Optimization in forestry

- Motivation, principles, methods and results

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Forest Ecology and Management
seminar series at SLU

14:30 – 15:30, December 13, 2011

Optimization in forestry

\- ***Motivation*** *from the point of view of* ***Forest Ecology & Management****)*

Citation from ”**Forest Ecology & Management**”, ”**Silviculture**”, http://www.sekско.se/ (2011-12-05):

”**The aim of silvicultural research** is to **evaluate the effects of** forestry practices, like **regeneration**, **pre-commercial thinning**, **thinning**, **fertilization**, and **felling**, on the future development of forests.

The research is based on long-term field experiments, survey-studies, laboratory experiments, and simulations.

The department is responsible for the **development of knowledge for forming silvicultural practices and systems, which enable a sustainable use of the forest resource.** The topic is central to the department's education, at both undergraduate and graduate level.” (End of citation)

OBSERVATION:

In order to develop ”the best” methods in forestry, we need well defined objective functions and explicit optimization of activitites in forestry.

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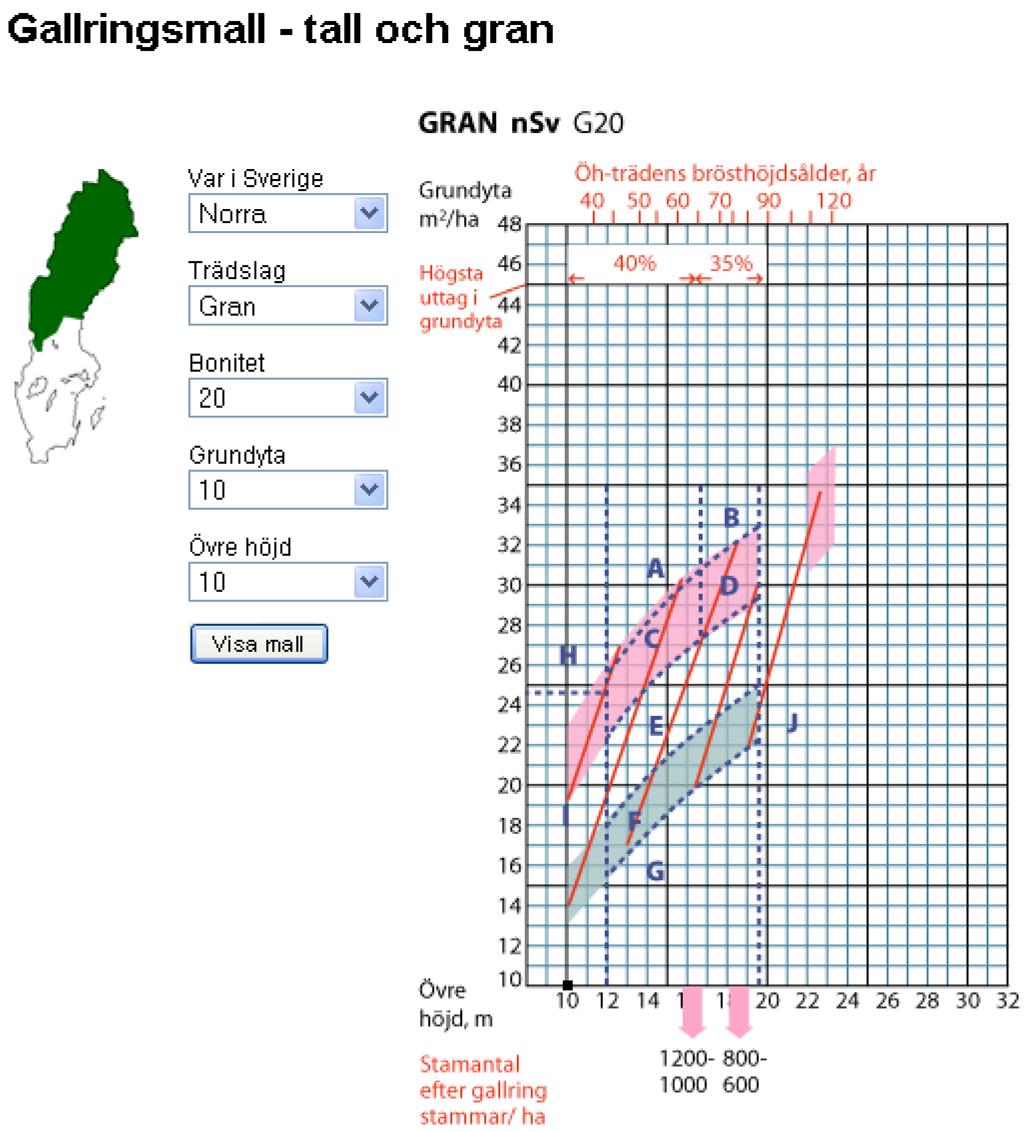

KUNSKAP DIREKT

A classical tool that is interesting to use and that makes it possible to ”simulate” different combinations of thinning times, thinning volumes and clearfellings.

<u>OBSERVATION!</u>
There is an infinite number of such possible combinations!
The tool does not optimize the combined Decisions.

***<u>If you want the best plan, you</u>* should *<u>optimize</u>* the decisions!**

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A simple but typical deterministic final felling problem

<u>Example:</u>
Stand volume right now = 100 m3 per hectare
The stand grows 5 m3 per hectare and year.
Price – harvest cost = 200 SEK / m3

Today, t=0, we have a forest stand with the following properties:

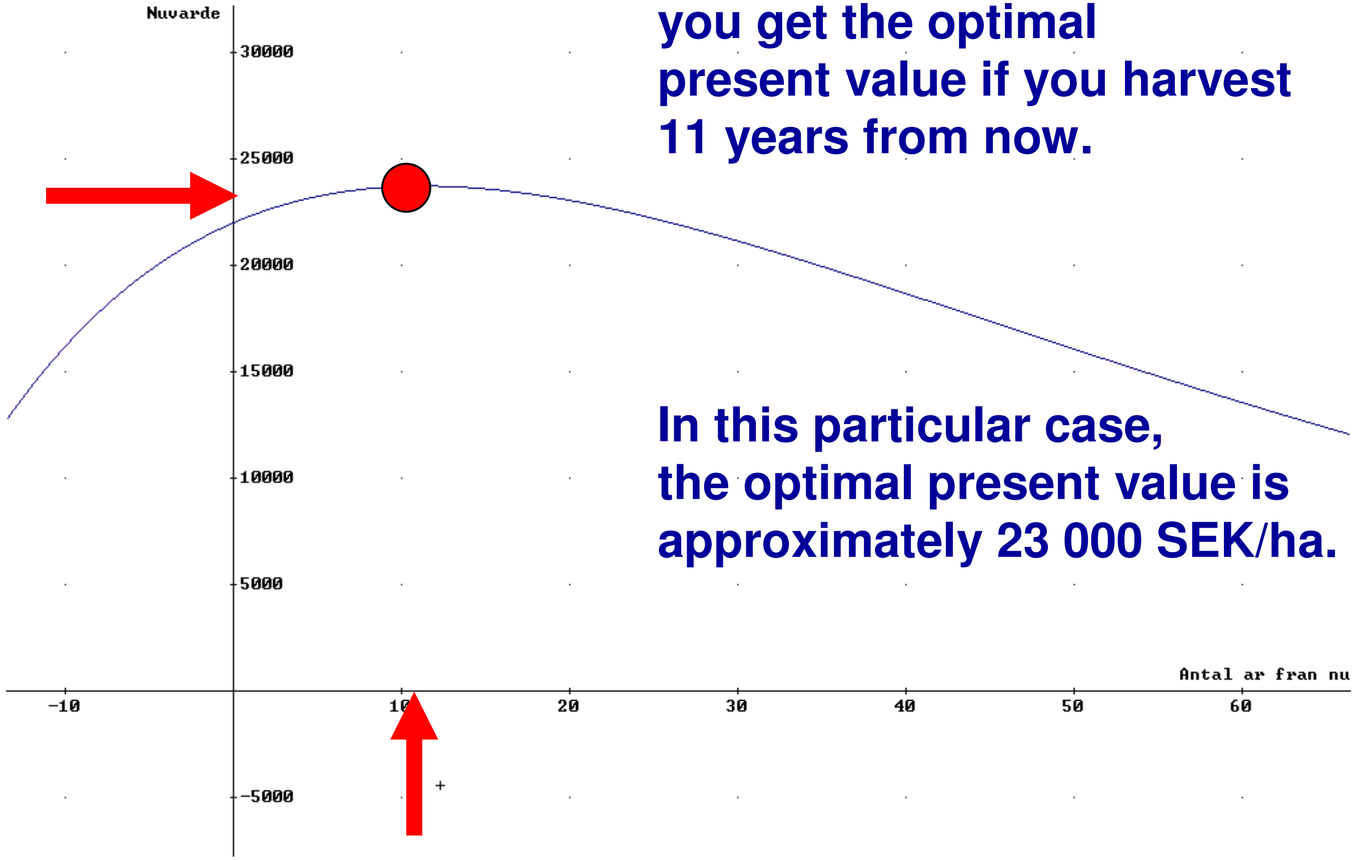
B(t) = Value of the stand if we harvest t years from now. (SEK/ha)

