}} - \hat{X}_{\alpha,\text{lo}}) / (2\hat{X}_\bullet^*)$$

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## Definition of the bootstrap sample

- Drawing with replacement in  $s_n$  same diameter distribution at  $t_0$  than in  $s_n$
- Other sampling schemes bring other ways of drawing a bootstrap sample
- Example: for a path, number of trees in each diameter class is controlled drawing with replacement in the subset of  $s_n$  corresponding to class  $i$ , for each class  $i = 1, \dots, K$

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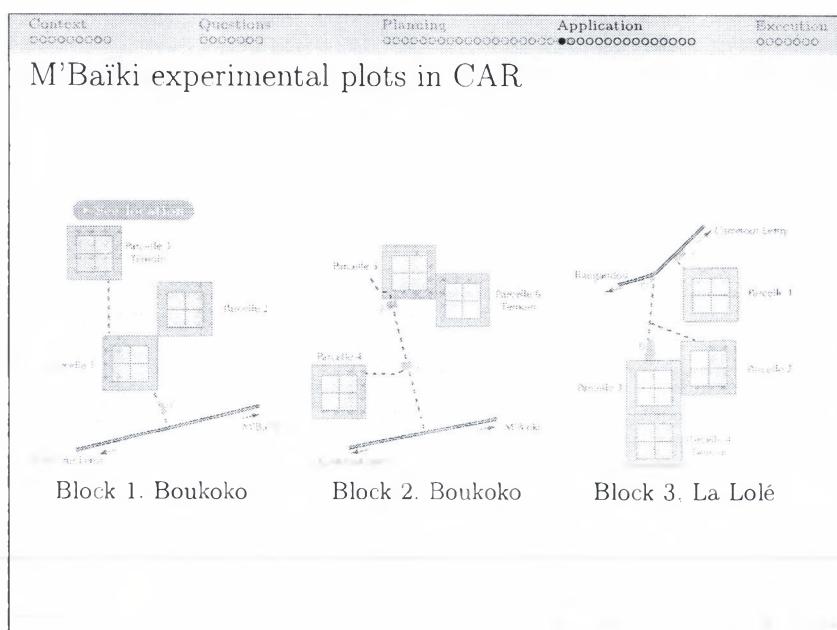
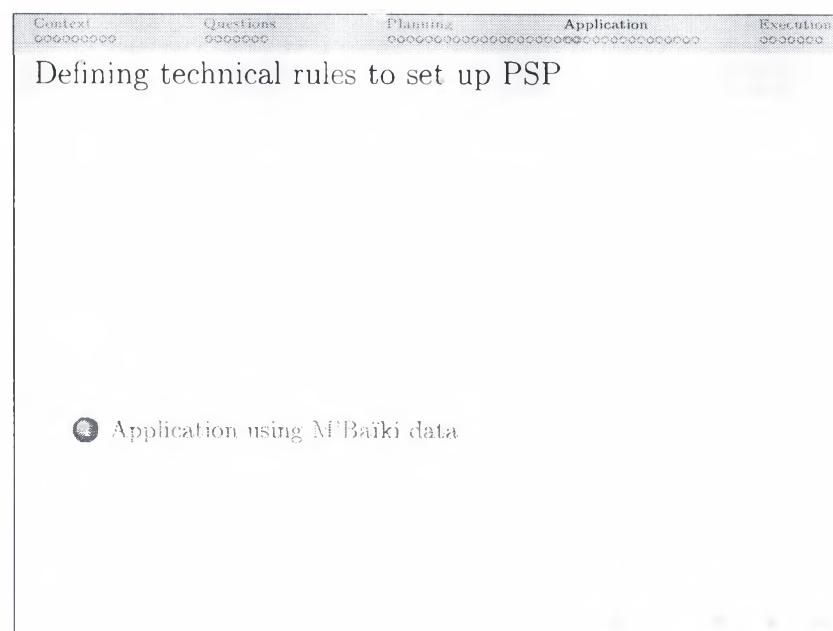
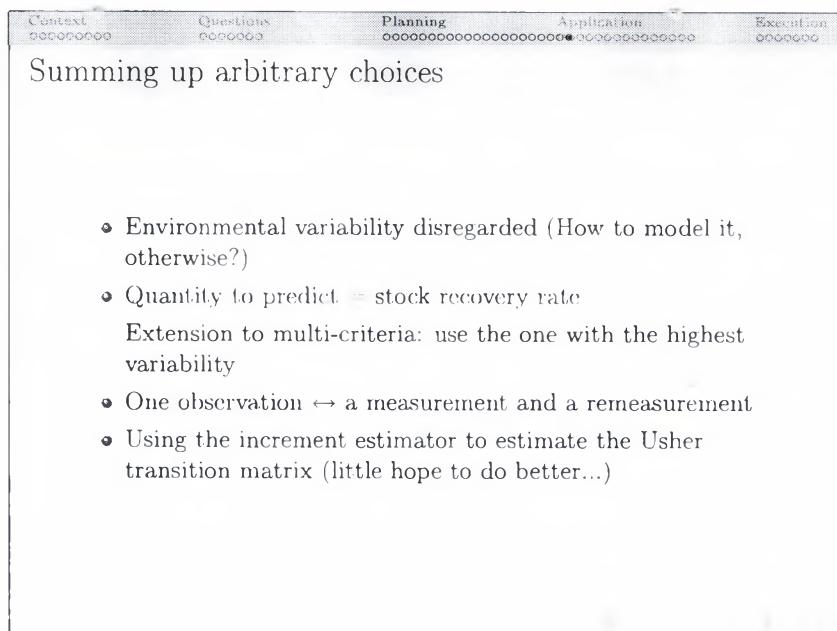
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## Relationship between $\varepsilon_\alpha$ and $n$

