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Accounting for urban trees

Revising the VAT03 compensation value model

Laura Lauwers
David N. Barton
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Anders Often
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NINA

Norwegian Institute for Nature Research

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CONTACT DETAILS

NINA head office	NINA Oslo	NINA Tromsø	NINA Lillehammer	NINA Bergen:
P.O.Box 5685 Torgarden	Gaustadalléen 21	P.O.Box 6606 Langnes	Vormstuguvegen 40	Thormøhlensgate 55
NO-7485 Trondheim	NO-0349 Oslo	NO-9296 Tromsø	NO-2624 Lillehammer	NO-5006 Bergen.
Norway	Norway	Norway	Norway	Norway
P: +47 73 80 14 00	P: +47 73 80 14 00	P: +47 77 75 04 00	P: +47 73 80 14 00	P: +47 73 80 14 00

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Abstract

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Urban trees provide a range of cultural, provisioning, regulating and supporting ecosystem services. Despite trees' important role in the urban environment, Norway lacks a system to value urban trees that is adapted to conditions in cities in Norway. Currently the VAT03 valuation system, developed by Randrup et al. (2003) in Denmark, is used without adjustment by tree appraisers in Norway. VAT03 is used to estimate a monetary compensation value for trees damaged or killed on both municipal and private land. Nevertheless, the method's application in Norway to date has lacked a standard for appraisal and calibration across valuation cases.

In this report we test the VAT03 method in Oslo and propose and test a more detailed documentation of tree characteristics. We evaluate the effect of adding more information about trees using uncertainty analysis. We demonstrate how VAT03 can be used for accounting of the total compensation value of trees at street, district and citywide level. We applied the VAT03 model to a random selection of 82 trees in the greenest streets of each city district in Oslo, Norway. The greenest streets were identified using Lidar scanning data of tree point densities. The greenest streets in each city district were chosen with an awareness raising purpose in mind.

We used the modelling tool Bayesian Belief Networks (BBN) to replicate the VAT03 formula structure as a network model. BBNs make it possible to carry out advanced uncertainty analysis on models with a hierarchical structure – such as VAT03 – and to assess the relative information value of different variables. The appraisal of the different variables in the VAT03 model and the proposal for a more detailed approach to documentation contribute to the process of revising the VAT system, adapting it to conditions in Norwegian cities.

Laura M. Lauwers, Scheldestraat 23, 9040 Gent (Belgium), lauralauwers4@gmail.com
David N. Barton, david.barton@nina.no
Stefan Blumentrath, stefan.blumentrath@nina.no
Anders Often, anders.often@nina.no
Megan Nowell, megan.nowell@nina.no

Sammendrag

Lauwers, L., Barton, D.N., Blumentrath, S. & Often, A. 2017. Accounting for urban trees. Updating the VAT03 compensation value model. NINA Report 1453. Norsk Institutt for Naturforskning

Bytrær gir en rekke økosystem-tjenester til byens befolkning, deriblant regulerende tjenester som luftrensing og vannhåndtering; de utgjør habitat for et mangfold av arter, som igjen er viktig for opplevelse av livskraftige grønne byrom. På tross av bytrærenes viktige rolle som grønn infrastruktur, mangler Norge et system for verdisetting av bytrær som er tilpasset lokale forhold i våre byer. I dag brukes systemet "verdsetting av trær' fra 2003 – kjent som VAT03 – som er utviklet av Randrup et al. (2003) i Danmark. VAT03 brukes til å beregne en kompensasjonsverdi for trær som ødelegges både på private og kommunal grunn. VAT03 brukes i dag av arborister uten tilpasninger til forhold i våre byer. Metoden mangler et system for dokumentasjon og kalibrering av ekspertskjønnet som utøves, basert på en sammenligning på tvers av et større erfaringsgrunnlag.

Her rapporterer vi en test av VAT03 i Oslo. Vi tester en mer detaljert dokumentasjon av tre-egenskaper som er grunnlag for verdivurderingene. Vi vurderer effekten av å legge mer detaljert informasjonen til VAT03 modellen ved hjelp av usikkerhetsanalyse. Vi demonstrerer hvordan VAT03 kan brukes i et grønt byregnskap og til formidling om verdien av bytrær på gateplan, per bydel og for byen som helhet. Vi har teste VAT03 på et tilfeldig utvalg på 82 trær i de grønneste gatene i Oslo. De grønneste gatene i Oslo ble definert som gatene med høyeste tetthet av gatetrær (utenom byens parker). De grønneste gatene ble valgt for å øke oppmerksomheten om bytrær og deres verdi i Oslo.

Vi brukte et modell verktøy – Bayesianske sannsynlighetsnettverk (BBN) – til å reprodusere formelen til VAT03 som et nettverk. Sannsynlighetsmodellen brukes til å utføre usikkerhetsanalyse på VAT03 for å vurdere informasjonsinnholdet i hver av variablene i forhold til verdien som beregnes. Usikkerhetsanalyse kan brukes som grunnlag for å revidere modellstrukturen. Forslaget vårt til mer detaljert dokumentasjon kan være grunnlag for arbeid med standardisering av VAT03 for norske byer.

Laura M. Lauwers, Scheldestraat 23, 9040 Gent (Belgium), lauralauwers4@gmail.com
David N. Barton, david.barton@nina.no
Stefan Blumentrath, stefan.blumentrath@nina.no
Anders Often, anders.often@nina.no
Megan Nowell, megan.nowell@nina.no

Contents

Foreword

The report is based on experiences with the VAT03 model for city tree valuation of trainee Laura Lauwers and senior research scientist David N. Barton at the Norwegian Institute for Nature Research (NINA). The data collection, data analysis and report writing was done over a 6-month period (August 2016 – January 2017) in Oslo. The study contributes to the exploration of accounting compatible valuation methodologies in the Experimental Urban Ecosystem Accounting (URBAN EEA). The study also contributes to methodologies that identify functional traits of city tree that determine ecosystem services and compensation values as part of the ENABLE project.

Anders Often contributed by introducing Laura Lauwers to the application of VAT03 in the field and helping with tree age assessments. He has provided all the uncertainty estimates on tree characteristics. Megan Nowell identified the greenest streets of Oslo using GIS. The report provides a revised version of a field evaluation form for city trees initially developed and tested in Oslo by two students, Friederike Stockmann and Anna Lisa Berge in 2015. Stefan Blumentrath implemented the extended VAT03 field evaluation form in a tree database for Oslo, which was the basis for the Bayesian belief network model of VAT03 discussed in this report.

We would like to acknowledge Tørres Rassmussen, Matthew Wells and Tore Næss from Bymiljøetaten (Oslo kommune) for actively following the research and giving good advice to improve the report and the related factsheets. They were always willing to meet and to discuss the progress of the research.

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19.12.2017 Laura Lauwers and David N. Barton

1 Introduction

Trees have a range of effects on the urban environment including air temperature, pollution removal, building energy use, water cycling and quality, ultraviolet radiation and wildlife (Nowak, 2017). City trees have a positive influence on human health, both physically and mentally (Donovan et al., 2013). City trees can have important historical and monumental values. A number of tools exist to consider the effects and needs of city trees in planning and management of urban greenspaces (Miller et al. 2015) including streetscapes (Vogt et al. 2017).

Oslo's population was 666,757 people on 1.1.2017 and was expected to grow to between 787 200 and 949 900 inhabitants by 2040[1]. In the years to come city trees will be competing for space in an increasingly dense urban environment. City trees are not well protected under Norway's Nature Diversity Act (Oslo Kommuneplan 2015). The City of Oslo's Municipal Plan for 2030 includes objectives to introduce regulations requiring protection of valuable vegetation and trees as part of land use regulation, introduce guidelines for conserving large trees and regulations for conservation and planting of trees along roads. Oslo Municipality's City Tree Strategy has as its main objective that "city trees shall contribute to well-being and public health. City trees as green infrastructure shall contribute to solving physical environmental problems. City trees shall promote biodiversity. City trees shall have a key architectural role in city spaces. City trees shall be healthy and safe." (Oslo Kommune Strategi for Bytrær 2016).

The NINA project Experimental Urban Ecosystem Accounting (URBAN EEA) aims to develop and test methodologies for mapping and valuing urban ecosystems, in order to demonstrate the usefulness of ecosystem accounting to municipalities in the Oslo Region. The project also aims to provide lessons learned from the urban application of ecosystem accounting as feedback to the further development of the UNSTAT's System of Environmental and Economic Accounts – Experimental Ecosystem Accounting (UN 2014). The project is testing mapping and valuation methods at different spatial scales and resolutions. City trees represent one of the ubiquitous green structures in urban and peri-urban ecosystems. Their mapping and valuation also presents methodological challenges in terms of identifying and valuing individual trees at spatial scales spanning a whole city. Low cost physical accounting of individual trees over whole municipalities has recently become possible with Lidar remote sensing. Oslo Municipality has conducted tri-annual Lidar scanning 2011-2013-2017. This will make it possible to account for detailed changes in city tree density, also on private land, and changing in natural capital value (Barton et al. 2015).

Furthermore, valuation methods in ecosystem accounting should be based on market prices to conform to standards for national environmental accounts. Oslo Municipality has adopted a method for calculating the value of trees (VAT) developed in Denmark by Randrup (2003). The VAT03 method estimates a monetary value for trees damaged or killed on municipal land, which is used as a basis for calculating compensation value and fines to responsible parties. Compensation value is based on observed prices for replacement and establishment cost of trees, adjusted for the quality of the tree and the quality of a selection of ecosystem services. This report contributes to the URBAN EEA evaluation of whether this 'quality adjusted replacement cost' methodology can conform to valuation standards in ecosystem accounting. In combination with physical inventorying of trees using Lidar, the VAT03 method offers a potentially practical monetary ecosystem accounting method at a city level.

Assigning trees a monetary value using VAT03 also facilitates urban planning and juridical decisions concerning the removal, replacement and protection of trees. Urban trees include street trees, trees on minor public urban localities, in gardens, in parks or trees belonging to an urban residual biotope such as a small forest. Oslo Municipality's Agency for the Urban Environment has thus far applied VAT03 using the same methodology as developed in Denmark. The VAT03 methodology relies heavily on expert judgement in determining tree quality and ecosystem services.

[1] SSB prognosis 1.1.2016. https://www.ssb.no/folkfram/

The original methodology does not demonstrate how to record observable characteristics of trees and their neighbourhoods in support of expert judgement. With the current report we therefore aim to update the methodology by testing observable qualities of trees and their correlation with expert value judgements. The aim is to contribute to a more verifiable valuation methodology in the local context of compensation value claims, as well as at the city level for ecosystem accounting.

The methodologies tested in this report focuses on trees in or near public spaces, typically:
1) Solitary trees
2) Small stands or groves of trees
3) Trees in avenues

Monetary valuation using VAT03 was designed to address common trees in public places. The report does not address, or addresses only partially:
1) Trees on private property. The report does assess trees on private property that are observable from the public streetscape.
2) Extraordinary trees, such as trees that harbour a special cultural significance, trees judged to possess rare or valuable botanical characteristics, endangered tree species, or that are an integrated part of protected cultural landscape. Where a case can be made for protecting a city tree using biodiversity or cultural heritage legislation, VAT03 may not be appropriate, or only partially address a tree's value
3) Ecosystem services. The VAT03 method only partially addresses ecosystem services.
4) Trees cultivated for production of timber, firewood or pulp
5) Trees in peri-urban forest managed for recreation (such as the municipally owned Oslomarka forest)
6) Bushes. In vegetation surveys low trees are distinguished from bushes with a canopy height of at least 2 meters. The examples calculated in this report are for trees taller than 5 meters as identified in Lidar surveys.

The VAT03 model was developed in response to the increased need for a generally accepted model in Denmark to give monetary value to trees (Randrup et al., 2003). The model was originally constructed as a tool to support court cases, but could also be used for planning situations and as an economic instrument for the protection of trees (Randrup, 2005). Determining a value for trees is challenging. Some ecosystem services, e.g. timber values, are more straightforward to assess economically than subjective and non-marketed qualities such as aesthetics. Tree valuations were previously based on timber value, which often led to a low value for urban trees (Randrup et al., 2003). A new monetary valuation method for urban trees was needed that included aesthetics and human appreciations (Randrup et al., 2003). A second reason for the construction of the VAT03 model was the large amount of money that is invested in urban trees (Randrup et al., 2003). The VAT03 model was originally based on the American tree risk assessment of ISA (International Society of Arboriculture), but was adapted for its use in Denmark.

Barton et al. (2015) implemented the VAT03 model of Randrup for calculating the total compensation value of trees in Oslo. To account for large variation in tree sizes, qualities and locations across the city, a modelling tool for handling uncertainty was used. Bayesian Belief Networks (BBN) uses a software provided by the Danish company Hugin Expert A/S. This network model also makes it possible to calculate tree compensation values by accounting for the subjectivity of expert assessments in terms of probabilities, rather than fixed values, of the different factors in VAT03. This report uses the network to model tree data obtained during a onemonth period of urban tree valuations in Oslo in 2016. The network model and assessment of more than 80 trees allow us to validate and discuss the underlying VAT03 equations.

The field data was also used to enrich the VAT03 field evaluation form (Form 1). This report provides a technical explanation of the use of the field evaluation form, and updates of the VAT03 calculation model to be compatible with the form. We also provide some recommendations for future development of the VAT method and its documentation. Inspired by the presentation in the original VAT03 manual we explain the updated evaluation form, supported by illustrations and an example of its application.