B(t) = a + bt   a = 20000, b = 1000

L = Value of the land (bare land) after harvesting (= 2000 SEK/ha).

r = Rate of interest in the capital market (in continuous time).

Present value



t

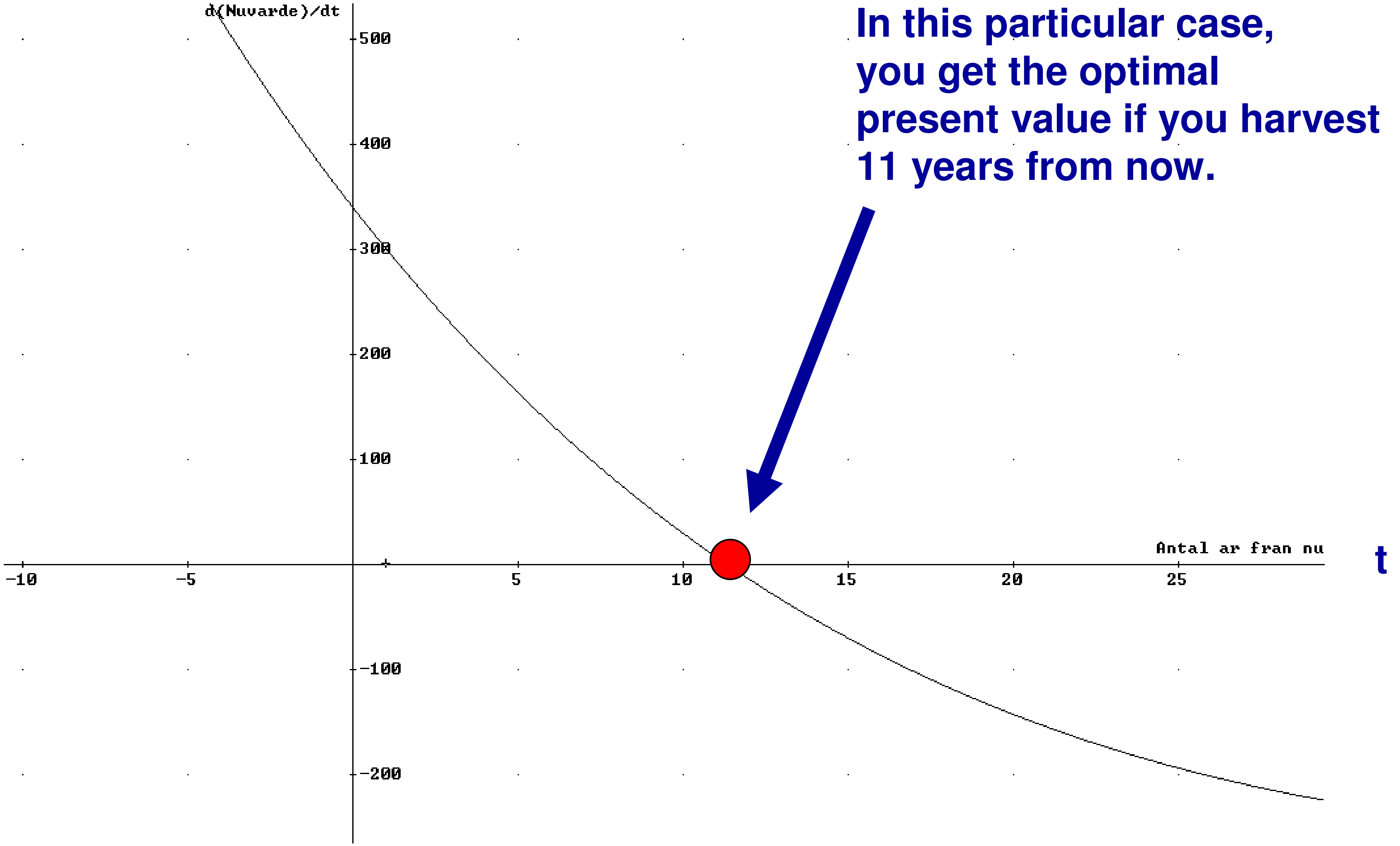
In this particular case, you get the optimal present value if you harvest 11 years from now.

In this particular case, the optimal present value is approximately 23 000 SEK/ha.

With one (or two) decision(s), you can plot the objective function and easily find the optimum for particular parameter values.