- Bootstrap algorithm (quite long)
- Good approximation: given a dataset of  $n_0$  observations with corresponding precision of estimation  $\hat{\varepsilon}_\alpha$ , the sample size required to get a prescribed precision of  $\varepsilon_\alpha$  is:

$$n \simeq n_0 \left( \frac{\hat{\varepsilon}_\alpha}{\varepsilon_\alpha} \right)^2$$



Context oooooooo	Questions oooooo	Planning oooooooooooo	Application oooooooooooo	Execution oooooo
<b>Priority species</b>				
Pilot name	Latin name	Family	#	MDL (cm)
Sapelli	<i>Entandrophragma cylindricum</i>	Meliaceæ	273	80
Kosipo	<i>Entandrophragma candollei</i>	Meliaceæ	66	80
Tiama	<i>Entandrophragma angolense</i>	Meliaceæ	144	80
Acajou blanc	<i>Khaya anthotheca</i>	Meliaceæ	114	80
Padouk rouge	<i>Pterocarpus soyauxii</i>	Papilionaceæ	107	80
Tali Yaoundé	<i>Erythrophleum suaveolens</i>	Caesalpiniaceæ	76	80
Ayous	<i>Triplachiton scleroxylon</i>	Sterculiaceæ	153	80
Limba (Fraké)	<i>Terminalia superba</i>	Combretaceæ	94	80
Ebène	<i>Diospyros crassiflora</i>	Ebenaceæ	174	80
Mboulou	<i>Aningeria altissima</i>	Sapotaceæ	170	80
Monzounzé	<i>Gambeya africana</i>	Sapotaceæ	81	80
11 species				

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## Species not treated

Not enough trees (7 species)

Pilot name	Latin name	Family	#	MDL (cm)
Sipo	<i>Entandrophragma utile</i>	Meliaceæ	6	80
Doussié	<i>Afzelia bipindensis</i>	Caesalpiniaceæ	28	80
Dibétou	<i>Lovoa trichilioides</i>	Meliaceæ	32	80
Iroko	<i>Milicia excelsa</i>	Moraceæ	46	80
Bossé clair	<i>Guarea cedrata</i>	Meliaceæ	13	80
Fromager	<i>Ceiba pentandra</i>	Bombacaceæ	15	80
Mobambou	<i>Gambeya lacourtiana</i>	Sapotaceæ	46	80