In summary, an urban tree valuation model for Oslo has a number of potential uses:

1) Calculating compensation value after a municipal tree is injured or killed, as a basis for calculating a fine or financial requirements for replacement of trees
2) Calculating financial guarantees for trees on a property to be developed, which can be placed in escrow account and released when a development is successfully completed without damaging protected trees.
3) Estimating the monetary value of the City of Oslo's natural capital, to be reported with other city accounts.

MONETARY VALUE ON TREES

P_n = Price, new tree
Locality: ………………………………………………… Sn = Stem circumference, new tree
Ss = Stem circumference, injured tree

……………………………………………………………………………. a: actual age (in years)
b: expected age (in years)
Species: ………………………………………………………… S_S = Stem circumference, injured tree
Average calculated with 2 decimals
Date: ……………………………………………………………… Sum approximated to nearest 100 kr.
If: a < b/2, then A = 1
No. of assessment:…………………………………

BASIC FACTOR(B)= E+(Pn/Sn)x(Ss–Sn)

……… kr. + (……… kr./……… cm) x (……… cm – ……… cm) = ……………… kr.

HEALTH FACTOR (S)	**PLACE OF GROWTH FACTOR (S)**
No. of points (0-5, five is best)	No. of points (0-5, five is best)
Roots………………………………………	Adaption,care…………………………………
Stem ………………………………………	Architecture……………………………………
Main branches…………………	Aesthetic……………………………………………
Minor branches………………	Visibility…………………………………………
Twigs and buds………………	Environment………………………………………
Sum / 25………………………………	Sum /12.5………………………………

AGE FACTOR (A) = square root [(b-a)2/b]

VALUE OF THE TREE = B x S x P x A

………… kr. x ………………… x ………………… x …………………… = ______________ kr.

Form 1. *The original VAT03 evaluation form for valuing urban trees, designed by Thomas Randrup (2003).*

2 Guidelines

This section explains the revised evaluation form with examples of notes and/or pictures that support the expert evaluation of the tree characteristics. The evaluation form aims to facilitate tree evaluations and minimize the variation across different evaluators.

The form is divided into three parts:
1) General: locality and tree measurements
2) Health factor
3) Location factor

2.1 Revised field evaluation form

The form presented in this section is an improved version of an initial form tested by Stockmann and Berge in 2015 (Appendix 1).

Name:		**Street:**
Locality:	**Part of an avenue**	**Tree Species:**
Street	Yes	**Tree survey number:**
Square	No	**Date:**
Unbuilt Area	**Part of a forest**	**Number of stems:**
Small park	Yes	at a hight of ....m divided into ....stems
Large park	No	**Stem cirumference:**
Urban residual biotope	**Single Tree**	Min: Max:
Small forest	Yes	**Actual age:**
Riparian area	No	Min: Max:
Dry area	**Tree number within tree**	**Actual height:**
Slope, degree:	**height radius:**	<5m 5-10m 10-15m 15-20m 20-25m 25-30m >30m
0-10 10-30 >30		**Crown area (diameter)**
Small hill		Min: Max:

Health Factor			
Roots	**Lower Stem**	**Stem**	**Main branches**
Excavation / Exposure	Rot / Fungi	Rot / Fungi	Deadwood / Dying of branches
Soilbulge and Soilrupture	Hollow	Hollow	< 1/3
Rot	perhaps	Injury of the bark	1/3 - 2/3
perhaps	Injury / Injuries	crack / cracks	> 2/3
Girdling root	Dog urination	Sloping Postion	Scars
Ants/insects	Parasites	Angle:	Big
Injury / Injuries	Epicormic shoots	Fork	Small
Soil conditions		Resin flow	Parasites
Limited volume		(Proliferation)	Epicormic shoots
Saturated		Parasites	Cracks
Shallow		Epicormic shoots	
Compacted		Missing terminal shoot	
Scars		**Value: 0 - 1 - 2 - 3 - 4 - 5**	**Value: 0 - 1 - 2 - 3 - 4 - 5**
Loads/pavement over roots:	**Minor branches**	**Twigs and buds**	
……%	Deadwood/Dying of branches	Dead	
Root formation restricted	< 1/3	a little	
In one direction	1/3 - 2/3	a lot	
More directions	> 2/3	Injury of leaves	
Value: 0 - 1 - 2 - 3 - 4 - 5	Big Scars	Injury of buds	
	Parasites	few leaves	
		some twigs are cut	
	Value: 0 - 1 - 2 - 3 - 4 - 5	**Value: 0 - 1 - 2 - 3 - 4 - 5**	
SUM / 25:			

Location Factor			
Adaption, care	**Architecture**	**Aesthetic**	**Environment**
Stress factors:	fits together with tree	residence within tree height distance	darkens the area
De-icing salts	doesn't fit together		Habitat function for:
Trampling Mechanical compression	Contact with built structures	impressive because of	
Few light restricted infiltration area ....%	Traffic:	height	protection against
		growth form	wind
	Road demarcation	aesthetic in a group	dust
Air pollution	Blocking road visibility		sun
Old / historically / cultural important tree	no visible link to architecture		rain
			noise
Site changes:	**Value: 0 - 1 - 2 - 3 - 4 - 5**	**Value: 0 - 1 - 2 - 3 - 4 - 5**	**Value: 0 - 1 - 2 - 3 - 4 - 5**
None	**Visibility**		
Grade change	public space		
Site change	private space		
Changed hydrology	distance from public space:		
Root cuts			
Value: 0 - 1 - 2 - 3 - 4 - 5	frequency		
	high		
	medium		
	few		
	visible from:		
	all directions		
	.....direction(s)		
	Value: 0 - 1 - 2 - 3 - 4 - 5		
SUM / 12.5:			
Notes / Complements:			

Form 2*. Revised field evaluation form for VAT03 model*

2.2 Tree measurements

The first part of the field evaluation form concern a description of the location, and the size of the tree. Tree stem circumference and age are key to determining that basis value of the tree. Stem circumference is measured 1m above the ground. Figure 1 illustrates different cases and the recommendations in the original VAT03 (Randrup et al. 2003) for where to measures circumference.

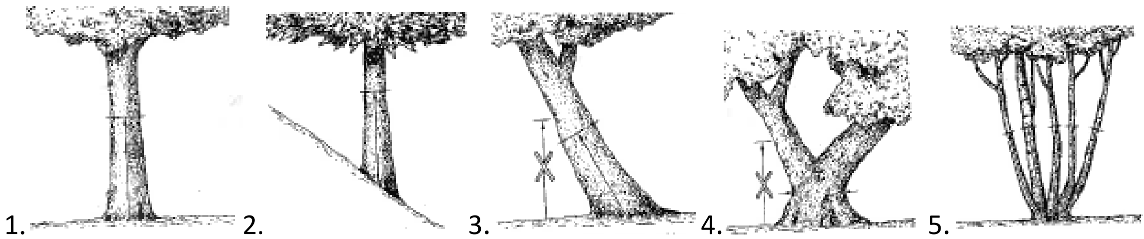


Fig. 1. Illustration of stem circumference measurement in different cases. Adapted from VÆRDISÆTNING AF TRÆER. Assessing monetary value on ornamental trees (Guidelines) (p. 11), by T. B. Randrup et al., 2003.

1) Strait stem growing on plain surface: The circumference is measured 1 m above ground.
2) Strait stem growing on a slope: The circumference is measured 1 m above ground, measured upward from the middle of the stem.
3) Sloping stem. The circumference is measured 1 m up along the stem, not at the height of one meter
4) The stem is divided in to stems below the height of one meter. The circumference in measured below the point of the divide.
5) A multi-stemmed tree. Each stem is measured at the height of 1 meter. The circumference is taken to be the sum of all stems.

Different methods exist for determining the actual age of a tree:

1) Derived from historical data on the tree's location.
2) Estimated from the number of annual produced whorls of branches, particularly for conifers.
3) Estimated from the diameter multiplied by the trees' growth factor. For some tree species these growth factors are registered in tables, though not for urban trees (Appendix 2).
4) Appendix 3 provides tree age estimations for Oslo.
5) Count the rings on exposed stump, only applicable for felled trees.
6) Use an increment bore to obtain a sample of the tree rings.

2.3 Illustrations of tree characteristics used in the evaluation form

After defining the locality of the tree, the health of the tree is assessed. The health is judged separately for the root, stem, main branches, small branches, twigs and buds. Unless otherwise indicated all photos were taken by Laura Lauwers.

Health Factor
Roots
Excavation / Exposure
Soilbulge and Soilrupture
Rot
perhaps
Girdling root
Ants/insects
Injury / Injuries
Soil conditions
Limited volume
Saturated
Shallow
Compacted
Scars
Loads/pavement over roots:
......%
Root formation restricted
In one direction
More directions
Value: 0 - 1 - 2 - 3 - 4 - 5

2.3.1 Roots

An optimal root condition is observed when the roots have enough space to grow in all directions, they are completely covered with soil and no health issues are observed. The projection of tree crown circumference (assuming a perfect round crown) on the ground can serve as a good reference for a sufficient root area. Within this area, the absence/presence of the different features affecting the tree health can be checked. The features describing the root health are illustrated below and where needed an explanation was added:

Excavation/Exposure

The exposure of the roots due to natural processes (i.e. removal of top soil due to changing water level) or human induced processes (i.e. excavation of the roots).

Girdling root

A root that grows around the stem base of the tree.

Soil bulge and soil rupture

Deformation of the soil/pavement due to the strong growth of the roots in the top soil.

Rot

A rot on the roots is often not directly observed because excavation would be needed, but its presence can be derived from severe injuries on the roots, the base of the stem, the stem or an overall unhealthy appearance of the tree.

Injury

Root injuries can only be assessed for exposed roots. Exposed roots are often more vulnerable for mechanical damage or damage caused by insects or other organisms.

Loads/pavement over roots

An example of heavy loads (stones) on the roots. The root growth becomes restricted when the roots are covered by pavement or heavy loads. This coverage will also influence the water movement into the root zone. Photo: Hanne Gjesteland Wells

Scar

Root scars can only be assessed for exposed roots. Scars are a result of the tree's healing process after being injured. The size of the scars can tell how good the tree copes with damage and thus may be indicative for the tree's vitality.

Restricted root formation

An example of how the root formation is restricted in all directions to create enough space for parking spots.

Saturated soil condition

Soil saturated due to poor drainage, high water table, excess irrigation, or location in a low area. May be saturated now or have a history of inundation. (ISA, 2013)

Shallow soil condition

Rooting depth limited by one or more factors including high water table, rock ledges, compacted layers, or underground structures such as parking decks. (ISA, 2013)

Compacted soil condition

Soil is severely compacted, limiting the depth, spread, and distribution of the root system, often caused by trampling or mechanical compression

2.3.2 Stem

An optimal stem is straight and shows no health issues. A sloped stem is often the cause of reduced light infiltration at one side of the tree. This results in a higher pressure on the other side of the tree, which makes the tree less stable during harsh weather conditions (heavy snow or wind). The different features that can affect the stem health are illustrated below and explained where needed.

	Lower Stem		Stem
	Rot/ Fungi		Rot / Fungi
	Hollow		Hollow
	perhaps		Injury of the bark
	Injury / Injuries		crack / cracks
	Dogs uric		Sloping Postion
	Parasites		Angle:
	Epicormic shoots		Fork
			Resin flow
			(Proliferation)
			Parasites
			Epicormic shoots
			Missing terminal shoot
			Value: 0 - 1 - 2 - 3 - 4 - 5

Rot

A rot is directly visible if the rot/fungus grows on the tree stem. The presence of a rot can indirectly be observed if black rotted parts of bark are present on the bark.

Hollow

Hollowness is often an indication of a great tree age, but can also be caused by stress, for example attacks of insects or fungi.

Epicormic shoots

A shoot that grows out of dormant buds on the stem under certain conditions (i.e. damage of higher tree parts). Can also occur on branches.

Crack

Cracks can develop when extreme temperature changes occur or as part of the trees' development process.

Fork

Deep crack between two or more stems making the tree vulnerable to crack in two under harsh weather conditions

Resin flow

An extensive flow of resin on the trunk or a brownish resin are an indication of health problems.

Proliferation

A rounded outgrowth on a tree trunk or branch, often covered with small knots from dormant buds.

Missing leading stem

Due to topping the tree lacks a single leading stem. This can result in the development of new leading stems. If these stems are not balancing each other, the tree can become more vulnerable to crack under extreme weather conditions.

Parasite

A parasite species benefits from the host by extracting nutrients and/or water. Example: *Yponomeuta evonymella* Karlstrøm W. (2010). *Mindre heggspinnmøll i år*. Available at: https://www.trollheimsporten.no.

Sloping position

The slope angle is the angle between the stem and the perpendicular line on the ground.

2.3.3 Main Branches and Minor Branches

The health value for the main and minor branches is at first determined by the amount of dead wood. The other features indicating health issues are similar to those described for the stem. Therefore, no separated explanation for these features is given in this section.

Main branches			
	Deadwood / Dying of branches		
			< 1/3
			1/3 - 2/3
			> 2/3
	Scars		
			Big
			Small
	Parasites		
	Epicormic shoots		
	Cracks		
Value: 0 - 1 - 2 - 3 - 4 - 5			

Minor branches			
	Deadwood/Dying of branches		
			< 1/3
			1/3 - 2/3
			> 2/3
	Big Scars		
	Parasites		
Value: 0 - 1 - 2 - 3 - 4 - 5			

2.3.4 Twigs/Leaves/Buds

Regarding the foliage, the density of leaves gives a first impression of health issues. Further the size of leaves (i.e. compared to expected size of leaves on a vital individual of the actual species), the colour of the leaves and attacks by insects give a sign of health issues. These health issues are combined in one feature "injury of leaves". Injury of buds can refer to infected, proliferated or dry buds. Examples of bud and leaf infections are illustrated below.