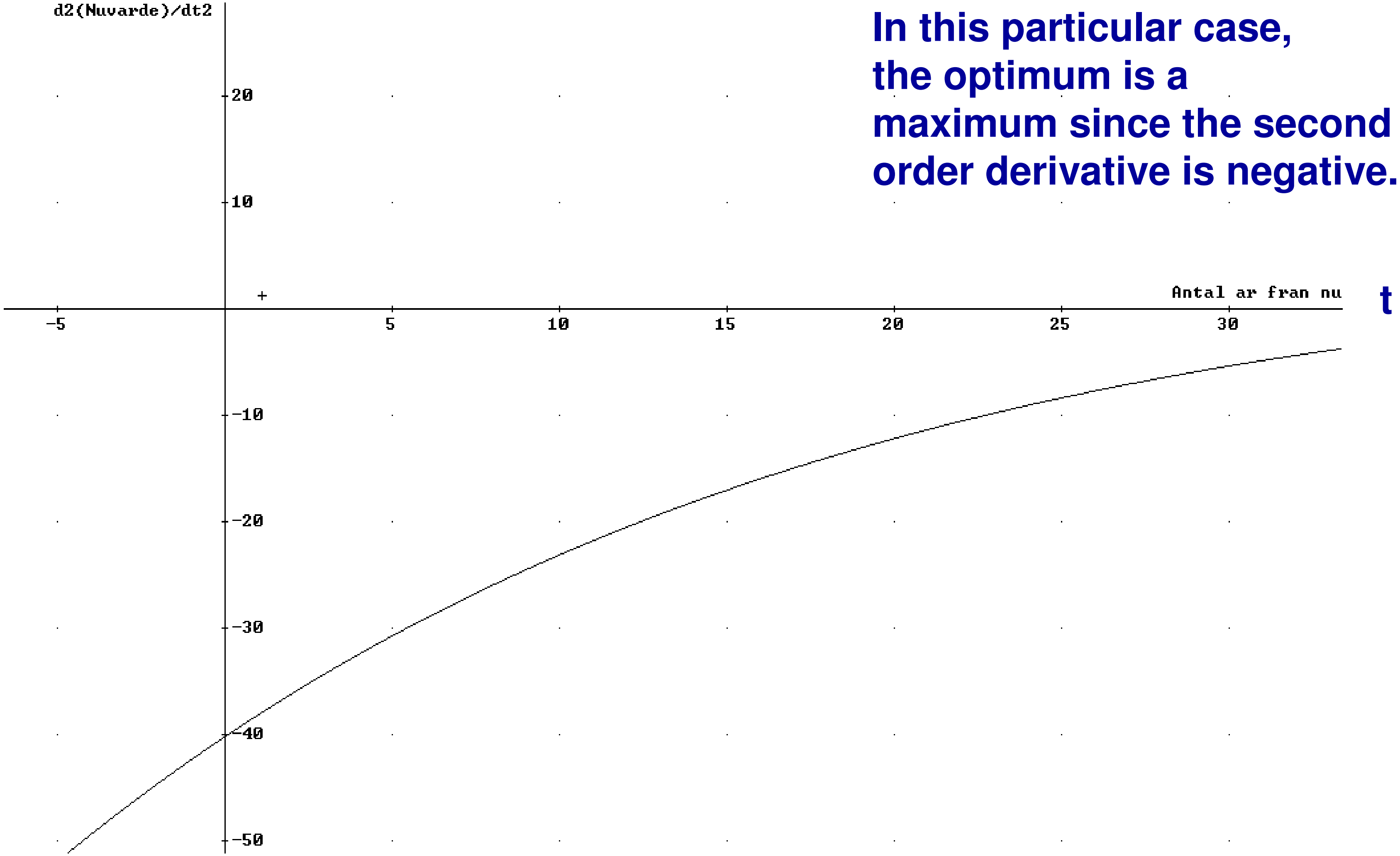
Present value = EXP(- 0.03·t)·(20000 + 1000·t + 2000)

d(Present value) / dt



In this particular case, you get the optimal present value if you harvest 11 years from now.

d2(Present value) / dt2



In this particular case, the optimum is a maximum since the second order derivative is negative.

It is better to derive the optimal decision as a function of the parameters!

$$\Pi(t) = e^{-rt}(B(t) + L)$$

Objective function

$$\Pi'(t) = -re^{-rt}(B(t) + L) + e^{-rt}B'(t)$$

First derivative w.r.t. t

$$\Pi'(t) = e^{-rt}\left(-r(B(t) + L) + B'(t)\right) = 0$$

First derivative w.r.t. t = 0

$$e^{-rt} > 0$$

$$-r(B(t) + L) + B'(t) = 0$$

First derivative w.r.t. t = 0

$$-r(B(t)+L)+B'(t)=0$$

B(t) = a + bt

$$-r(a+bt+L)+b=0$$

$$-ra - rbt - rL + b = 0$$

$$-rbt = -b + ra + rL$$

$$t = \frac{-b + r(a+L)}{-rb}$$

$$\boxed{t = \frac{1}{r} - \frac{(a+L)}{b}}$$

Optimal harvest time, t, as a function of the parameters.

$$t^* = \frac{1}{r} - \frac{(a+L)}{b}$$

Optimal harvest time, t, as a function of the parameters.

a	b	L	r	t*
20000	1000	2000	3%	11
20000	1000	2000	4%	3

Optimal present value

$$\Pi^{*} = e^{-rt^{*}} (B(t^{*}) + L)$$

$$\Pi^{*} = e^{-rt^{*}} (a + bt^{*} + L)$$

Maximum or minimum?
Unique maximum or minimum?

The second order maximum condition is important and should be investigated.

More details:

http://www.lohmander.com/Kurser/SkogEkIntro/SEIntroWeb.html

A simple but typical deterministic plantation problem

More details:

http://www.lohmander.com/Kurser/SkogEkIntro/SEIntroWeb.html

A simple but typical deterministic thinning problem

More details:

http://www.lohmander.com/Kurser/SkogEkIntro/SEIntroWeb.html

We should optimize:

Seedlings or seeds?
Numbers of seedlings (or seeds)?
Species mix of seedlings (or seeds)?

When to harvest?
How much to harvest?
What species to harvest?
Quality, dimension or other selection criteria?

One important decision:

- **Continuous cover forestry with trees of different sizes and ages?**

or

- **Forestry with clear fellings and trees of the same age and size?**

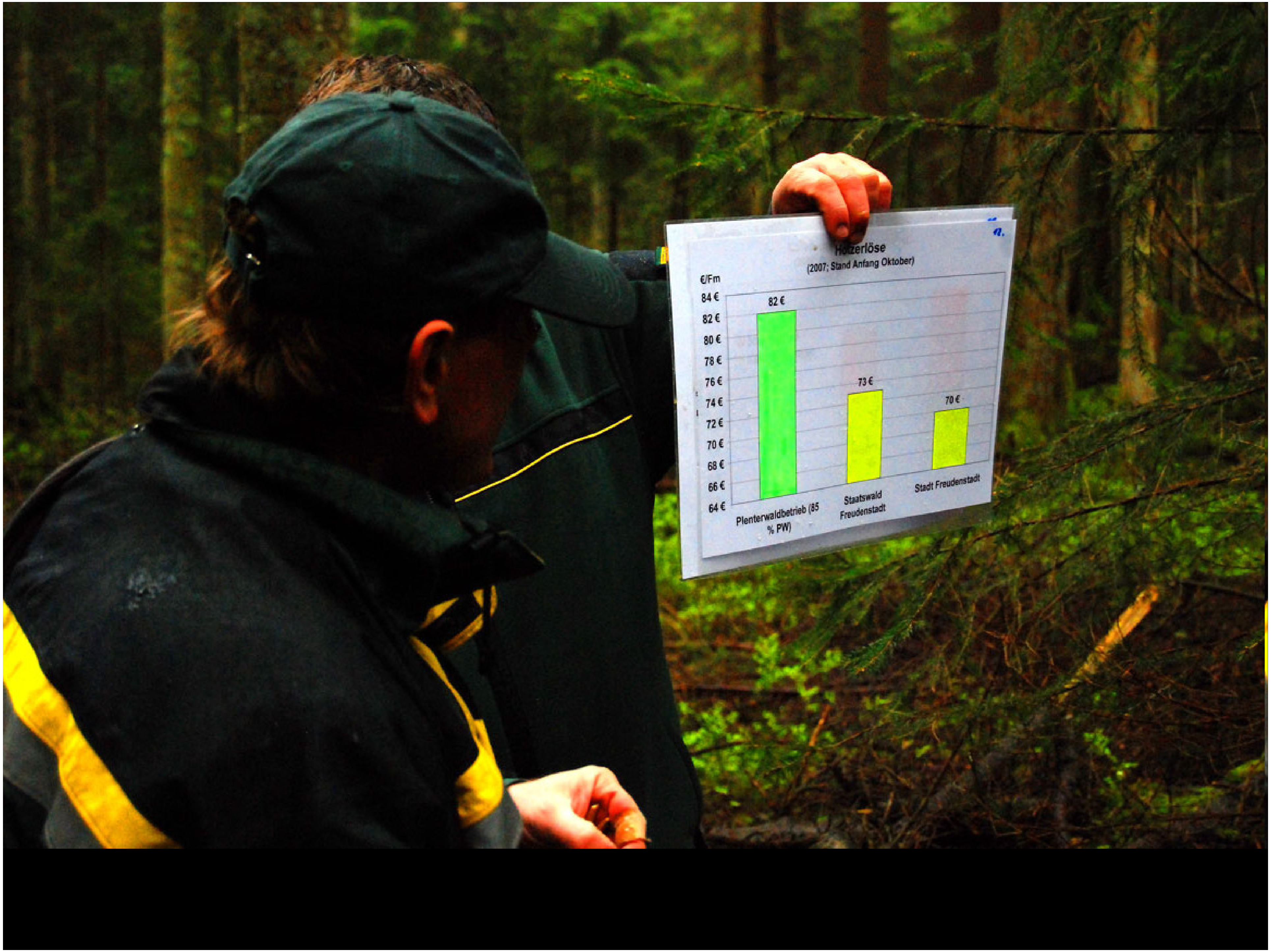
Read about these things and look at excursions:

http://www.lohmander.com/Kont11/Kont11.htm

http://www.lohmander.com/Arjeplog_2011/Arjeplog_2011.htm

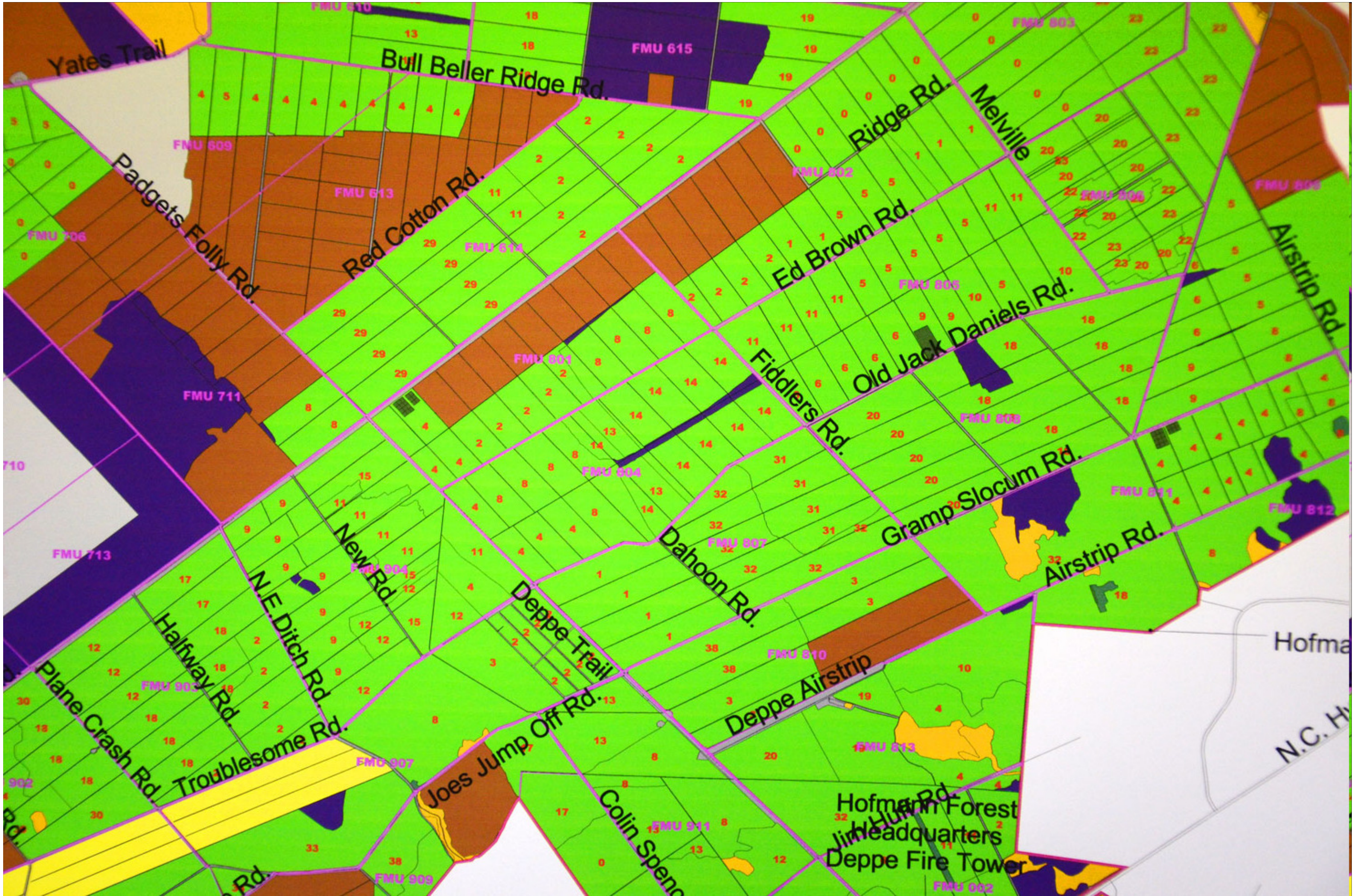
Arjeplog, Sweden, 2011

Schwartzwald, Germany, 2009



Holzerlöse
(2007; Stand Anfang Oktober)
€/Fm
84 €
82 €
80 €
78 €
76 €
74 €
72 €
70 €
68 €
66 €
64 €
82 €
73 €
70 €
Plenterwaldbetrieb (85 % PW)
Staatswald Freudenstadt
Stadt Freudenstadt

Neuchatel, Switzerland, 2009


Yates Trail
Bull Beller Ridge Rd.
FMU 615
FMU 809
Padgets Folly Rd.
FMU 613
Red Cotton Rd.
Ridge Rd.
Melville
FMU 802
FMU 614
FMU 706
Ed Brown Rd.
FMU 805
Old Jack Daniels Rd.
Airstrip Rd.
FMU 801
FMU 711
Fiddlers Rd.
FMU 808
FMU 804
Gramp Slocum Rd.
FMU 811
FMU 812
FMU 713
New Rd.
Dahoon Rd.
FMU 807
N.E. Ditch Rd.
Deppe Trail
Halfway Rd.
Airstrip Rd.
Hofma
FMU 810
Plane Crash Rd.
Deppe Airstrip
FMU 903
Troublesome Rd.
Joes Jump Off Rd.
FMU 907
N.C. H
Hofmann Forest
Headquarters
Deppe Fire Tower
Colin Spenc
FMU 909
FMU 002

NC, USA, 2011


PRENTICE
410-C

[redacted]


CANAL


610

SkogsNolia, Umea, Sweden, 2011


PONSSE


PONSSE
SuperGrip II
PONSSE

*We should **also optimize:***

Types of harvesters, forwarders and other machines?

Numbers of such machines?