Trees too small ( $D < 80$  cm)

Niové	<i>Staudia kamerunensis</i>	Myristicaceæ	1165	80
Mbaléké	<i>Gambeya boukokoensis</i>	Sapotaceæ	70	80

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Sample size required to get prescribed precision  
Example of sapelli

Table gives sample size and corresponding area in ha (in parenthesis)

sapelli ( $\lambda = 6.825 \text{ ha}^{-1}$ )		Precision		
$\alpha$		10 %	20 %	30 %
0.8		4432 (649)	1039 (152)	485 (71)
0.9		6648 (974)	1939 (284)	831 (122)
0.95		13296 (1948)	2216 (325)	1074 (157)

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Worst case: mboulou

mboulou ( $\lambda = 4.25 \text{ ha}^{-1}$ )

$\alpha$	Precision		
	10 %	20 %	30 %
0.8	7944 (1869)	1986 (467)	883 (208)
0.9	14182 (3337)	3545 (834)	1576 (371)
0.95	21667 (5098)	5417 (1275)	2407 (566)

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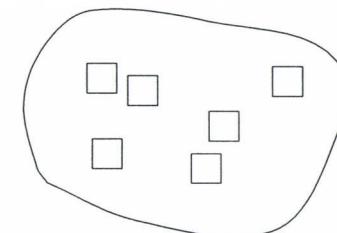
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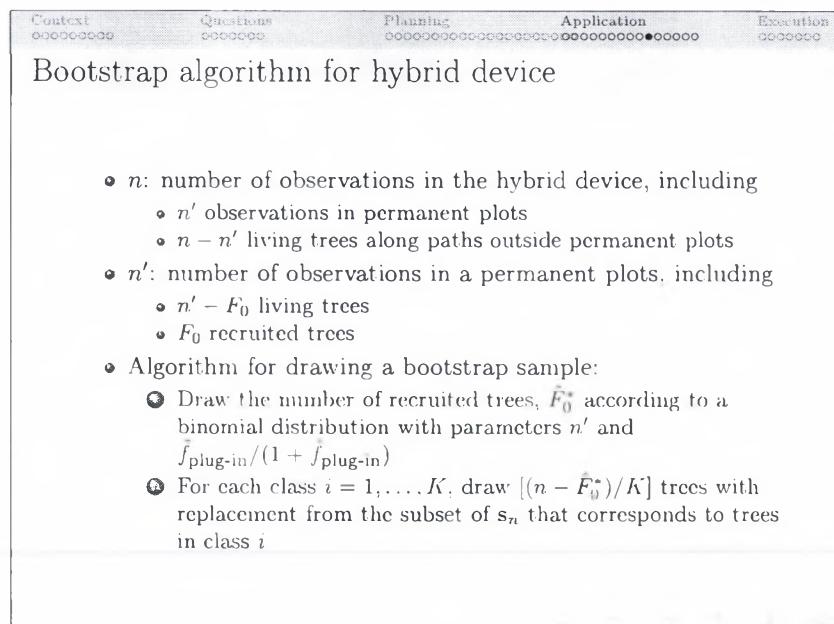
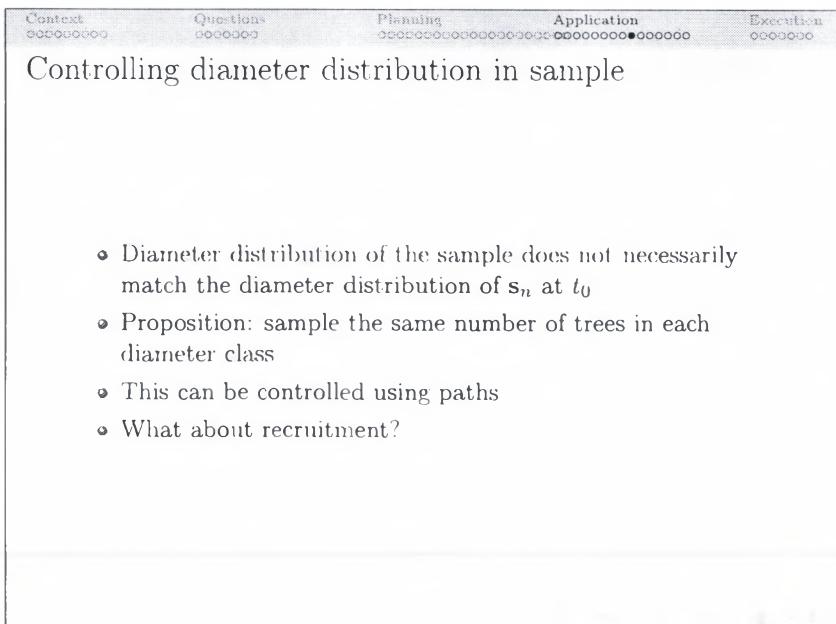
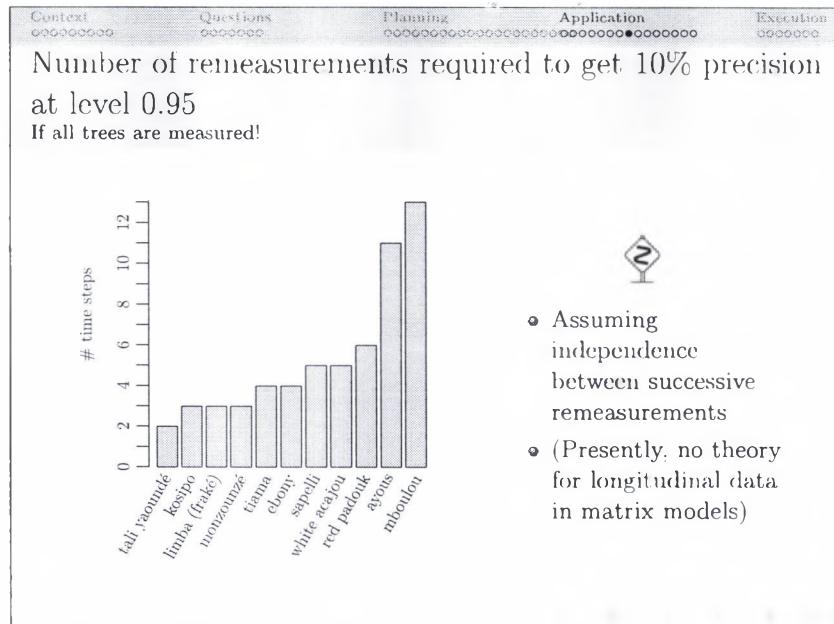
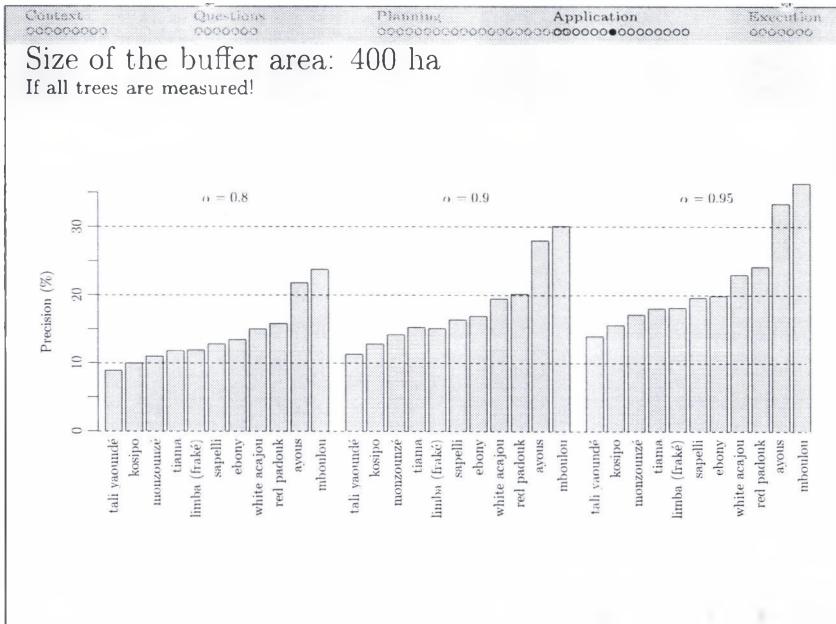
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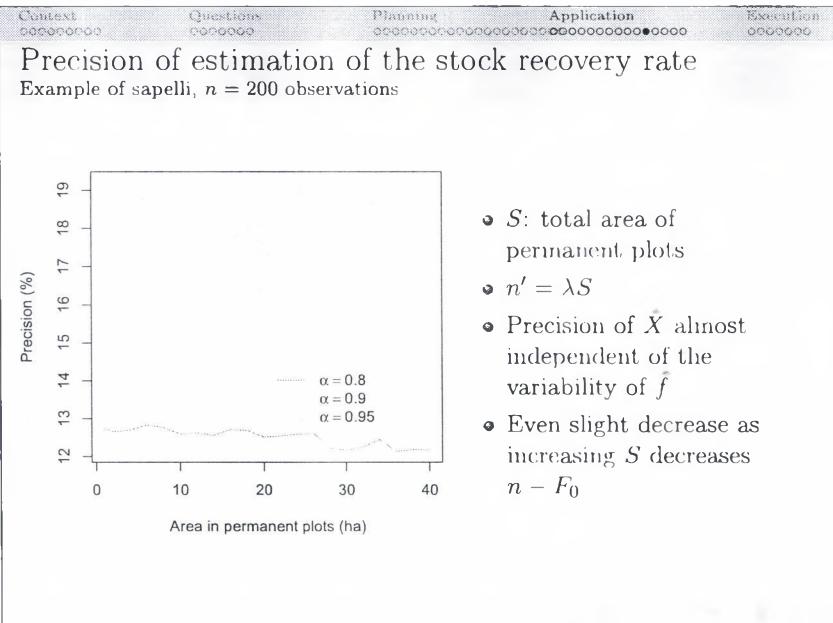
Type of device