Twigs and buds			
	Dead		
			a little
			a lot
	Injury of leaves		
	Injury of buds		
	few leaves		
	some twigs are cut		
Value: 0 - 1 - 2 - 3 - 4 - 5			

Injury of the buds

Dry buds, damaged buds, or in this case bud proliferations are indications of unhealthy buds.

Injury of the leaves

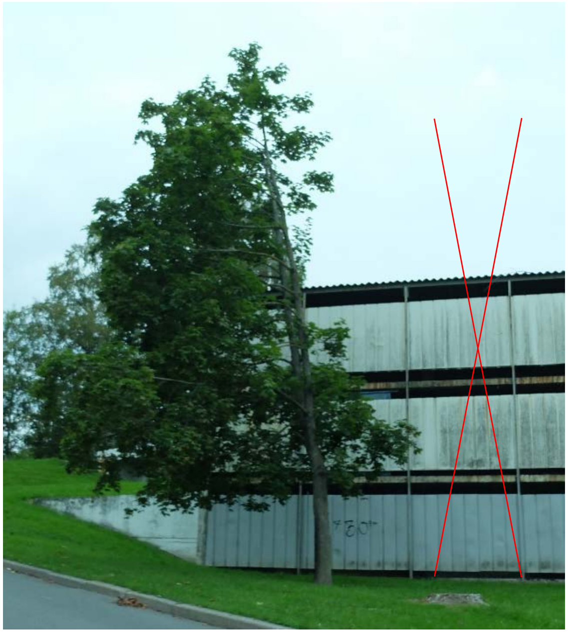
Discoloration, feeding damage, or in this case an infection (by mildew) are indications for unhealthy leaves.

2.4 Explanation of the tree characteristics: Location Factor

2.4.1 Adaptation and care

If a tree stands in a suboptimal environment containing factors that might cause stress for the tree, for example strong air pollution or severe changes in its environment (for example construction works), a tree might show signs of reduced vitality. In this case the value for “adaptation and care” will be lower than 2.5. In contrast, a tree might be very resistant to suboptimal conditions and not show any health problems, in this case these conditions and the value will be higher than 2.5.

Restricted infiltration area



The red cross indicates the location of a cut tree that used to restrict the light infiltration at one side of the present tree resulting in a deformed crown.

Location Factor		
Adaption, care		
	Stress factors:	
		De-icing salts
		Trampling Mechanical compression
		Few light restricted infiltration area ....%
		Air pollution
	Old / historically / cultural important tree	
	Site changes:	
		None
		Grade change
		Site change
		Changed hydrology
		Root cuts
Value: 0 - 1 - 2 - 3 - 4 - 5		

Trampling

The passage of bikers and pedestrians can damage exposed roots and create a compact soil condition

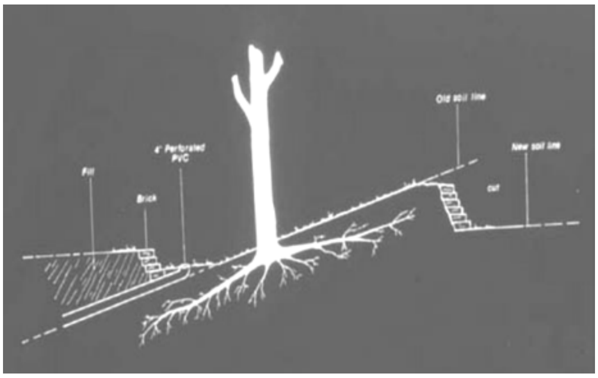
Mechanical compression

The passage of vehicles can damage exposed roots, and create a great pressure on the roots.

Air pollution

Air pollution is the introduction of particulates, photochemical oxidants and ground-level ozone, carbon monoxide, sulphur oxides, nitrogen oxides, and lead into Earth's atmosphere (“Criteria Air Pollutants”, 2016). Air pollution may come from anthropogenic or natural sources. In addition, dust and the effect of ventilation systems are included as a form of air pollution in this manual. The effect of air pollution on trees can be derived from the presence of lichens and mosses. A high diversity of both groups might indicate a good air quality.

Grade change



This includes both soil cuts and fills within the dripline of the tree. Grade change is usually associated with construction around the tree but may also be caused by landslides or other natural actions (Smiley et al., 2006).

Site clearing

Site clearing is normally the first operation to be done when the alignment has been set out. It is done in order to prepare the site for the excavation and formation of the road. It consists of the removal and disposal of all bushes, trees, fences and loose boulders as well as the grass within the top soil (ILO, 1981)

Changed hydrology

Hydrological changes or water level changes in the soil can be a result of water management projects (e.g., drainage, river bed regulations) or extensive groundwater use to meet increasing agricultural demands.

Root cuts

Caused by human intervention, often during a construction period.

2.4.2 Architecture

Architecture refers to the relation between the tree and a neighbouring building or to the broader architectural plan. Within an architectural plan for example of a whole street, the choice and location of the trees can be in accordance with the way the buildings are standing. Further, a tree can have an important indicative function in the traffic. If there is no link between the tree and the architecture, a neutral value of 2,5 is given.

Architecture		
	fits together with tree	
	doesn't fit together	
	Contact with built structures	
	Traffic:	
		Road demarcation
		Blocking road visibility
	no visible link to architecture	
Value: 0 - 1 - 2 - 3 - 4 - 5		

Tree fits together with architecture

The trees in Sageneparken (Oslo) are planted in a way that reflects the architectural plan of Sagene kirke (seen in the back).

Integrated in traffic demarcation

The trees are part of a roundabout, clarifying further the direction for the cars. The presence of trees within traffic marks often results in a decrease in driving speed.

Blocking road/traffic mark visibility

A tree can also have a negative effect on traffic, for example the branches/leaves of a tree may cover a traffic light or demarcation.

Risk for built structures

The extensive growth of a tree can damage structures, a common example is the rupture and bulge of the pavement by the roots.

2.4.3 Aesthetics

Assigning an aesthetic value to a tree is subjective. A tree can be aesthetic when it has a symmetrical growth form, an attractive coloration, an impressive height or also a non-symmetrical but remarkable growth form. The scheme describing the tree's aesthetics is very compact. An extension of the scheme is suggested in the discussion section. The pictures below give some examples of trees that are aesthetic for different reasons.

Aesthetic		
	residence within tree height distance	
	impressive because of	
		height
		growth form
	aesthetic in a group	
Value: 0 - 1 - 2 - 3 - 4 - 5		

Aesthetic in a group

Impressive height

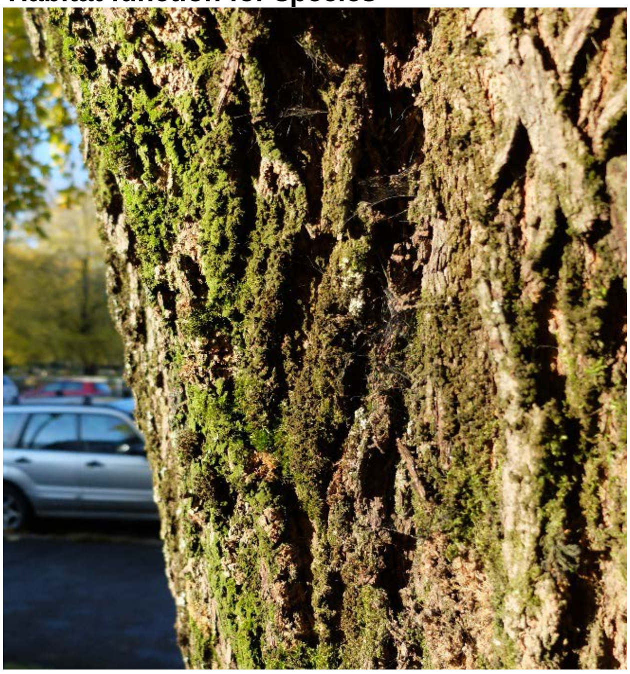
Impressive growth form

2.4.4 Environment

The category “Environment” is a single variable in VAT03, capturing essentially what we described as ecosystem services in the introduction. At the time of writing VAT03 in 2003 – ecosystem service concepts were still not widely used in urban forestry. Two examples are illustrated below. A number of ecosystem services of trees are not described in the revised evaluation form. Ecosystem services are considered further in the discussion section.

Environment		
	darkens the area	
	Habitat function for:	
	protection against	
		wind
		dust
		sun
		rain
		noise
Value: 0 - 1 - 2 - 3 - 4 - 5		

Habitat function for species



Often different lichen species, mosses and bird nests can be observed.

Protection against the sun

2.4.5 Visibility

Visibility is influenced by the performance of the tree, the presence/absence of neighbouring trees or other structures and by the amount of people that would notice the tree. In busy streets, the visibility can be high due to the passage of people, even though the tree is not that tall. In more quiet streets, the visibility of a tree can still be high due to its position and appearance in the street. Examples of a tree with high visibility and a tree with lower visibility are illustrated below.

Visibility		
	public space	
	private space	
		distance from public space:
	frequency	
		high
		medium
		few
	visible from:	
		all directions
		.....direction(s)
Value: 0 - 1 - 2 - 3 - 4 - 5		

High visibility

Lower visibility

2.5 Estimating a score for each factor

2.5.1 Health factor (H)

For each tree element (Roots, Stem, Main branches, Minor branches, Twigs/Leaves/Buds) a value from 0-5 is given, where 5 represents the optimal situation and 0 the worst case situation where the tree is dead or clearly dying (Randrup, 2005). The maximum value 5 can be used as a reference for perfect health - all characteristics under the Health factor have a negative influence on the tree health. We lowered the value in proportion to the number of negative characteristics or the severity of the negative characteristics that were encountered for the tree. For example, the roots will obtain a factor 5 if the roots are not exposed, no signs of rot are observed, the roots are not restricted in any direction and no heavy loads or pavement cover the roots because no negative characteristics were encountered (Fig. 2). In contrast, if the roots are strongly restricted and the tree shows clear health issues, like scars or a rot infection, the value will be 0 (Fig. 3). If the roots show either only structural problems (restrictions, heavy loads) or health problems the value will be between 0 and 5. Uncertainty in scoring may be expressed by indicating a score range, e.g. 2-3. The same idea applies for the other tree elements. The sum of the 5 ratings is divided by the maximum amount 25, which results in a normalised value for the health factor between 0 and 1. The evaluation is experience-based and becomes more consistent after a period of practicing on different tree examples.

Fig. 2. *Although a building is close to the tree, the tree has enough space for its roots. Further signs of health problems can not be observed.*

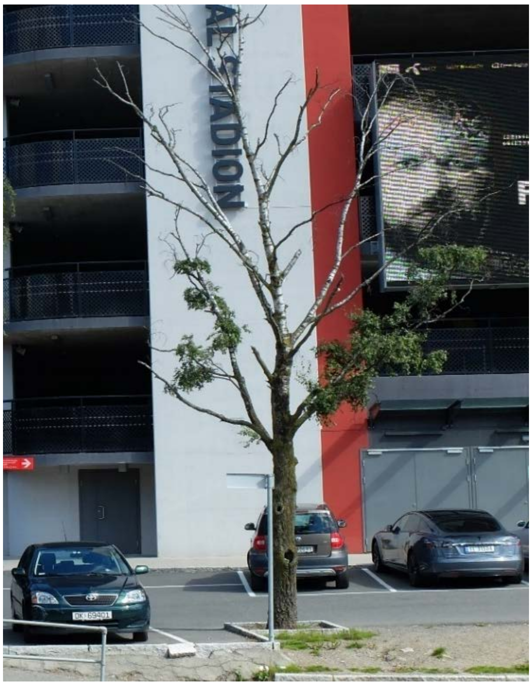


Fig. 3. *The roots are restricted in every direction and clear signs of a root rot are observed.*

For each element of the location factor (Adaptation/Care, Architecture, Aesthetics, Environment, Visibility) a value from 0-5 is given. With other factors the score 5 represents the highest positive contribution and 0 no contribution to the value of the tree. A challenge with the location factors is that the score is now a contribution of the tree to the quality of the location, rather than an attribute of the tree. A tree can add to or detract from the quality of the location, meaning that the 0-5 scale requires a different interpretation. There is no guidance on this issue in the original VAT03 methodology. In this study we used a mid point value 2.5 as a starting point. The value will increase if positive characteristics are selected, and decrease if negative characteristics are selected. For example a tree that has an aesthetic growth form, upgrades the area with its presence and is highly visible. It will obtain a higher value for the location factor (Fig. 4) than a tree that has a deformed crown due to cuttings, rather degrades the area with its presence and has a low visibility (Fig. 5). The valuation of the location factor is perhaps the most vulnerable to subjective judgement, but should become more consistent after a period of practice.

For further discussion of the value of individual trees versus trees in a stand, we also record the number of trees within the tree height radius from the stem.

Fig. 4. A tree with a naturally shaped crown, enough space for the roots to grow. Part of a small park and close to busy road (Sognsveien), resulting in a high visibility

Fig. 5. *Tree top cut off, resulting in a poor aesthetic quality. Note also, restricted root space and a low visibility.*

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3 VAT03 Formulae

The VAT03 model (Randrup 2005) uses the following formula to calculate a monetary compensation value for a tree:

$$\textbf{Tree value} = B \times H \times L \times A$$

where B is a Base Value, H is tree health, L is tree location, and A is tree age.