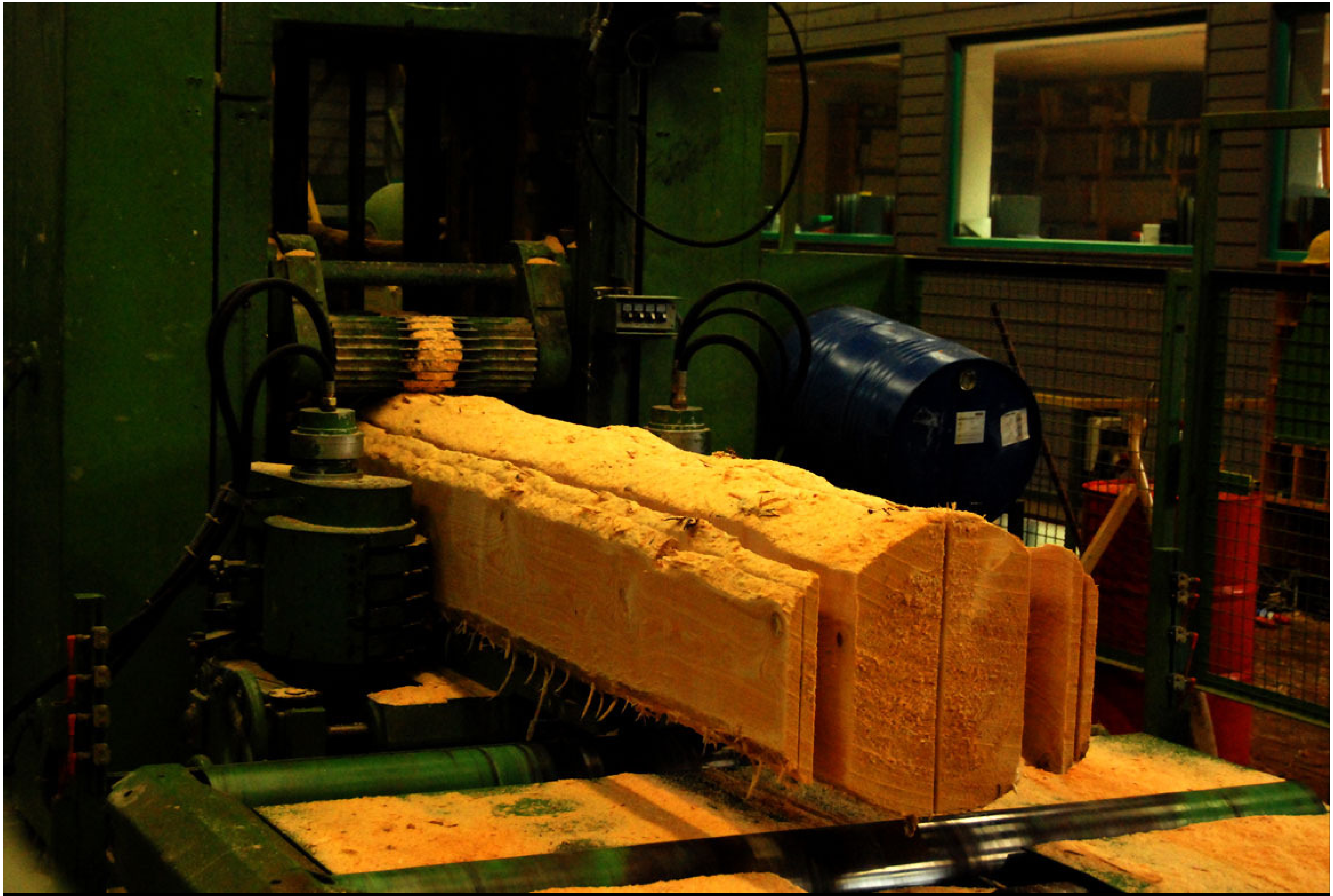
Sizes of harvest areas?

Infrastructure investments and maintenance?

Road and/or railroad network properties such as distances between roads, qualities of roads,…

Investments in labour, education,…

SCA Nordliner, Umea, Sweden, 2008



Baden- Wurttemberg, Germany, 2009

Dåva 2, Umea, Sweden, 2010

Skelleftekraft, Lycksele, Sweden, 2010

Roundwood stored at Dåva 2 CHP, Umeå, Sweden, 2010

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OPTIMAL RESULTS FROM DHINV
Software by
Peter Lohmander 2010

OPTIMAL TIME AND STATE DEPENDENT DECISIONS AND EXPECTED PRESENT VALUES

 t =   1
 i(t)   E(PV)    i(t+1)   DEC   CVIA   Entering Partial States
 ---------------------------------------------------------------
   1     34830.     5       1     0       0 0 0

 t =   2
 i(t)   E(PV)    i(t+1)   DEC   CVIA   Entering Partial States
 ---------------------------------------------------------------
   5     40538.     7       2     1       1 0 0

 t =   3
 i(t)   E(PV)    i(t+1)   DEC   CVIA   Entering Partial States
 ---------------------------------------------------------------
   7     45062.     8       3     2       1 1 0

 t =   4
 i(t)   E(PV)    i(t+1)   DEC   CVIA   Entering Partial States
 ---------------------------------------------------------------
   8     51517.     8                     1 1 1
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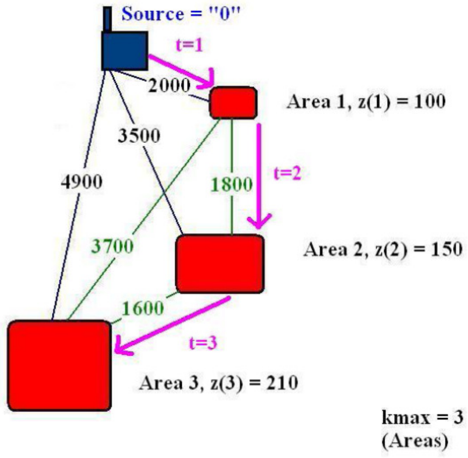


Electrical generator at Dåva 2 CHP, close to Umeå, Sweden, 2010.

We should ***also optimize:***

Forest industry investments and maintenance
(sawmills, pulp mills, combined heat and power stations, …)

…

When?
Where?
Capacities?
Properties?

…

Continuous cover forestry excursion, Bräcke, Sweden, 2011.

Optimization in forestry

- Motivation

Person A says:

”This forest management activity is the best”.

You should say:

”It is possible that A is right. With some combination of objective function, constraints and information structure, A may be right.”

”However, with most other combinations of objective function, constraints and information structure, A is probably wrong.”

”Please describe your objective function, constraints and information structure! Otherwise, I can not determine if your suggested forest management activity is the best (= optimal) !”

Optimization in forestry

- Principles

Always start with the problem definition!

Objective function, Constraints,

Information structure

Optimization in forestry

- Methods

We should determine the activitites in forestry that optimize the objective function with consideration of the relevant constraints and the information structure.

The optimal method is a function of the objective function, constraints and information structure.

Sometimes we may desire solutions in the form of general functions.

Sometimes we may need a concrete figure, a numerical solution.

$$\max \Pi = p_1 q_1 + p_2 q_2 + \ldots + p_n q_n$$

$$s.t.$$

$$a_{1,1} q_1 + a_{1,2} q_2 + \ldots + a_{1,n} q_n <= c_1$$

$$a_{2,1} q_1 + a_{2,2} q_2 + \ldots + a_{2,n} q_n <= c_2$$

....