- Plot or transect: too big!
- Path: no possibility to assess recruitment
- Hybrid device: path + plot



buffer area where paths are found





Context Questions Planning Application Execution

### Not all parameters play the same role

$$\hat{X} = \varphi(\hat{m}_1, \dots, \hat{m}_K, \hat{p}_1^*, \dots, \hat{p}_K^*, \hat{f})$$

Let us denote

$$\begin{aligned}\hat{\theta} &= (\hat{m}_1, \dots, \hat{m}_K, \hat{p}_1^*, \dots, \hat{p}_K^*, \hat{f}) \\ \theta &= E(\hat{\theta})\end{aligned}$$

Then ( $\delta$ -method):

$$\text{Var}(X) \simeq \sum_{i=1}^{2K} \text{Var}(\hat{\theta}_i) \left[ \frac{\partial \varphi}{\partial \theta_i}(\theta) \right]^2 + \sum_{i=2}^{2K} \sum_{j < i} \text{Cov}(\hat{\theta}_i, \hat{\theta}_j) \left[ \frac{\partial \varphi}{\partial \theta_i}(\theta) \right] \left[ \frac{\partial \varphi}{\partial \theta_j}(\theta) \right]$$

- $(\partial \varphi / \partial f)$  low  $\Rightarrow \text{Var}(\hat{f})$  does not matter much
- High impact of  $p_i^*$  and  $\hat{m}_i$  for  $i$  close to MDL

Context Questions Planning Application Execution

### Limits of the reasoning

- Optimize the sample scheme to maximise the precision of estimation of  $X$ ? This would signify
  - Disregard recruitment
  - Measure large trees only
- It is not satisfactory!
- Limits of the reasoning
- Alternatives:
  - Use another target quantity than the stock recovery rate?
  - Set some constraints on the precision of estimation of  $f$ ,  $\hat{m}_i$ ,  $\hat{p}_i^*$ ?
  - Use an *ad hoc* rule such as: as many recruited as dead trees
- Current proposition: 18 ha in permanent plots