The Base value (B)

$\mathbf{B} = E + ((S_d - S_n) \times (P_n/S_n))$

where E is establishment costs of the new tree, Pn is the price of the new tree and Sn is the size of the new tree. New tree refers to a new tree of the same species with a size of 18 to 20 cm stem circumference measured at 1m above ground. Sd is the size (stem circumference at 1m aboveground) of the assessed tree. Establishment costs should include removal of the damaged tree, replacement of substrate and rooting medium, purchase of a new tree (18-20 com diameter), planting, aeration and watering systems, re-estabilishment of surface materials and tree maintenance and maintenance guarantee for 5 years.

For the valuation examples in this report we used a range of quotes for total costs for the establishment of new trees as obtained by the Oslo Agency for Urban Environment. These quotes did not include tree removal. The quotes obtained were not for complex or constrained planting situations. Consequently the base value estimated in our examples is likely to be a conservative value. Further, there is concern that the quoted prices obtained in a typical tree appraisal, or in a bidding round between entrepreneurs, do not represent the actual realised expenses.

The Health Factor (H) $\mathbf{H} = (r + t + mb + mib + t)/25$

where r = roots (0–5), t = trunk (0–5), mb = main branches (0–5), mib = minor branches (0–5), and t = twigs, leaves and buds (0–5). The sum of the 5 ratings is divided by 25, which results in a normalized value for the health factor between 0 and 1.

The Location Factor (L) $\mathbf{L} = ac + ar + ae + v + e/12.5$

where ac = adaptation and care (0–5), ar = architecture (0–5), ae = aesthetics (0–5), e = environment and v = visibility (0–5). The sum of the 5 ratings is divided by 12.5, which results in a normalized value for the location factor between 0 and 2.

The Age Factor (A) **A** = the square root of ((Ae – Aa) × 2)/Ae

where Aa = actual age of the tree and Ae = expected age of the tree.

The functional form of the age factor leads to maximum value in the middle of a trees expected life, with value falling with increasing age towards the trees expected lifetime. This means that qualities of older trees such as habitat for biodiversity must be addressed elsewhere, such as in the environment criteria.

The VAT03 method weights the tree's contribution to location characteristics twice as much as the different health traits of the tree itself. No justification for this weighting is given in the original VAT03 methodology. However, the combined functional form of the health, location and age factors were determined for the VAT03 methodology such that the range of values were deemed a reasonable incentive in cases of damaged trees in Danish (Randrup 2005). The formula has since then become a convention for calculating compensation value of trees in both Denmark and Norway.

4 Valuation of individual trees – examples

In this section, 4 examples of tree valuations of urban trees in Oslo are given, using evaluation form 2, discussed in the previous section. At first two low value trees are discussed, followed by two high value trees.

4.1 Low value tree – example 1

Date: 21/09/2016
Street: Refstadsvingen
Locality :
Unbuilt area
Single Tree
Tree number within tree height radius: 1

Tree Species: *Betula pendula*

Tree measurements:
Number of stems: 1
Stem circumference: 80 cm
Actual age: ca 20 years
Actual height: 5-10 m
Crown area: 4.5 m

Fig. 6. *Two silver birch, Betula pendula in Refstadsvingen, Oslo. Right tree: low valued tree, assessed on 21th of September 2016.*

Health Factor:
Roots: 1
Trunk: 1
Main branches: 1
Minor branches: 1
Twigs: 1

SUM/25 = 0.2

Location Factor:
Adaptation, care: 2.5
Architecture: 2
Aesthetic: 1
Environment: 3
Visibility: 3

SUM/12.5 = 0.92

Tree Value = 26 834 NOK

The silver birch, *Betula pendula*, illustrated right in Fig. 6 shows clear signs of reduced vitality. The presence of a rot was derived from big scars at the base and higher parts of the stem and the presence of a lot of ants at the base. The scars are deep and stem hollowness might be expected. A great amount of the bark is dead and cracks are present. Most branches and twigs are dead. Further, the buds showed proliferations. The combination of these features resulted in a low health factor. The tree scores low for aesthetics and architecture as the tree contributes negatively to the public space and in relation to the building (in the opinion of the lead author). The tree caries a lot of different lichen species and caries a bird nest, giving on balance a positive outcome for the relation of the tree with its environment.

Date: 21/09/2016
Tree Species*: Pinus syl-*
vestris
Street: Hans Nielsen Hauges gate
Locality :
Street
Single Tree
Tree number within tree height radius: 1

Tree measurements:
Number of stems: 1
Stem circumference: 120
cm
Actual age: 50-60 years
Actual height: 15-20 m
Crown area: 4 m

4.2 Low value tree – example 2

Fig. 7. *Scots pine, Pinus sylvestris in Gladvollveien, Oslo. Medium valued tree, assessed on 21th of September 2016.*

The Scots pine, *Pinus sylvestris,* illustrated in Fig. 7, shows clear signs of health problems. The roots are very restricted, in several directions, with the pavement covering a big part of the roots. The bark is clearly infected (Fig. 8) and is probably the reason behind the presence of a great scar on the stem, where bark is absent (Fig. 9). Some main branches are dead and a lot of branches are missing over the total stem. This might be a trace of earlier light restriction, but the tree does not seem to have developed new branches yet, resulting in a low adaptive value. The tree experiences trampling stress from pedestrians and more importantly from cars entering and leaving the entranceway of the nearby house. The tree is impressive because of its height and is part of several pines that were saved along the street during the construction of this neighbourhood. The tree has a neutral relation towards its environment as it does not have any clear function or negative impact on the environment. The tree is very visible, but as the street has a low pedestrian passage, the visibility received a medium score.

Health Factor:	**Location Factor:**
Roots: 2	Adaptation, care:
1	
Trunk: 2	Architecture: 2.5
Main branches: 2	Aesthetic: 3
Minor branches: 3	Environment: 2.5
Twigs: 3	Visibility: 3.5
SUM/25 = 0.72	SUM/12.5 = 1.28

Tree Value = 56 906 NOK

Fig. 8. *Infection of the bark.*

Fig. 9. *Great scar with damaged bark on the trunk.*

4.3 High value tree – example 3

Date: 20/09/2016
Street: Hans Nielsen Hauges gate
Locality :
Large park
Single Tree
Tree number within tree height radius: 5

Tree Species*: Pseudotsuga menziesii*

Tree measurements:
Number of stems: 1
Stem circumference: 110 cm
Actual age: ca 40 years
Actual height: 15-20 m
Crown area: 4 m

Fig. 10. *Douglasfir, Pseudotsuga menziesii in Hans Nielsen Hauges gate, Oslo. Left tree: high valued tree, assessed on 20th of September 2016.*

Health Factor:
Roots: 4
Trunk: 5
Main branches: 5
Minor branches: 4.5
Twigs: 4.5
SUM/25 = 0.92

Location Factor:
Adaptation, care: 2
Architecture: 4
Aesthetic: 5
Environment: 4
Visibility: 5
SUM/12.5 = 1.6

Tree value = 189 031 NOK

The Douglas fir, *Pseudotsuga menziesii,* illustrated left in Fig. 10, shows no signs of reduced vitality. The root formation is potentially restricted in the direction of the pavement, but seems not to affect tree health. Some minor dead branches and twigs are observed. However, the overall health factor is high. Figure 11 shows some trampling stress due to passing bikers and pedestrians and therefore the category “adaptation, care” has a lower rate. The Douglas fir is not common in Norway and is very impressive because of its height. This results in a good fit with the neighbouring high building, whereby people have a good view on the tree instead of the busy street from their balcony. Further, the tree is part of a natural designed screen to isolate the park from the street. The tree provides protection against the sun for people waiting at the bus stop and might please the people with its good smell.

Fig. 11. Showing the base of the Douglas fir under potential trampling stress.

4.4 High value tree – example 4

Date: 20/09/2016 Street: Bjørnstjerne Bjørnsons plass **Locality :** Unbuilt area Single Tree Tree number within tree height radius: 0	Tree Species*: Acer platenoides* **Tree measurements:** Number of stems: 1 Stem circumference: 180 cm Actual age: 60-70 years Actual height: 15-20 m Crown area: 12 m

Fig. 12. *Norwegian maple, Acer platenoides in Bjørnstjerne Bjørnsons plass, assessed on 20th of September 2016.*

Health Factor: Roots: 4 Trunk: 5 Main branches: 5 Minor branches: 4.5 Twigs: 4.5 SUM/25 = 0.92	**Location Factor:** Adaptation, care: 2 Architecture: 4 Aesthetic: 5 Environment: 4 Visibility: 5 SUM/12.5 = 1.6

Tree value = 130 954 NOK

This Norwegian maple is somewhat restricted in its root formation by the pavement, but this does not seem to affect the tree health. Due to the presence of a building, one part of the tree has a restricted light infiltration, resulting in some dead minor branches and twigs. However, the crown is not deformed, indicating a good adaptation towards this light restriction. The tree has a high architecture value because two Norwegian maples were symmetrically planted at both sides of the building, as part of the architectural plan. The tree is very aesthetic due to its well-formed crown with purple shades in the leaf coloration.

5 Valuing trees at street level using VAT03

In this section we apply the VAT03 model to assess an estimated compensation value for the trees on the greenest streets in Oslo. We first use the standard set of variables in the VAT03 model, without the additional information of the revised Form 2. In Section 7 we evaluate the effects of including further detail from Form 2 in the model.

We randomly selected five trees on each of the greenest streets based on a Lidar inventory, by dividing each street segment into 5 equidistant lengths. The sampling intensity per street varied because of different street lengths. Appendix I describes how the tree inventory for Oslo was used to select the greenest streets. If the selected tree was not present on the ground, we evaluated the nearest tree (>5m) instead. The tree age was estimated with help of researcher Anders Often.

The valuation form was implemented in a Bayesian Belief Network using the program Hugin Expert. A Bayesian Belief Network is a graphical modelling tool that organizes the knowledge about a domain, in our case the compensation value of urban trees, as a network of conditionally dependent variables (Fig. 16). This tool is useful for research areas where appraisal uncertainties exists. Each variable can be represented by a probability distribution among the different states of the variables.

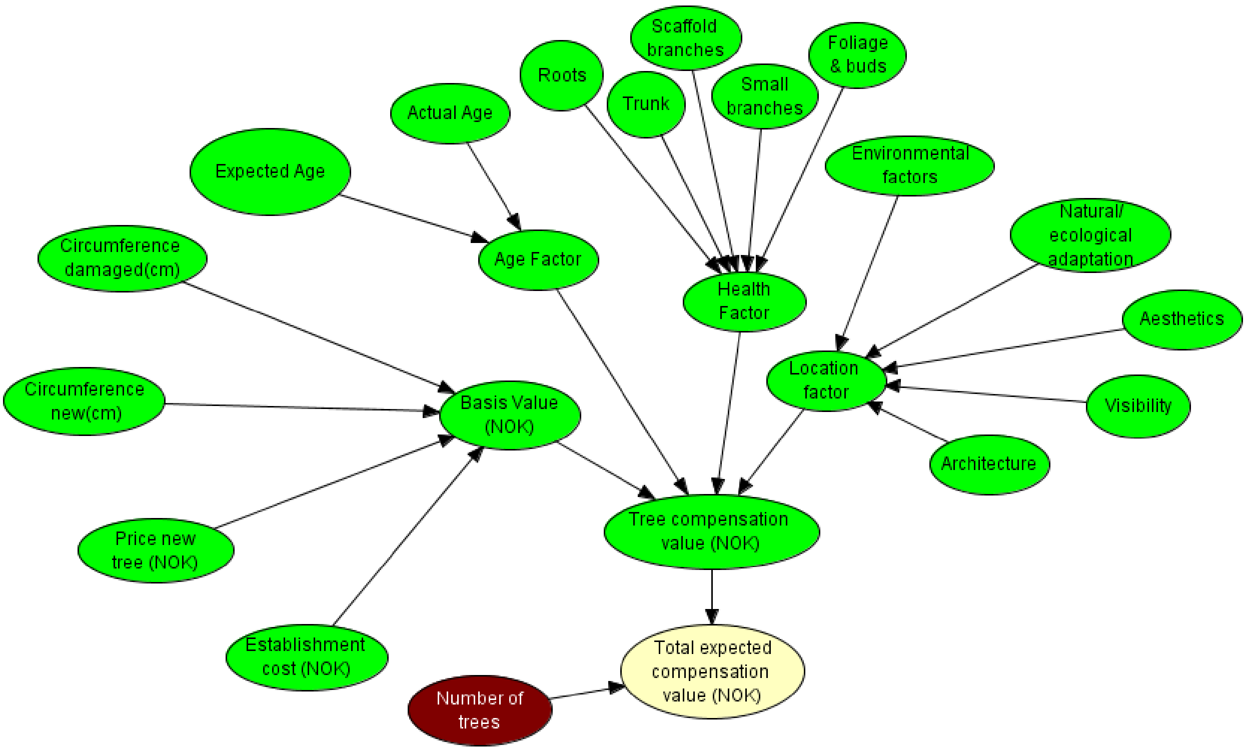


***Fig. 16.** A network model of the VAT03 valuation equation.*

The equations of the VAT03 model were implemented for each factor (Location, Health, Age and Basis) in the network. Each of the 5 trees were evaluated on site by applying the basic VAT03 variables in Form 2 ("Guidelines"), and shown in Figure 16. The states (intervals) of the circumference, price and establishment costs of a new tree were derived from information provided by a range of entrepreneur bids received by Oslo's municipality. Instead of choosing a single or average price we ran all model calculations with equal probability of a new tree price (kroner 3500 - 6500/tree) and establishment costs (40 000-70 000 kroner/tree).