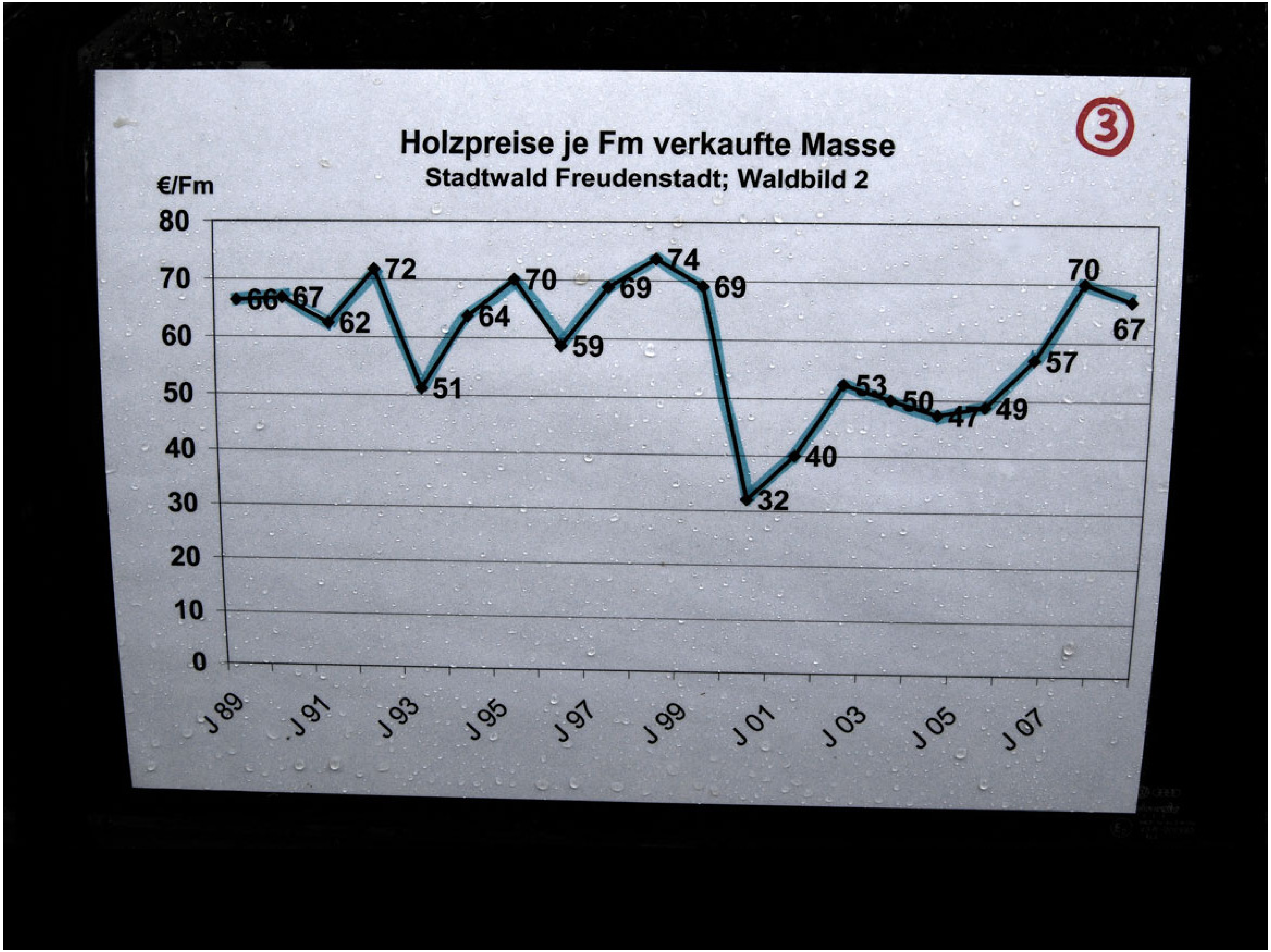
$$a_{m,1} q_1 + a_{m,2} q_2 + \ldots + a_{m,n} q_n <= c_m$$

A classical linear programming problem

Baden- Wurttemberg, Germany, 2009

Schwartzwald, Germany, 2009


FORSTVERWALTUNG



③
Holzpreise je Fm verkaufte Masse
Stadtwald Freudenstadt; Waldbild 2
€/Fm
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J 89
J 91
J 93
J 95
J 97
J 99
J 01
J 03
J 05
J 07

Optimization in forestry

- Methods

Do we have perfect information about future events?

The answer is generally NO. Most people pretend that perfect information exists, because it is easier!

Reality:

Stochastic prices of forest products,
Stochastic insect damages,
Stochastic fungi damages,
Stochastic storms and windthrows,
Stochastic forest fires,
...

Optimization in forestry

- Methods

MOSTLY (!!!), we do not have perfect information concerning all future events. Then, this method is necessary if we want to optimize activitites in forestry:

Stochastic dynamic programming (in discrete time and with discrete state space)

Special version:
Stochastic optimal control in continuous time (and with continuous state space).

Important observation:
Continuous time is not always more relevant. Furthermore, in continuous time and space formulations, the functional forms are often simplified to irrelevant functions.

$$W^*(i,t) = \max_{\substack{h \\ h \in H(i)}} \left(R(i,t,h) + e^{-r} \sum_{j=1}^{J} \tau(j \mid i,t,h) W^*(j,t+1) \right)$$

Stochastic dynamic programming (in discrete time and with discrete state space)

Min Z = $\sum_i w_i$

s.t.

$$w_i - \beta \sum_j \tau(j|i,u) w_j \geq R_{i,u} \quad \forall i,u\Big|_{u \in U(i)}$$

Sometimes, solutions to ***Stochastic dynamic programming problems (in discrete time and with discrete state space)*** can be calculated via linear programming. Then, commercial software can be used.

Stochastic optimal control in continuous time (and with continuous state space):

$$\int_t^{\infty} e^{-rt}(ku - pu^2 + fx - gx^2)\,dt$$

$$dx = (u - mx - n)\,dt + sx\,dz$$

Optimal CCS, Carbon Capture and Storage, Under Risk

The objective function is the total present value of CO2 storage minus CCS costs.

$$\int_t^{\infty} e^{-rt}(ku - pu^2 + fx - gx^2)dt$$

Discounting factor

u = control = CCS level

x = The total storage level of CO2

The controlled storage

A stochastic differential equation:

$$dx = (u - mx - n)\,dt + sx\,dz$$

Change of the CO2 storage level.

Control = CCS level.

Expected CO2 leakage.

The CO2 storage level is to some extent affected by stochastic leakage and other stochastic events.
Z = standard Wiener process.

Optimization in forestry

- Methods

Sometimes we may desire solutions in the form of general functions:

Then, we need general analyical methods to determine optimal objective function values and activitites, as more or less general functions of different parameters.

Optimization in forestry

- Methods

Sometimes we may need a concrete figure, a numerical solution.

Then, we can use numerical methods to determine the optimal objective function values and activitites.

Sometimes, commercially available software with mathematical programming subroutines can be used to solve the problems.

Sometimes, the easiest way is to create a new software.

Optimization in forestry

- **Results**

Now, different examples will follow!

Make sure that you know the:

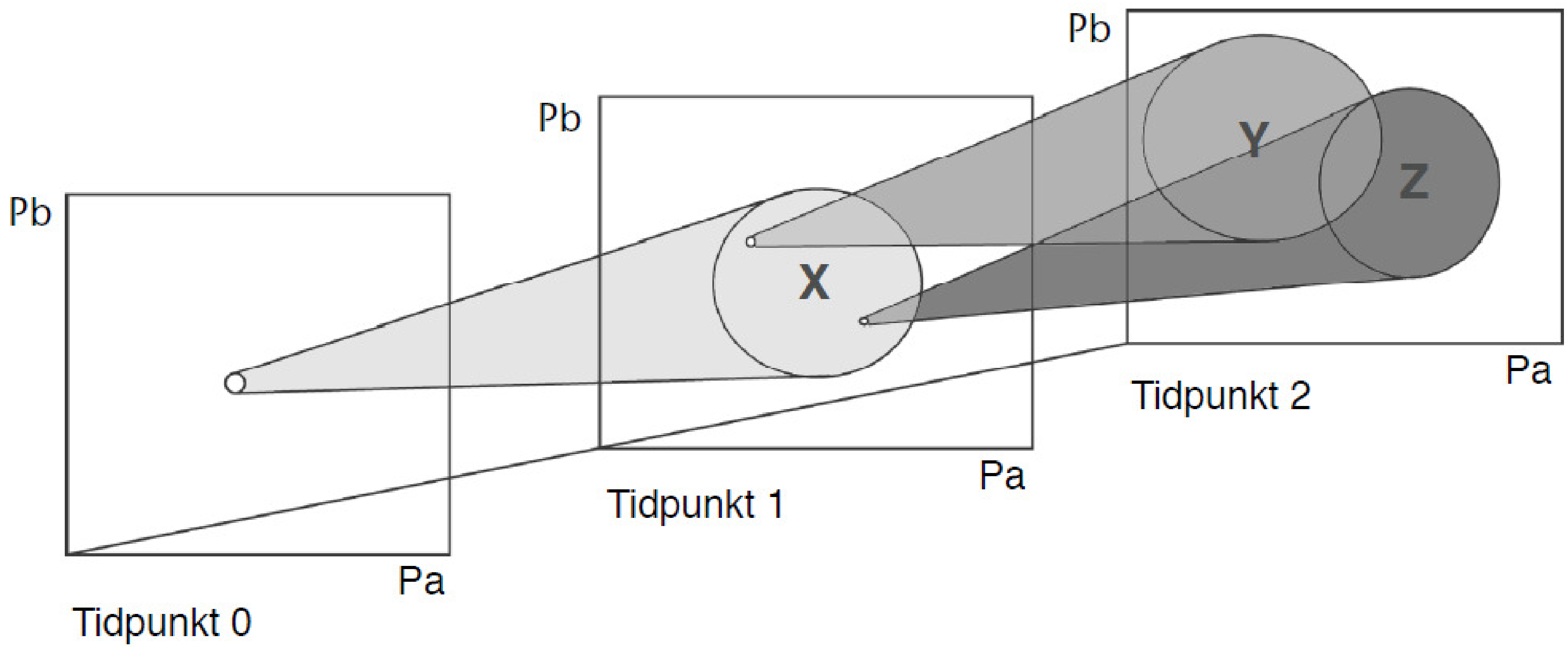
The objective function

The relevant constraints

The information structure

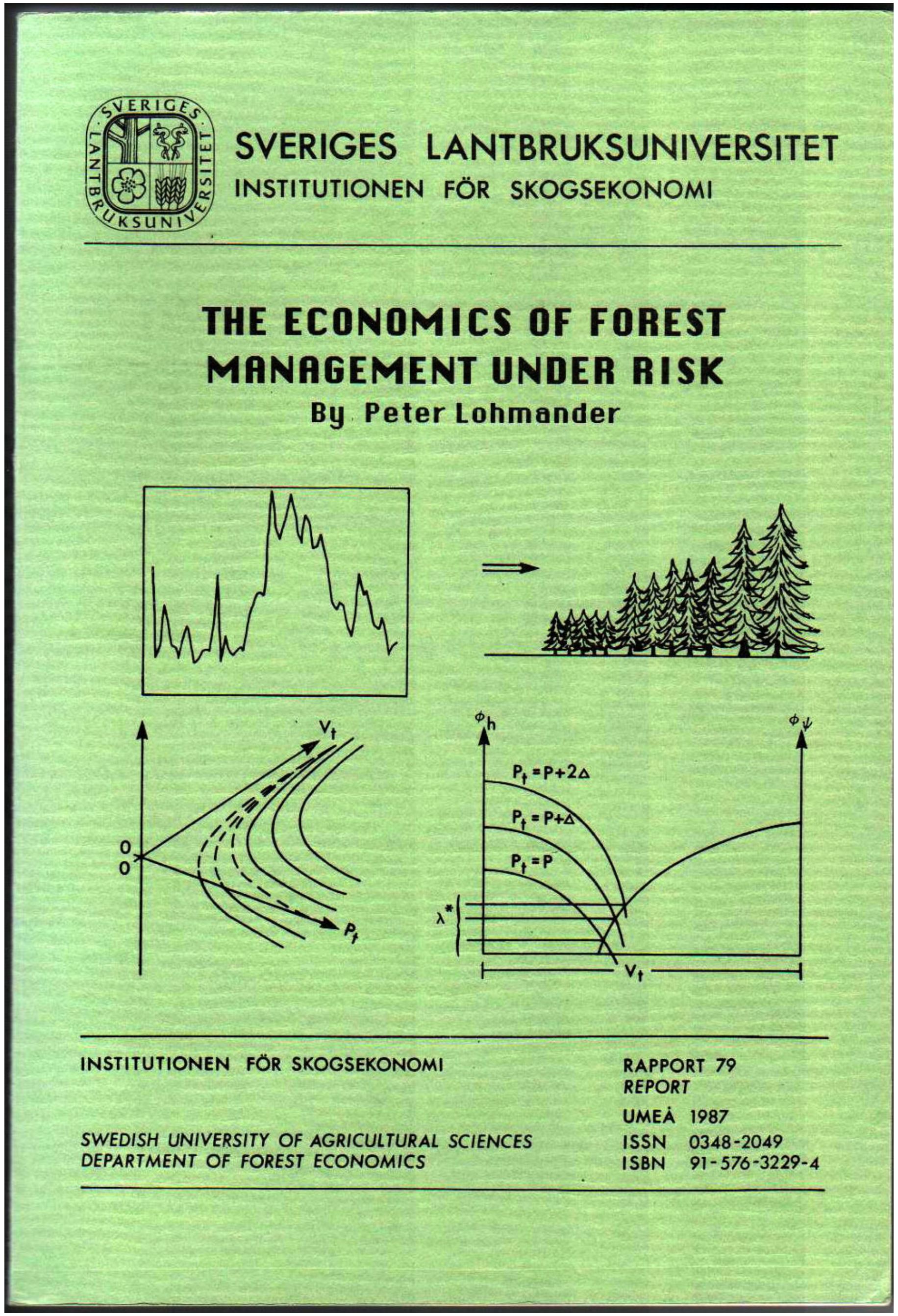
And the optimal forestry decisions!

Arjeplog, Sweden, 2011



Lohmander, P., Optimala beslut inför osäker framtid, FAKTA SKOG, SUAS, Nr 10, 2001