Context Questions Planning Application Execution

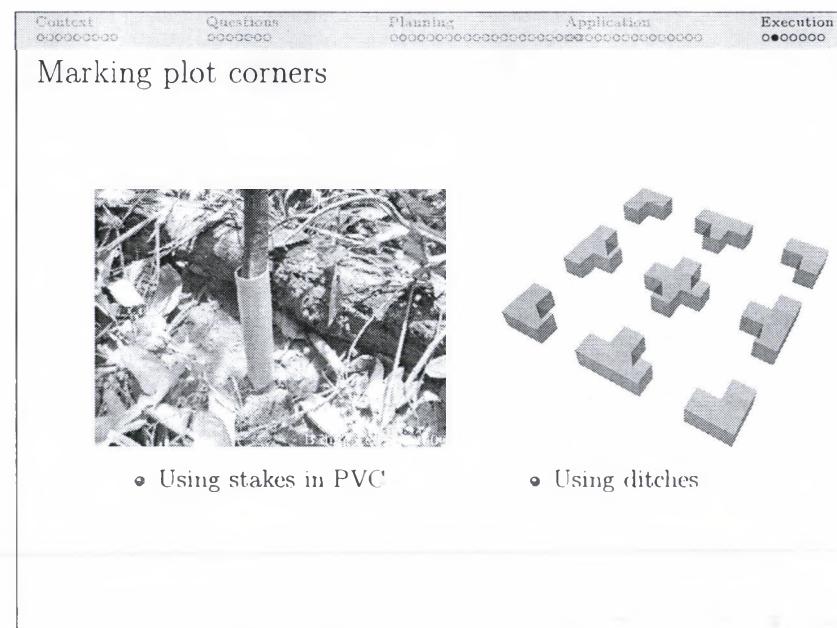
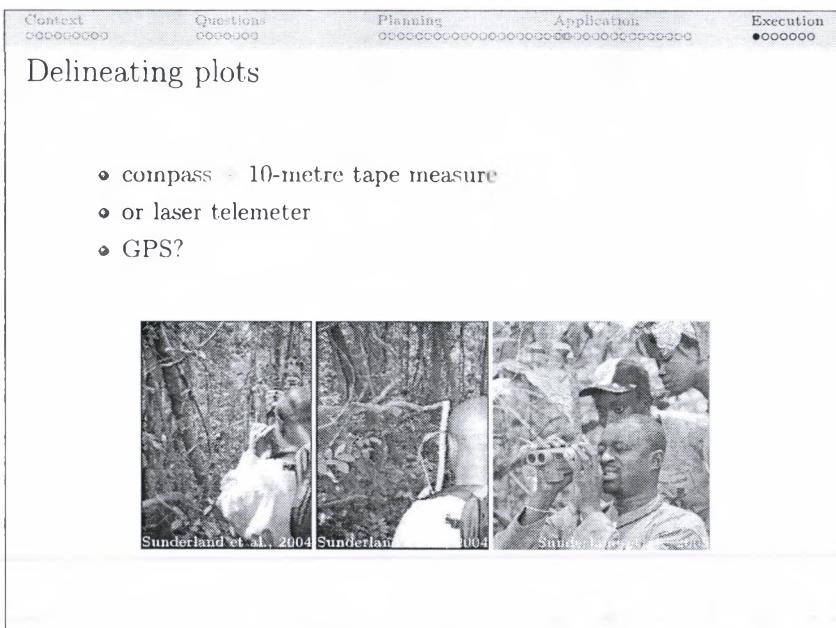
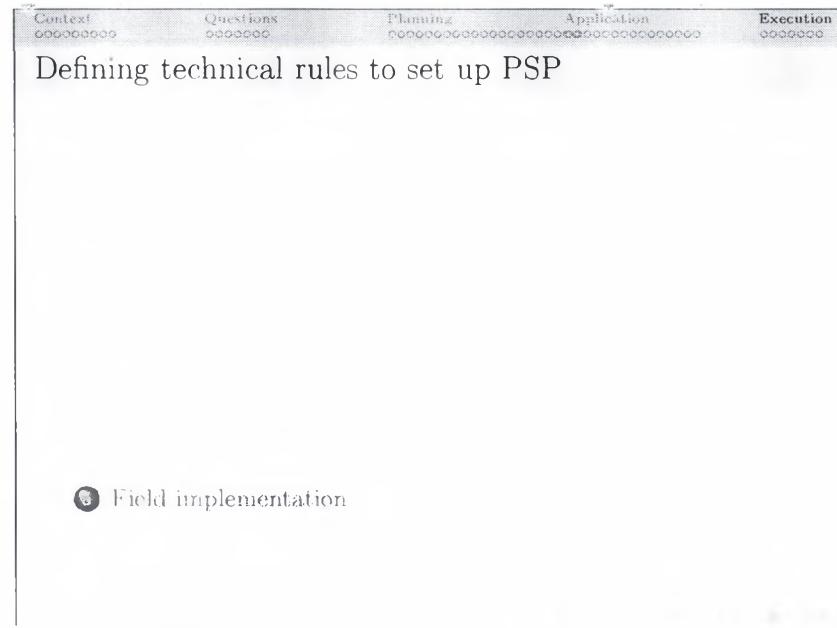
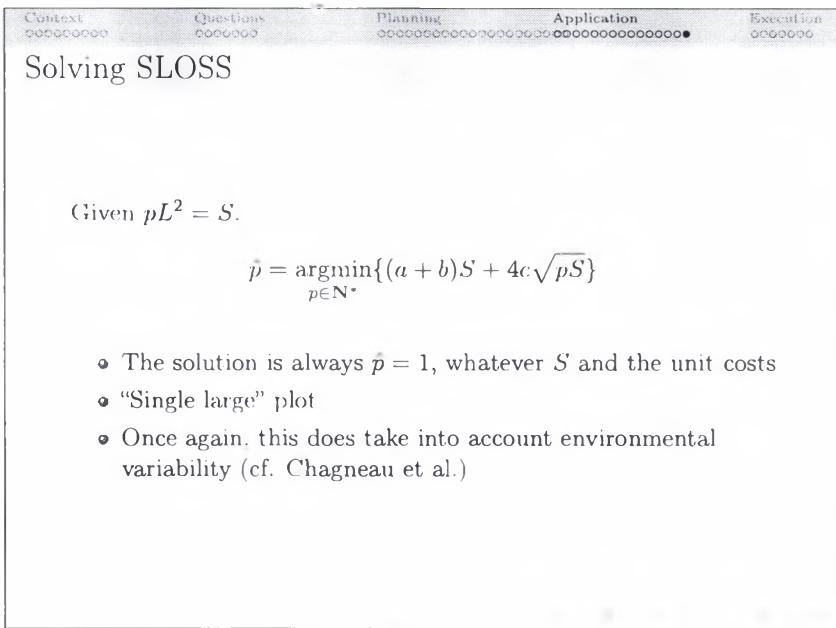
### SLOSS trade-off

Cost to set up  $p$  plots of size  $L \times L$

$$C = \underbrace{apL^2}_{\text{inventory}} + \underbrace{bpL^2}_{\text{division in subplots}} + \underbrace{4cpL}_{\text{setting outline}}$$

According to Croise & Fabbri (1991) for Ngouha2: for one person.

- surface cost of inventory:  $a = 8.333 \text{ day ha}^{-1}$  (without measuring tree location!)
- surface cost for subplot grid:  $b = 8 \text{ day ha}^{-1}$
- linear cost for outline:  $c = 3.125 \text{ day dam}^{-1}$



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### Marking trees permanently

**20 m × 20 m subplot**

Combine at least two ways of identifying trees:

- tree location
- tag:
  - number painted on the trunk (using stencil)
  - aluminium label nailed to the tree
- new technology? (RFID transponder...)

Bullinga et al., 2006

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### Measuring diameters

• Ring of paint at height of measurements

• Two rings with a space for the tape

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### Tree buttress

• Measure diameter above buttress

• Rise measurement height as buttress grows

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### Species botanical identification

What field effort?

- climb trees to collect vouchers, collect a voucher for every tree, make herbaria...
- or simply visual identification

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Data management on the field

- paper and pencil
- or data collector