When all states of each factor in the VAT03 method are given an equal probability – i.e. we are selecting at random across all trees – the expected tree compensation value is 49 697 NOK. We used the model to calculate the expected compensation value of each of the 5 sampled trees on the greenest streets, the mean compensation value expected on each street and the expected total compensation value for all trees on that street (Fig. 17 and Table 1). Based on the trees sampled, the trees in Prinsens gate (Sentrum) have the highest mean compensation value: 134 692 NOK. Gladvollveien (Nordstrand) has the lowest mean compensation value for trees: 69 682 NOK (Table 1).

Table 1. *An overview of the mean compensation value and the total compensation value for the trees ofeach street, based on the random sample of trees in Oslo's greenest streets (excluding public parks).*

City district	Street	Total Compensation Value (NOK)	Mean Compen-sation Value (NOK)
Grorud	Vestbyveien	20 499 984	83 570
St. Hanshaugen	Bjørnstjerne Bjørnsons plass	12 516 471	99 639
Stovner	Stovnerbakken	21 314 935	114 031
Vestre Aker	Ris skolevei	20 499 998	102 334
Søndre Nordstrand	Nordåsveien	21 527 408	97 871
Ullern	Noreveien	20 500 000	116 241
Alna	Edvard Munchs vei	20 607 096	87 623
Frogner	Bygdøynesveien	20 504 792	94 167
Nordre Aker	Sognsveien	846 981 613	109 682
Nordstrand	Gladvollveien	20 569 540	69 682
Sentrum	Prinsensgate	2 289 767	134 692
Østensjø	Byggveien	2 050 000	99 817
Bjerke	Refstadsvingen	20 499 650	103 254
Gamle Oslo	Konows gate	20 499 985	76 023
Grünerløkka	Fjordgløttveien	2 049 843	111 909
Sagene	Hans Nielsen Hauges gate	20 500 000	110 089

6 Extending VAT03 with detailed tree characteristics

The more detailed documentation of tree characteristics in Form 2 raises the question of whether all the information included in the form is really necessary as support for valuation. In this chapter we evaluate the extent to which detailed tree characteristics explain the variables in VAT03.

The VAT03 variables “Roots, Trunk, Main Branches, Minor Branches, Twigs & Buds, Adaptation & care, Architecture, Aesthetics, Environmental factors and Visibility” are referred to in this section as “criteria”. The tree characteristics describing the criteria in detailed (for example: “visible directions” within the criterium “visibility”) will be referred to as “features”. A network sub-model was created for each set of features in Form 2 describing each VAT03 criteria (See Form 2, in section “Guidelines”). These subnetworks were then evaluated with data from the sampled trees on the greenest streets in Oslo, using the statistical modelling software Hugin Expert. The software identifies the features that best explain each VAT03 criteria, as well as visualise correlations between the features themselves. This can be useful information in thinking about which features are the most important in explaining tree compensation value, and the possible effects of leaving some features out of the VAT03 model.

An example of a subnetwork explaining the VAT03 variable “roots”(r) is shown in Fig. 19 in the left hand panel. In the right hand panel the features which best explain root health – based on the field assessments – are listed in order. This is a so-called “value of information” analysis.

The subnetwork shows that besides the correlation between the features and the category “Roots”, some correlations exist between the features themselves. For example, the percentage of pavement that is covering the roots is correlated with a limited volume for the root system and restricted root formation in more directions. Another correlation exist between an exposed root system and injuries observed on the roots on one hand and a shallow soil condition on the other hand. A last correlation is found between the presence of a root rot and the presence of insects. All these correlations seem logical.

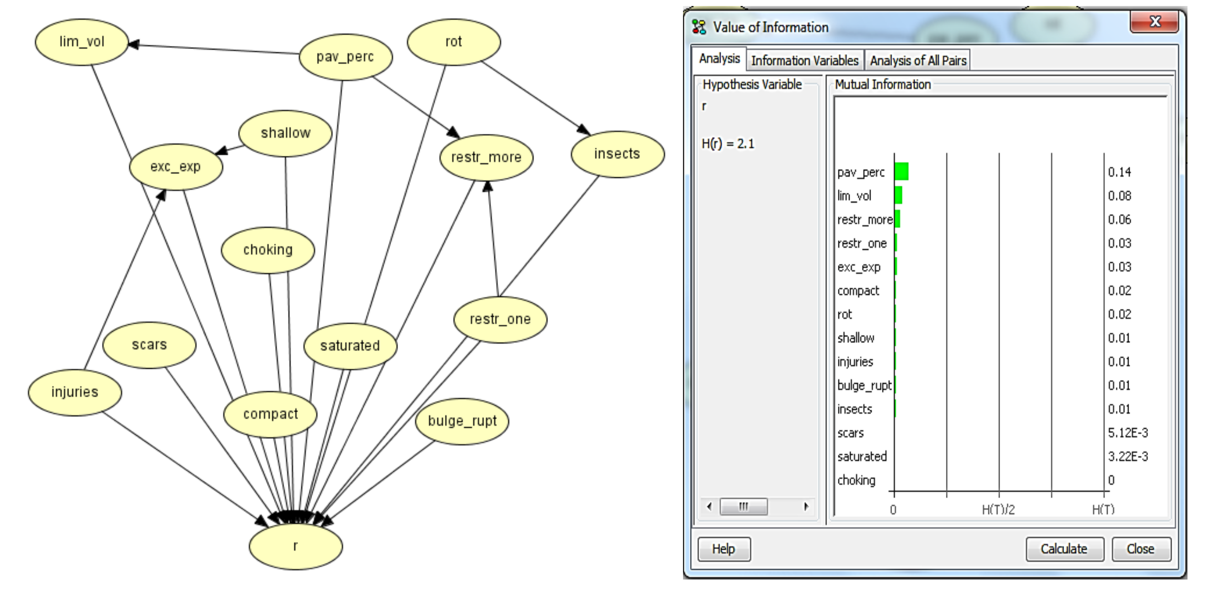


Fig. 17. *Subnetwork for the category “Roots” obtained via Learning wizard (left). Value of Information analysis for the features describing “Roots” (right). Appendix 7 shows the analysis for the other VAT03 criteria.*

The value of information analysis shows that the features giving the most information to the value devoted to the category “Roots” are: percentage pavement on the roots, limited volume and restricted root formation in more directions. Value of information analysis checks, which features within the criterum “Roots” influenced most the decision by the tree appraisor to give a certain value (0-1-2-3-4-5) to the roots. Appendix 7 shows the analysis for the other VAT03 criteria. The more features are included in the documentation of VAT03 the greater the complexity of the methods and the greater the information cost for appraisal in the field. We therefore constructed an extended the VAT03 network model with only the three most informative features for each criterium. (Fig. 18) ..

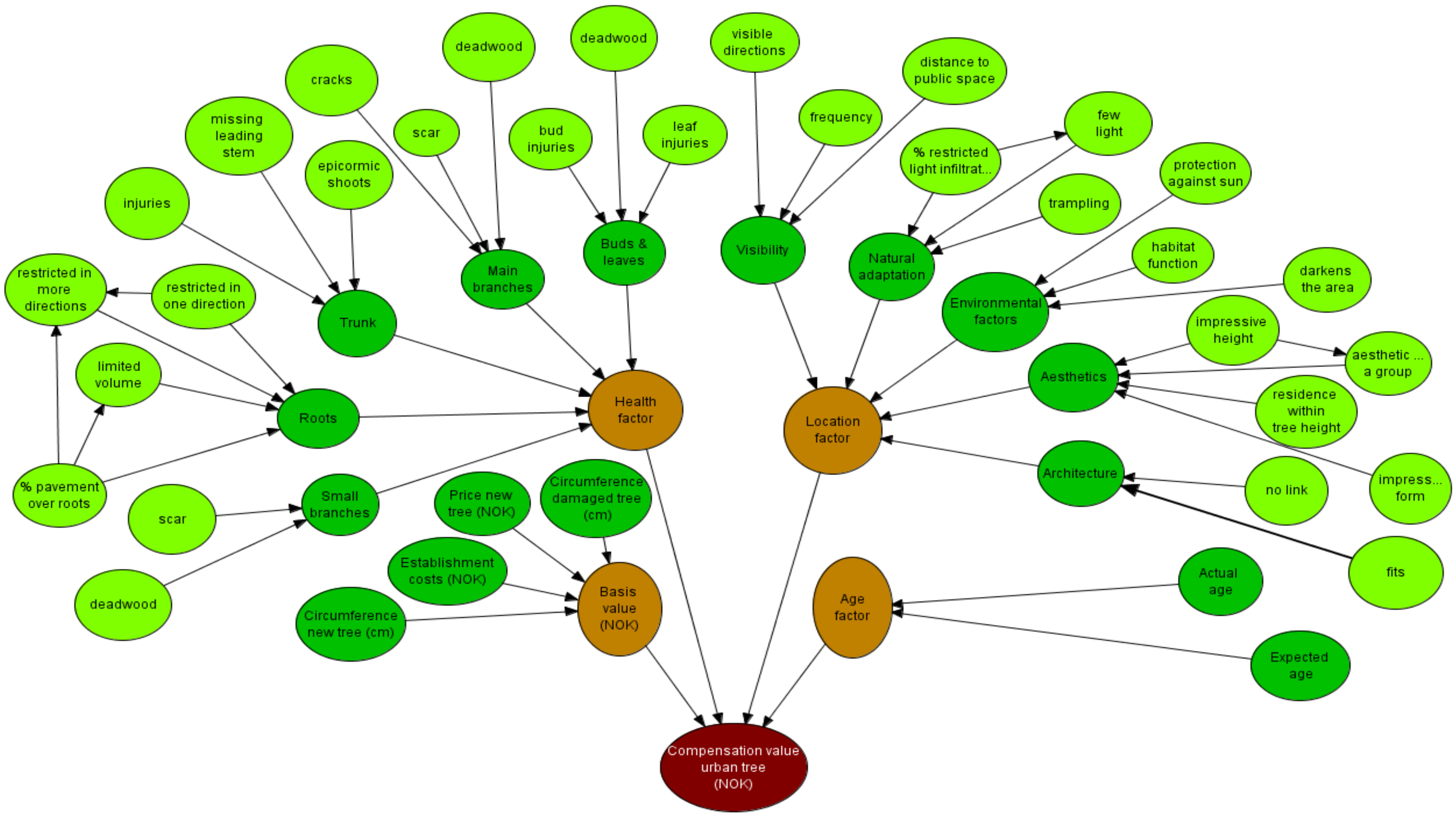


Fig. 18. *Total network including the most informative tree features in determining the scoring of the different VAT03 criteria.*

7 Discussion

7.1 Futher adjustments to the extended VAT03 appraisal form

The VAT03 is unique in giving weight to location-related benefits of trees' –such as aesthetics. Neither the American (ISA tree risk assessment), the Swedish (Alnarpsmodellen), the English (CAVAT) nor the Belgian (Technisch Vademecum Boom) model implement these benefits in the calculation of monetary compensation value.

The extended VAT03 form is a tool to further document urban tree evaluations and to help decreasing the variation among different observers. Some features will have more influence on the outcome value than others (See Value information analysis in previous section). Before using the form, the value of the tree should be compared to previous field experiences, to obtain a first impression of its value. This is important as use of the features in the form may deviate strongly from first superficial impressions.

Based on our tests of Form 2 on trees in the greenest streets of Oslo, we have suggest further simplifications. The changes are marked in yellow in the form below (Form 3). We explain each of the changes in order.

Most of the additional changes we suggest concern the Location factor. For example, in the category "Environment", Form 2 did not include negative impacts of a tree on its environment. This meant previously that a tree's environment factor would range from a median value of no environmental benefits (2.5) to large benefits (5). In a revised version negative effects – so-called disservices – could dominate positive effects leading to an Environment criterium <2.5.

This ambiguity in the Environment criterium highlights a gap in the methodology regarding ecosystem services and disservices of trees. Currently the VAT03 model does not include a systematic treatment of either. It is a complex task to define a set of observable indicators of ecosystem (dis)services of any particular tree. We return to this question in the next section.

Finally, it is important to note that the form is not species-specific. Some tree species cope more often with some limiting features than others. For example, a linden tree quickly develops epicormic shoots or the leaves of a Norwegian maple are typically covered with mildew at the end of the autumn. In both cases, the features should not be thought to affect the tree in the same way as for species where these features are uncommon and therefore a clear sign of health issues. The evaluator should be critical towards this aspect and should have enough background knowledge on the different species that are common on-site.