- http://www.slu.se/PageFiles/33707/2001/FS01-10.pdf


SVERIGES LANTBRUKSUNIVERSITET
INSTITUTIONEN FÖR SKOGSEKONOMI

THE ECONOMICS OF FOREST MANAGEMENT UNDER RISK

By Peter Lohmander

INSTITUTIONEN FÖR SKOGSEKONOMI

RAPPORT 79
REPORT

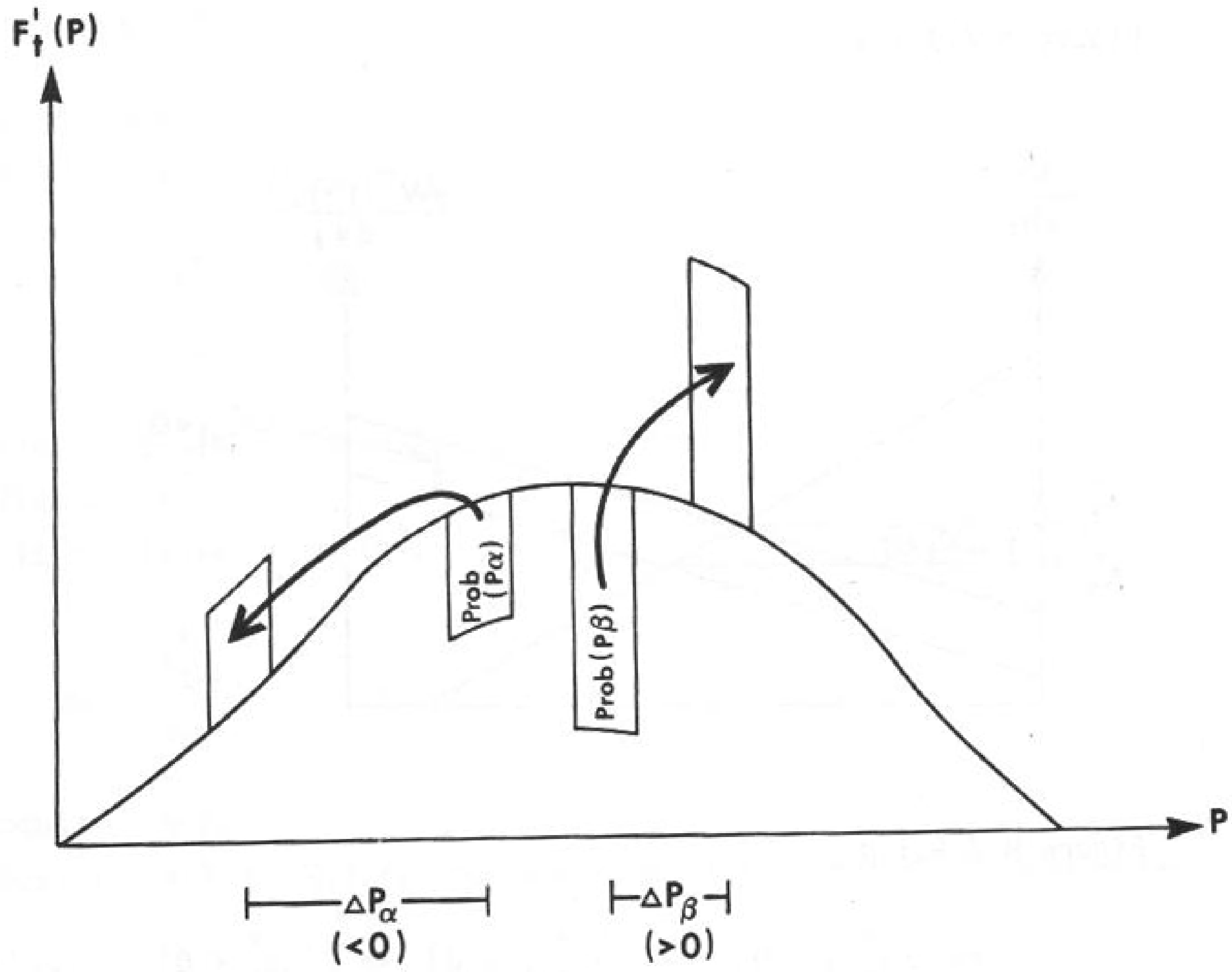
UMEÅ 1987

SWEDISH UNIVERSITY OF AGRICULTURAL SCIENCES
DEPARTMENT OF FOREST ECONOMICS

ISSN 0348-2049
ISBN 91-576-3229-4

Lohmander, P., The economics of forest management under risk, Swedish University of Agricultural Sciences, Dept. of Forest Economics,Report 79, 1987

(Doctoral dissertation) (Doktorsavhandling), 311p



A mean preserving spread (MPS) according to Rotschild and Stiglitz. "Probability density" is moved from the center of the distribution to the tails in such a way that the expected value of the stochastic variable is not changed.

Optimal continuous harvesting with stochastic prices and growth (Early)

Lohmander, P., Continuous extraction under risk, SYSTEMS ANALYSIS - MODELLING - SIMULATION, Vol. 5, No. 2, 131-151, 1988

Lohmander, P., Continuous extraction under risk, IIASA, International Institute for Applied Systems Analysis, Systems and Decisions Sciences, WP-86-16, March 1986

http://www.iiasa.ac.at/Admin/PUB/Documents/WP-86-016.pdf

http://www.lohmander.com/WP-86-016.pdf

Lohmander, P., The economics of forest management under risk, Swedish University of Agricultural Sciences, Dept. of Forest Economics,Report 79, 1987 (Doctoral dissertation) (Doktorsavhandling), 311p

Optimal pulse harvesting with stochastic prices and growth (Early)

Lohmander, P., Pulse extraction under risk and a numerical forestry application, SYSTEMS ANALYSIS -MODELLING - SIMULATION, Vol. 5, No. 4, 339-354, 1988

Lohmander, P., Pulse extraction under risk and a numerical forestry application, IIASA, International Institute for Applied Systems Analysis,
Systems and Decisions Sciences, WP-87-49, June 1987

http://www.iiasa.ac.at/Admin/PUB/Documents/WP-87-049.pdf

http://www.lohmander.com/WP-87-049.pdf

Lohmander, P., The economics of forest management under risk, Swedish University of Agricultural Sciences, Dept. of Forest Economics,Report 79, 1987 (Doctoral dissertation) (Doktorsavhandling), 311p

Optimal spatial dynamic harvesting with stochastic windthrows (Early)

Lohmander, P., Helles, F., Windthrow probability as a function of stand characteristics and shelter, SCANDINAVIAN JOURNAL OF FOREST RESEARCH, Vol. 2, No. 2, 227-238, 1987

Lohmander, P., Helles F., Skovstruktur og stormfald, En analyse af novemberstormen 1981, Dansk Skovforenings Tidskrift, No. 3, 1987

Lohmander, P., The economics of forest management under risk, Swedish University of Agricultural Sciences, Dept. of Forest Economics,Report 79, 1987 (Doctoral dissertation) (Doktorsavhandling), 311p

Lohmander, P., Ekonomiskt optimal avverkning med hansyn till stormfallningar, SKOGSBRUKETS EKONOMI, Skogsfakta Konferens, No. 11, 32-37, 1988

MORE OPTIMIZATION IN FORESTRY?

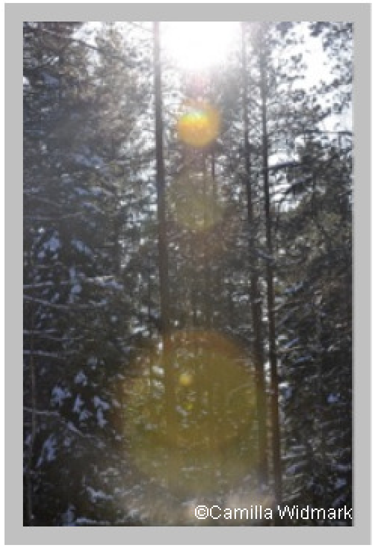
Welcome to PhD Courses in these areas!

Optimization in Dynamic and Stochastic Decision Problems (2011, ..?..)

Forest Economics (2012)

Applied Problem Solving via Computer Programming (2009,..?..)

Forest Economics



7,5 credits
PFS0057

Date:
2012-01-23 -- 2012-02-24

Language:
English

Prerequisites:
Suggested background: Most importantly, the course participants should be able to follow and understand the lectures. A general background in some quantitative area is suggested according to the three alternatives found below:
Alternative 1: Doctoral student and MSc och BSc in forestry (or jägmästare) including higher level courses in mathematical statistics and/or forest economics.
Alternative 2: Doctoral student and MSc or BSc in economics, management or business administration including higher level courses in quantitative analysis.
Alternative 3: Doctoral student with other background (such as engineering) including quantitative analysis and some economics and/or management.

Objectives:
After the course, the student should understand the fundamental principles of economic forestry, including the derivation of optimal decision rules in some situations. The student should be well aware of the underlying assumptions of the most typical decision rules, based on deterministic representations of reality. The student should be able to determine and understand in what ways the optimal decisions and decision rules change in case the underlying assumptions change within deterministic, single decision variable, forestry problems. The student should understand how optimal combinations of decisions can be determined in the presence of constraints caused by technology and laws. The student should also have some understanding of econometrics applied to forest economics, the consequences of information assumptions and different kinds of physical and economic disturbances, fundamental examples and applications of optimal stopping theory and more general stochastic multi period control in problems of forest sector relevance.

http://www-sekon.slu.se/~cala/forskarutbildning/forskarutbildning/PFS0057.html

http://www.lohmander.com/ODSDP_2011/ODSDP_2011.pdf

Applied Problem Solving via Computer Programming

http://www.lohmander.com/AppPro.pdf

Optimization in forestry

- Links to more information

http://www.Lohmander.com