Name valuator:
Tree species:

Street:
Tree survey number:
Date:

General

Locality

- Street
- Square
- Unbuilt area
- Small park
- Large park
- Garden
- Urban residual biotope
  - Small forest
  - Riparian area
  - Dry area
  - Small hill:
  - Slope degree
  - 0-10 10-30 >30

Part of an avenue

- Yes
- No

Part of a forest

- Yes
- No

Single tree

- Yes
- No
- Tree Number within tree height radius:

Tree measurements

Number of stems:
at a height of ....m divided into ....stems
Stem circumference:
Min: Max:
Actual age:
Min: Max:
Actual height:
<5m 5-10m 10-15m 15-20m 20-25m 25-30m >30m
Crown area (diameter):
Min: Max:

Health Factor

Roots

- Excavation/Exposure
- Girdling root
- Soilbulge and Soilrupture
- Rot
  - Perhaps
- Ants/insects
- Injury / Injuries
- Root cuts
- Scars
- Load/Pavement over
- ..... % of roots
- Root formation restricted
  - In one direction
  - In more directions

Value: 0-1-2-3-4-5

Trunk

- Rot/Fungi
- Hollow
  - Perhaps
- Injuries
- Scars
- Epicormic shoots
- Cracks
- Fork
- Resin flow
- Proliferation
- Missing leading stem
- Parasites
- Sloping position
- Angle:
- Dogs uric

Value: 0-1-2-3-4-5

Main Branches

- Deadwood /dying branches
  - <1/3
  - 1/3-2/3
  - >1/3
- Parasites
- Epicormic shoots
- Cut
  - A little
  - A lot
- Scars
- Injuries
- cracks

Value: 0-1-2-3-4-5

Minor Branches

- Deadwood /dying branches
  - <1/3
  - 1/3-2/3
  - >1/3
- Injuries
- Parasites
- Cut
  - A little
  - A lot

Value: 0-1-2-3-4-5

Twigs/Leaves/Buds

- Dead leaves
  - A little
  - A lot
- Dead twigs
  - A little
  - A lot
- Injuries of the buds
- Injuries of the leaves
- Parasites

Value: 0-1-2-3-4-5

SUM/25:

Location Factor		
Adaptation/care	**Architecture**	**Aesthetics**
Stress factors:	Fits together	~~Residence within tree height distance~~
De-icing salt	Doesn't fit together	
Compression: -Trampling -Mechanical (vehicles)	~~No link to architecture~~	Impressive because of:
Few light: .....% infiltration vertic. .....% infiltration horiz.	~~Contact with built structures~~	Height Growth form
	Traffic	Aesthetic in a group
Air pollution	Integrated in traffic de-marcation	Aesthetic as single tree in open location
Others		
Site changes:	Blocking road/ traffic mark visibility	Unhealthy poor aspect
Grade change		Non-natural growth form due to cutting
Site clearing	Risk for built structures	
Changed hydrology		Good smell
Soil conditions:		Bad smell
Shallow		Beautiful features:
Saturated		
Compacted		
Limited volume		
Old/historical/cultural tree		
Natural pruning		
New vitale leading stems		
Well-overgrown scars		
Value: 0-1-2-3-4-5	**Value: 0-1-2-3-4-5**	**Value: 0-1-2-3-4-5**
Environment	**Visibility**	
Habitat function for:	Public space	
	Private space	
	.... m from public space	
Protection against:	Frequency as single tree	
Sun	Low	
Rain	Medium	
Dust	High	
Noise	Frequency as a group	
Wind	Low	
Degrades the area	Medium	
Upgrades the area	High	
Blockage of private view	Visible from:	
Privacy function	All directions	
Pollen allergist	.... directions	
Value: 0-1-2-3-4-5	**Value: 0-1-2-3-4-5**	
SUM/12.5:		

Form 3. *Third revision of the VAT03 evaluation form*

Explanation of additional changes to the form

Change 1: addition of "garden" to locality
A tree standing in a private garden can still have an important value for the public area. This situation is well illustrated in following picture:

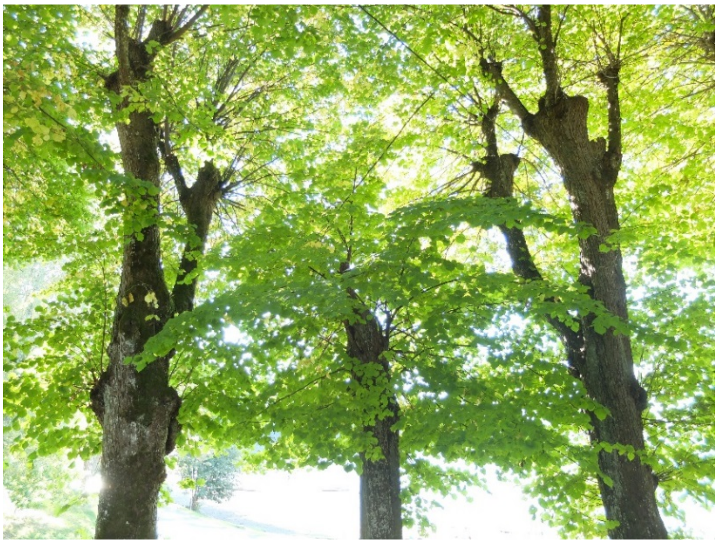
A 'public' tree in a private garden

Change 2: move "soil conditions" from Roots to Adaptation & Care
The soil condition is an indication of how well the tree is taken care of and how well the tree is able to adapt to undesirable soil conditions.

Change 3: move "root cuts" from Adaptation & Care to Roots
Root cuts directly affect the tree health, as the roots lose a part of their capability to take up nutrients/water and stabilize the tree.

Change 4: merge "lower stem" and "stem"
As it is not always clear were to draw the line between lower stem and stem and as this division unnecessarily increases the complexity the two categories are merged.

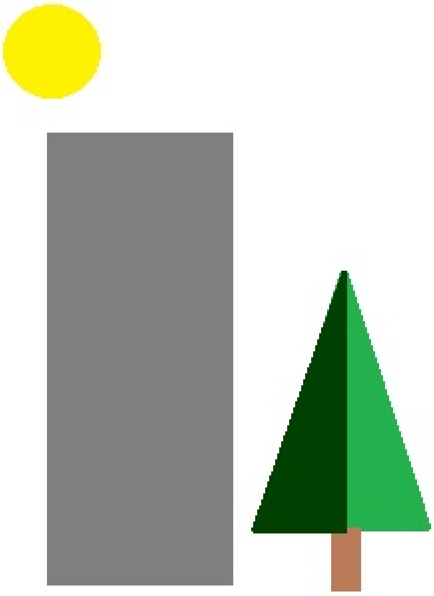
Change 5: add "cut" to Main Branches and Minor Branches, and "non-natural growth form due to cutting" to Aesthetics
Some trees experience health issues after severe pruning by caretakers, for example extensive sprouting of epicormics shoots, which will also have an effect on the aesthetic performance of the tree (Fig. 16).



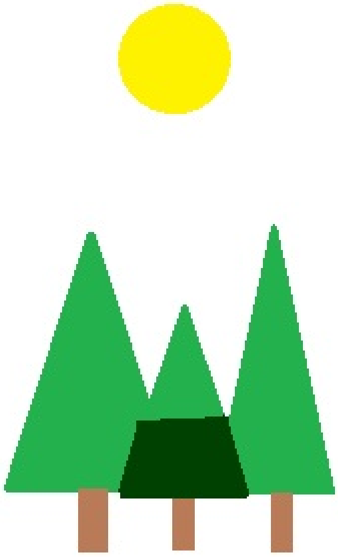
Vertically restricted light infilitration

Change 6: split "restricted infiltration area" into "lateral and vertical"

Laterally restricted light infiltration



Vertically restricted light infiltration



Change 7: add "natural thinning" to Adaptation & Care
As an adaptive reaction on decreased light conditions, the tree may undergo a natural process of self-thinning, resulting in the death of some branches.

Absence of leading stem

Change 8: add “new vital leading stems” to Adaptation & Care
The Health Factor considers the absence of a leading stem as a health threat, but depending on how the tree reacts to this absence, the replacement of an absent leading stem by multiple healthy leading stems can indicate a high vitality and adaptive value. It is important that the new stems balance each other out to avoid a decreasing stability.

Change 9: add “well-overgrown scars” to Adaptation & Care
The scars from cut or broken branches can show health issues, but in other cases the tree scars are overgrown which shows vitality and adaptation of the tree.

Change 10: remove “no link to architecture” from Architecture
If there is no link between the tree and the architecture the neutral value 2.5 is given to the Architecture section.

Change 11: replace “contact with built structures” with “risk for built structures”
The first description does not clearly explain that the tree has a negative impact on the built structures.

Change 12: remove “residence within tree height distance” from Aesthetics
It is not clear why a tree neighbouring a building would receive an additive aesthetic value.

Change 13: add “single tree in open location”, “unhealthy poor aspect”, “non-natural growth form due to cutting”, “good smell”, “bad smell”, “beautiful features” to Aesthetics
This will facilitate to declare why a certain value is given. The following picture illustrates the aesthetics of a single tree in an open location:

Aesthetics of a single tree in an open location

Change 14: add "upgrades/degrades area" to Environment
When an aesthetic tree stands in an area that is neglected, the tree can upgrade the area. On the other hand, when a tree looks unhealthy it might degrade the aesthetics of an area.

Change 15: add "privacy function" and "blocking private view" to Environment
A row of trees can clearly form a wall between a house and the public space (left photo below. Contrary, the presence of a tree close to a house can completely block the window view (right foto below).

Example of trees with a privacy function.

Example of tree blocking private view.

Change 16: add "pollen allergen"
Among the common urban trees, only hazel, elm, elder and birch are judged to be problematic for pollen allergists (Randrup et al., 2003).

Change 17: distinguish between visibility as a group of trees or as a single tree

A tree can have a low visibility as other trees surround it, but this group of trees might have a high visibility. See next section.

7.2 Assessing the relative importance of VAT03 variables

The mean compensation value for urban trees based on the data from the trees surveyed in Oslo's greenest streets using this extended VAT03 model was 90 901 NOK. We can compare this expected value of sampled trees in Oslo's greenest streets to a "null" model in which we have no information about the particular tree - criteria have expected scores of 2.5 on all VAT03 criteria. A range of expected costs of purchase and establishment of a new trees is used instead of a precise value. The mean compensation value for urban trees for the null model is 49 697 NOK. In a null model the valued trees in the sample are of a better health and contribute more to their environment.

As mentioned before Bayesian Belief Networks have the great advantage of handling data that cope with uncertainties, which in case of the tree valuations is the subjective variation among different expert appraisals by arborists.

In this section, we evaluate the relative importance of criteria in VAT03 in determining compensation value. This is called information value analysis.

The influence of the four factors (Basis, Health, Location and Age) on the final urban compensation value are not balanced. The Base value has a remarkably higher influence on the value than the three other factors. In the following we assess the extent to which this imbalance is due to the sample data from trees in Oslo's greenest streets or to the structure of the VAT03 model itself. We compared 4 models. For each test model a value of information analysis was performed.

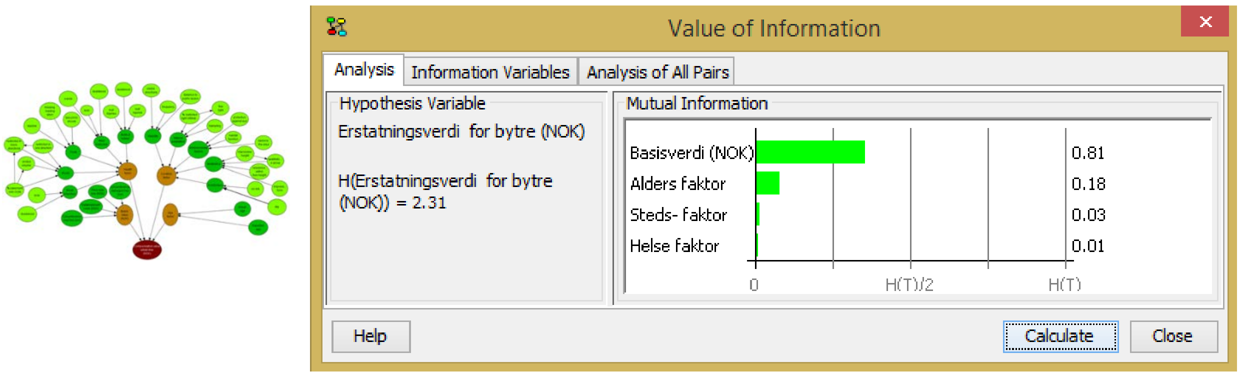


Figure 19.1 *The complete model as illustrated in Fig. 18 based on tree data gives the above output for the value of information analysis*

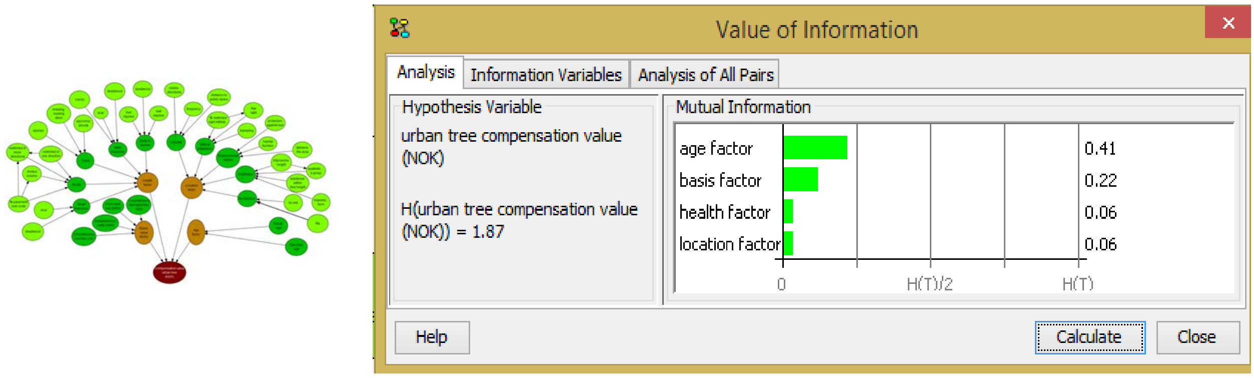


Figure 19.2*. The complete model as illustrated in Fig. 20 without including any sample data – setting all tree characteristics as equally likely - gives the above output for the value of information analysis*

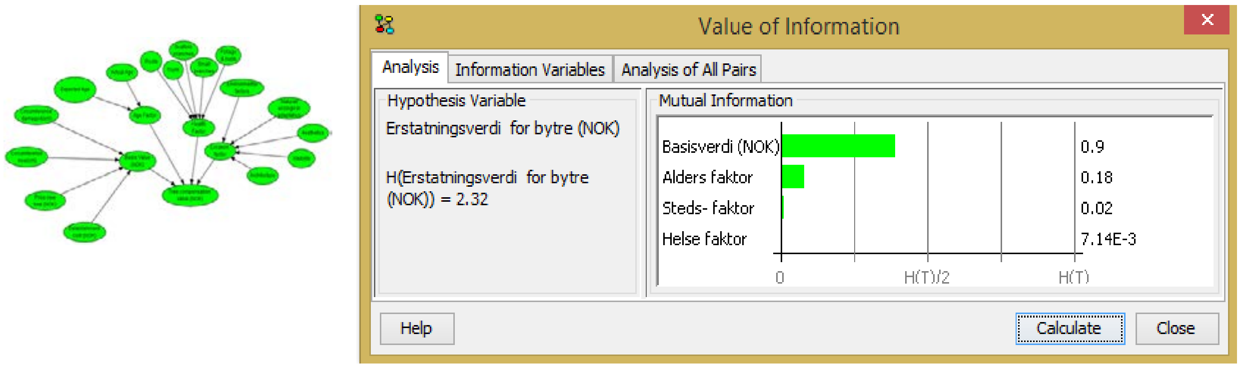


Figure 19.3*. The original VAT03 model using tree sample data from Oslo's greenest streets, gives the above output for the value of information analysis*

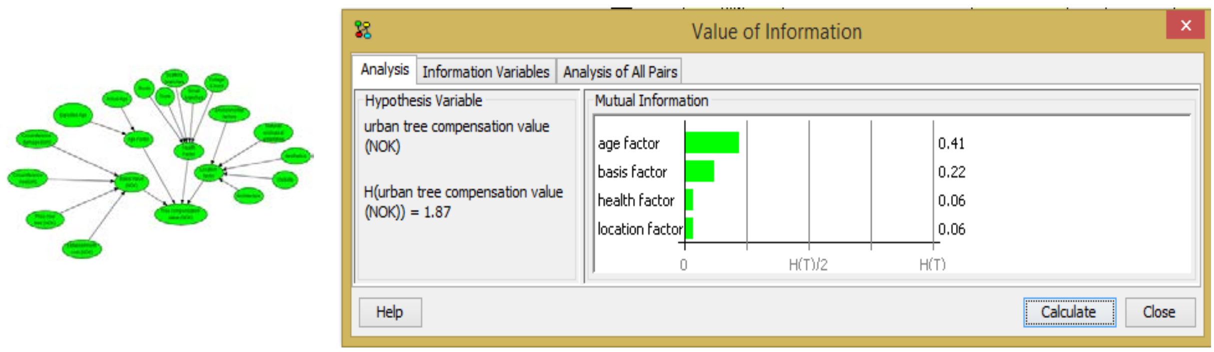


Figure 19.4 *The original VAT03 model without including any data on particular trees gives the above output for the value of information analysis*

The comparison of models shows that a difference in value of information analysis is not caused by the addition or exclusion of the features describing each VAT03 criterion. The greatest difference is found between the models including the tree data and the models excluding the tree data. In the model including the tree data the base value has the biggest influence on the compensation value, followed by the age factor. When the model does not include any tree data the age factor provides more information than the basis value. This can be explained by the fact that the age factor has a particular functional form (see below) which determines value – even when no particular characteristics of the tree are known.

A few more observations regarding these two most important criteria in VAT03 are needed:

Base value

The base value is defined by the difference in circumference between the damaged and a new tree, the price of a new tree and the establishment costs. In our model, the intervals for the circumference, the price and the establishment costs of a new tree were determined based on information from Oslo Municipality. The cost range used was based on a few larger contracts for planting a larger number of trees. VAT03 is focused on individual tree assessment - the conditions for replacing a tree vary widely. The greatest difficulty in defining the base value is the fact that different tree planting and replacement firms have different prices that vary over time and by location. A generalization of establishment costs, different contexts, would facilitate future calculations.

Age factor

The age factor described by Randrup et al. (2003) is calculated as the square root of ((expected age-actual age) * 2 / expected age). An important condition is made by Randrup (2005) concerning the calculation of the age factor. The age factor has no effect (=1) on the tree compensation value when the actual age is lower than a half of the expected age. It has a positive effect when the tree is over a half of its life span, but has a negative effect on the tree value when the tree approaches its death (Fig 20.). In our data 94% of the trees have not reached a half of their expected lifespan, resulting in an age factor of 1 and therefore not influencing the compensation value in the same way as the base value.

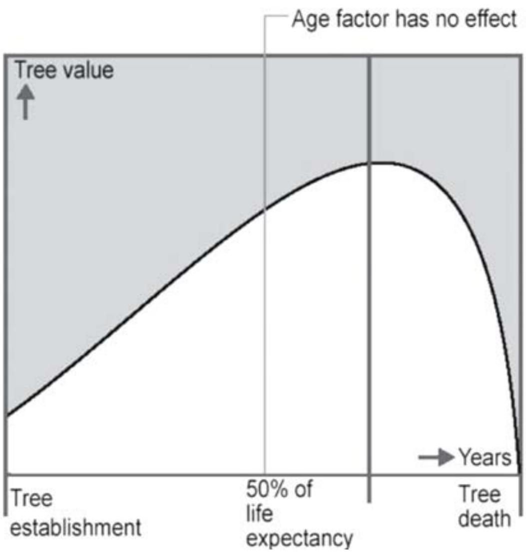


Figure 20. *Age Factor functional form in VAT03. From Randrup et al. (2003). The Age Factor has an influence on the total tree value when the tree has reached half of its expected total lifespan. However, it does not have a major impact until the tree approaches senescence (Randrup, 2005).*

The VAT03 model infers that a dead or heavily damaged tree has no value, whereas dead trees may offer important habitat to a variety of species. In the present VAT03 method, biodiversity considerations may be taken into account in the Environment factor. However, as seen in the information value approach, the Environment criterion plays a marginal role compared to the Age Factor due to the way the VAT03 formula is specified.

The expected age can be difficult to assess unless the tree is very close to the end of its total expected lifespan. The expected lifespan for trees in forests is registered for a range of species, but this lifespan does not directly apply to the urban environment. At the end of this report we provide a table with adjusted life expectancies for the most common species in Oslo (Appendix 3, Table 2 & 3). A new suggestion for life expectancies of urban trees, based on the average of both tables, is added to Appendix 3 (Table 3). Table 4 adds also some species (e.g. conifers) that were not included, but are common in Oslo. As mentioned by Randrup (2005) these lists are guidelines and do not generally apply for every tree. For example, a sick tree might not be able to reach the age suggested from the table; then an individual tree-based evaluation is needed.

The network model we have discussed in this report uses age intervals, rather than exact age. This uncertainty-based approach could be used to assess the potential compensation value of living trees, when a bore sample cannot be drilled.

7.3 Location - Environment Criterion - Ecosystem Services

Based on a reading of the formula structure (Section 3) it is evident that variables in the Location factor are weighted twice as high as those in the Health factor. However, the relative importance of the four main factors in VAT03 is not evident. The analysis in Fig. 19.1-4 shows that the influence of the Location and Health Factors on tree compensation value is relatively small.

The discussion about whether to specify ecosystem services and disservices of trees as part of the Environment Criterion is relevant here. Simply making a longer list of “features” under the Environment criterion will add hardly any new information to the calculation of tree compensation value, given the way the relative weighting of factors is specified in the VAT03 formula. Even if the Location factor was completely redefined in terms of ecosystem services, it would still make little difference to the compensation value due to the functional form of VAT03 formula. Revising VAT03 to include ecosystem services would require a complete revision of the formula structure.

Furthermore, considering ecosystem services would have to include a field methodology using visible physical characteristics of the tree and the location as proxy indicators of ecosystem services. The VAT method’s structural characteristics of trees could be revised to be consistent with the tree traits that are measured in i-Tree’s field methodology. Notably, VAT03 could be revised to include the traits that are indicators for regulating ecosystem services of trees including canopy volume, soil cover and permeability under the canopy (Text Box 1). Even if a revised VAT03 method does not estimate regulating services at the level of detail in –Tree, it would be cost-effective to harmonise field methodology in VAT03 so that tree canopy volume characteristics are recorded. Furthermore, the Location variables coud use the same landuse categories as in i-Tree.

A limited set of ecosystem services of priority importance to built environments may have to be considered, e.g. benefits assessed using the i-Tree model. The relative importance of each ecosystem service in a revised VAT03 model could be based on the relative economic importance of trees as calculated by i-Tree in well-studied cities. These ‘ecosystem service weights’ could be adjusted or standardised by a panel of local experts. In time standard ecosystem service weights could be calibrated against findings of an i-Tree or similar model estimated specifically for conditions in cities in Norway (which also vary).

Box 1 Tree and plot traits in the i-Tree field methodology (excerpts)

The i-Tree Eco model requires input data on tree traits which are used to calculate tree canopy volume. Combined with species information this is used to calculate leaf area index, which is the key tree trait used to calculate regulating ecosystem services. Tree regulating functions are modulated by ground cover characteristics under and near the tree (recorded for circular plot typically of 0.1 acre). Below are excerpts from the i-Tree Eco field manual.

Tree

- Species
- Total tree height
- Height to live top
- Height to crown base
- Crown width
- Percent crown missing
- Condition & percent dieback
- Crown light exposure
- Diameter at breast height (DBH)

Shrubs

- Species
- Height – average height of a shrub group (i.e., mass of shrubs of the same species)
- Percent of area – the amount of the shrub area in the plot covered by each shrub group
- Percent missing

Ground cover in plot

- Tree cover (%)
- Shrub cover(%)
- Plantable space(%)
- Ground cover type (building, other impervious, cement, tar, rock, bare soil, duff/mulch, herbs, maintained/unmaintained grass, water
- Percent of plot

Source: i-Tree Eco (2017)

7.4 Adjusting economic compensation values along landscape gradients?

Examples of local conditions in Norwegian cities that may need adjustment relative to the original Danish context of VAT03 include unmanaged forest patches and small woodlands within cities' built zones, and active forestry in close peri-urban forests. Furthermore, there is legal precedent in compensation value of trees in forests being calculated according to timber values only.

An adapted VAT03 would need to include some consideration of how trees' values transition from multiple cultural and regulating to a dominance of provisioning services as we move from individual trees through woodland fringes to trees within forests. Lacking other dedicated models such as i-Tree to quantify benefits of ecosystem services, landscape features such as tree density might be used to standardise a calculated compensation value based on tree density. The assumption in Figure 21 is that individual trees in built areas provide the highest value of ecosystem services due to their proximity to a large number of potential beneficiaries and to their relative scarcity. Such a simple density scaling modelling also assumes that at the other end of the spectrum a tree in the interior of a forest has one beneficiary and low/no scarcity.

Figure 21 illustrates not just increasing density of human use, but also different user composition, showing that there is no simple and also accurate approach to scaling ecosystems service values based on easily observable landscape characteristics. Nevertheless, some form of scaling simplification is required if the complexity and rapid assessment nature of VAT03 is to remain comparable to its current level.

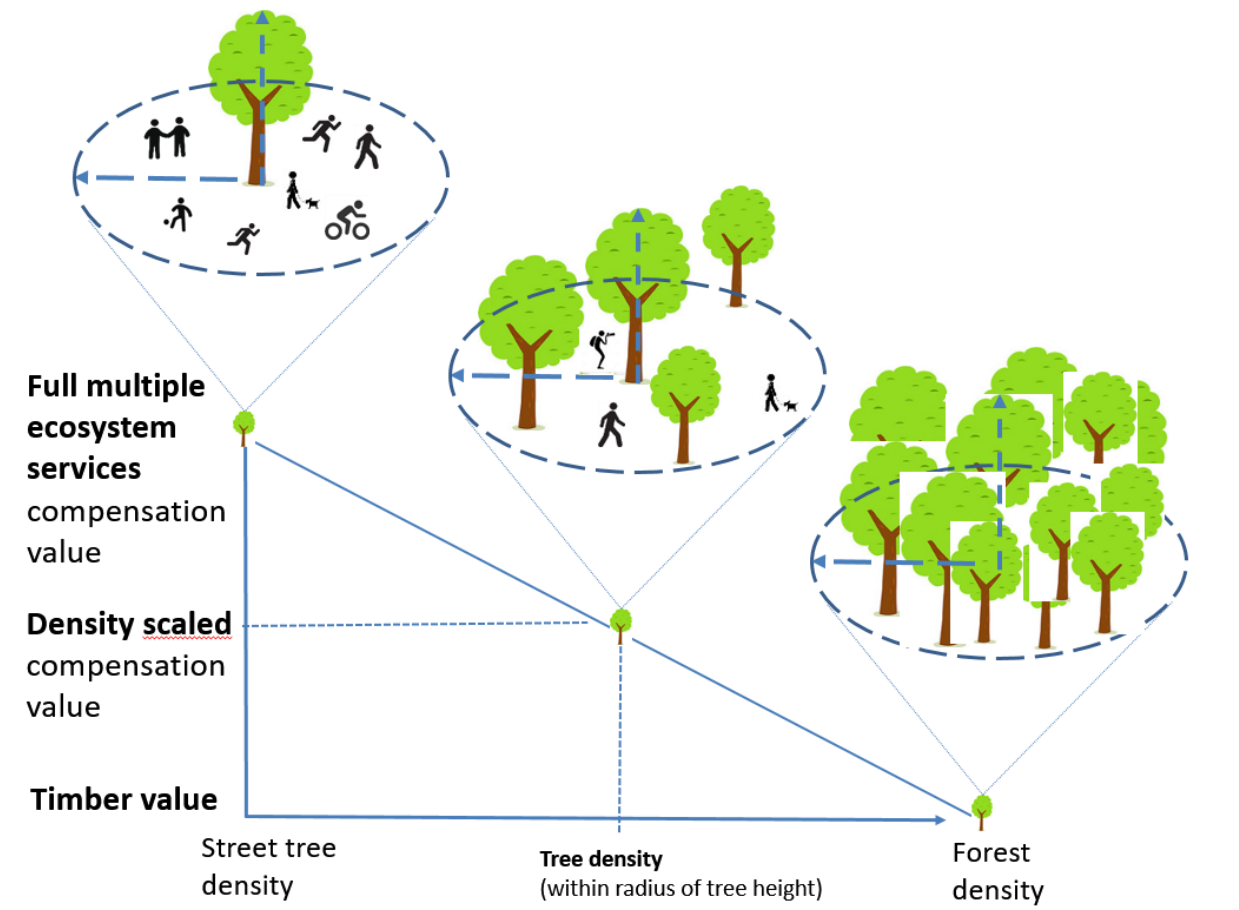


Figure 21 A simplified tree density approach to scaling compensation values calculated by a revised VAT method considering ecosystem services.

7.5 Adjusting compensation value to property rights?

Standardising a revised VAT03 method should also consider whether the method is generally applicable, or whether property rights should determine compensation. Currently the Norwegian "Neighbour Act" (Granneloven) specifies 1/3 the tree's height as the distance from a property boundary at which a neighbour can consider a tree to potentially be of "significant detriment" (Norwegian: "særlig ulempe"). There is no symmetrical legal standard regarding the distance from a tree within which ecosystem service benefits are of public concern. Figure 22 illustrates that the distance from the tree at which (detrimental/negative) public concern is legally defined by the Neighbour Act (Granneloven) is arbitrary in the context of ecosystem services. A standardisation of a revised VAT03 method would need to be explicit about whether the method was limited to trees on public land. If the method were general, it would have to clarify compatibility with potential benefits/costs of trees in current legal practice.

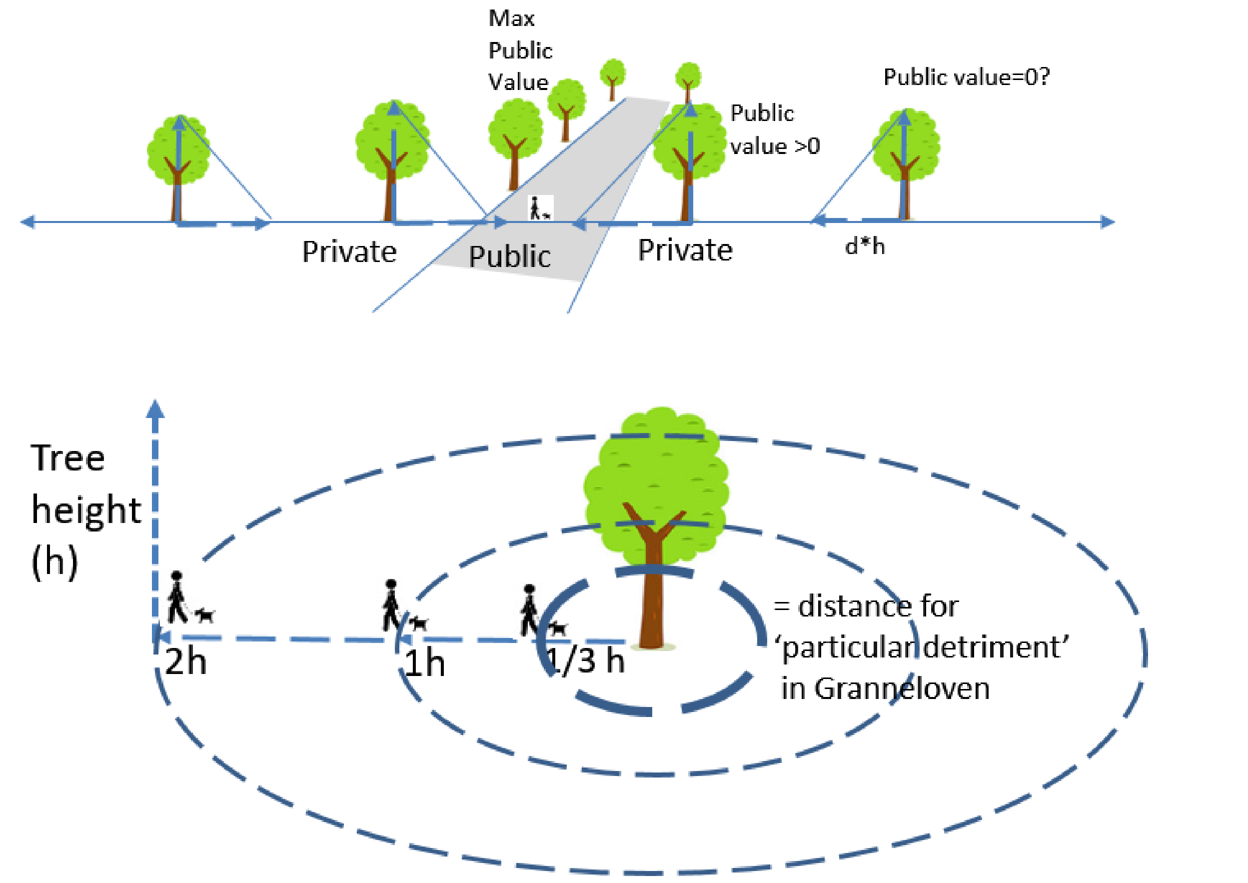


Figure 22 Trees on private land have public values. The distance from the tree at which public concern is legally defined by the Neighbour Act (Granneloven) is arbitrary in the context of ecosystem services.

8 Conclusion

In this report, we have proposed a more detailed tree appraisal form for the VAT03 method. The aim of the more detailed appraisal form is to contribute to better documentation of valuations. While not removing subjectivity of expert based appraisal methods, it may help to calibrate and standardise appraisals over time.

We have used a software tool – Hugin Expert – to implement and diagnose the VAT03 method. This approach recognises that the current VAT03 method involves a number of assumptions by tree appraisors, which currently go undocumented. We think that further documentation of expert judgement may increase the credibility of the method as a basis for legally determined compensation values.

By diagnosing the relative importance of variables in VAT03 we show that the appraisor currently should spend most of their appraisal effort “getting the prices right”. VAT03 requires three separate price quotations in order to triangulate a basis value. This is time demanding, and depends on which firms are contacted, and whether they know the purpose of the price quote. A periodically standardised price index for different tree purchase, establishment and maintenance activities would remove the largest source of judgement in the current method and help appraisors to carry out their work faster.

The age factor is the second most important criterion in VAT03. In appraising the age of living trees based on sight alone there can be great uncertainty. Obtaining a core from a live tree may not be possible. The expected age used in our assessment of trees on Oslo’s greenest streets was derived from the tables available in Appendix 4. In many cases, this standardised table of expected tree age does not apply to the context of a specific tree. However, standardisation is still required, perhaps differentiated for specific city environments.

In revising the VAT03 method consideration should be given to the value of information from different criteria in explaining compensation value, and the difficulty/cost of obtaining that information. This kind of diagnostic can be carried out using Hugin Expert to test different mathematical functions for combining criteria, as well as the criteria selected (Appendix 7).

The greatest challenge concerning the evaluation form and the model in general, is to find a method to implement ecosystem services associated with urban trees. Ecosystem services are already present in the original VAT03 method, although under different terminology, and not systematically with regard to both benefits and disadvantages. Even if a revised VAT03 method does not estimate regulating services at the level of detail in –Tree, it would be cost-effective to harmonise field methodology in VAT03 so that tree canopy volume characteristics are recorded. Furthermore, the Location variables coud use the same landuse categories as in i-Tree.

As many ecosystem services are not associated with a single tree, but rather a group of trees, an urban tree compensation method will also have to consider valuation of trees in stands and urban woodlands in and near cities.

Another challenge with more widespread use of VAT03 is the application to private trees. Private trees contribute to public values, particularly when next to a streetscape, but also when a tree cannot be seen from a public space because of its regulating ecosystem services. We discuss pros and cons of standardising this assessment using tree height, as is currently done in the Norwegian Neighbour Act (Granneloven).

In revising the VAT03 method to achieve better documentation of expert judgement, and more credibility through calibration and adjustment for ecosystem services and landscape context, a balance must be struck with costs of carrying out the appraisal and explaining it to parties in a dispute.

There is potential in future for standardising a VAT compensation value method for individual city trees also as a method for valuing trees across a whole city in the context of urban ecosystem accounting.

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Landscape and Urban Planning, Volume 157, January 2017, Pages 14-25.

Appendix 1 Valuing street trees using physical inventory-based indicators

Tree inventories can be used to create indicators of spatial distribution, which can represent the relative importance of trees across a city. Different spatial aggregations of the tree inventory, and different comparisons, emphasise different policy issues. As such, tree inventory indicators are also value indicators in as much as they can be used as arguments of importance (and relative value) in support of policy. Below we illustrate several examples of inventory indicators for different purposes.

Oslo has 15 city districts (bydeler): Alna, Østensjø, Gamle Oslo, Sentrum, St. Hanshaugen, Vestre Aker, Nordre Aker, Søndre Nordstrand, Stovner, Grorud, Frogner, Grünerløkka, Sagene, Nordstrand, Bjerke and Ullern. The tree data of Oslo was extracted from a LIDAR scan in 2011 provided by Oslo Kommune, which registered all the trees higher than 5 meters. Oslo's built zone counts in total approximately 700 000 trees (>5m). This estimate was based on a filtration of the original tree point dataset provided by Oslo Kommune, for double stemmed trees and confounding with registered lampposts. This results in approximately one large tree per inhabitant in Oslo's built zone. Of these roughly, 700 000 urban trees, 241 927 are street trees, resulting in 391 street trees per 1000 inhabitants. Comparing with statistics for a selection of other European cities, Oslo's city tree density in relation to inhabitants is large (Figure A1).

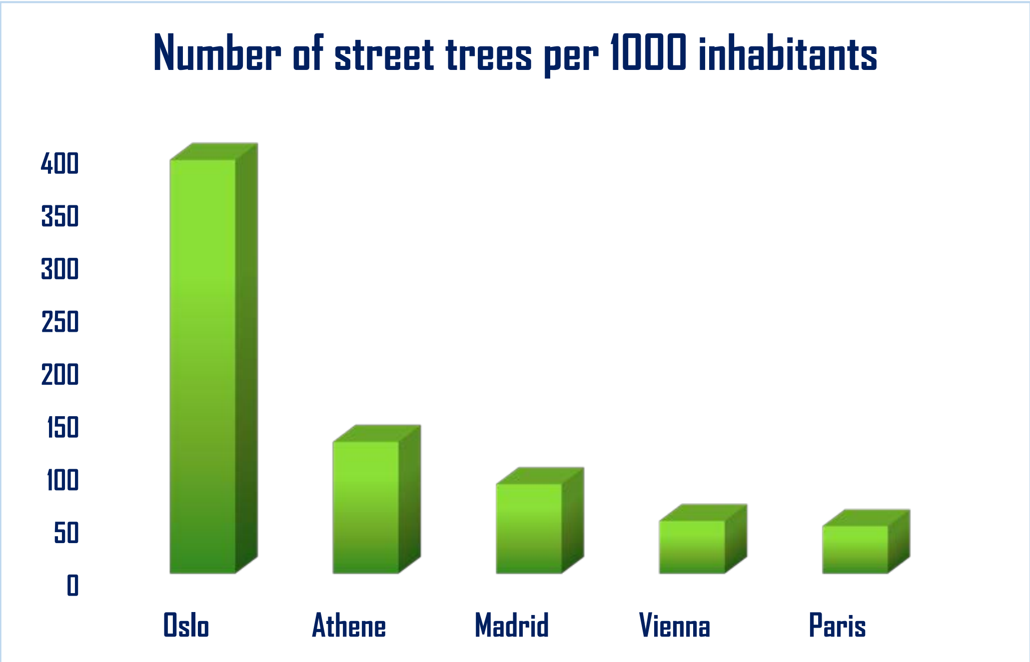


Figure A1. Number of street trees per 1000 inhabitants. Information on Oslo extracted from LIDAR data. Information on Athene, Madrid, Vienna and Paris extracted from Pauleit et al. (2002). The way the information on street trees was obtained, differs between the different cities, therefore this graph should just be considered as an illustration.

This data was compiled into district wise inventories and combined with population data using the program QGIS (Quantum Geographic Information System).

Figure A2 shows the city district coloured by density of trees > 5m (per km^2). The number indicated in each city district illustrates the number of trees per inhabitant per district. Vestre Aker has the highest tree density (6555 trees/km^2), while not surprisingly the city center (Sentrum) has the lowest tree density (1945 trees/ km$^{2)}$.

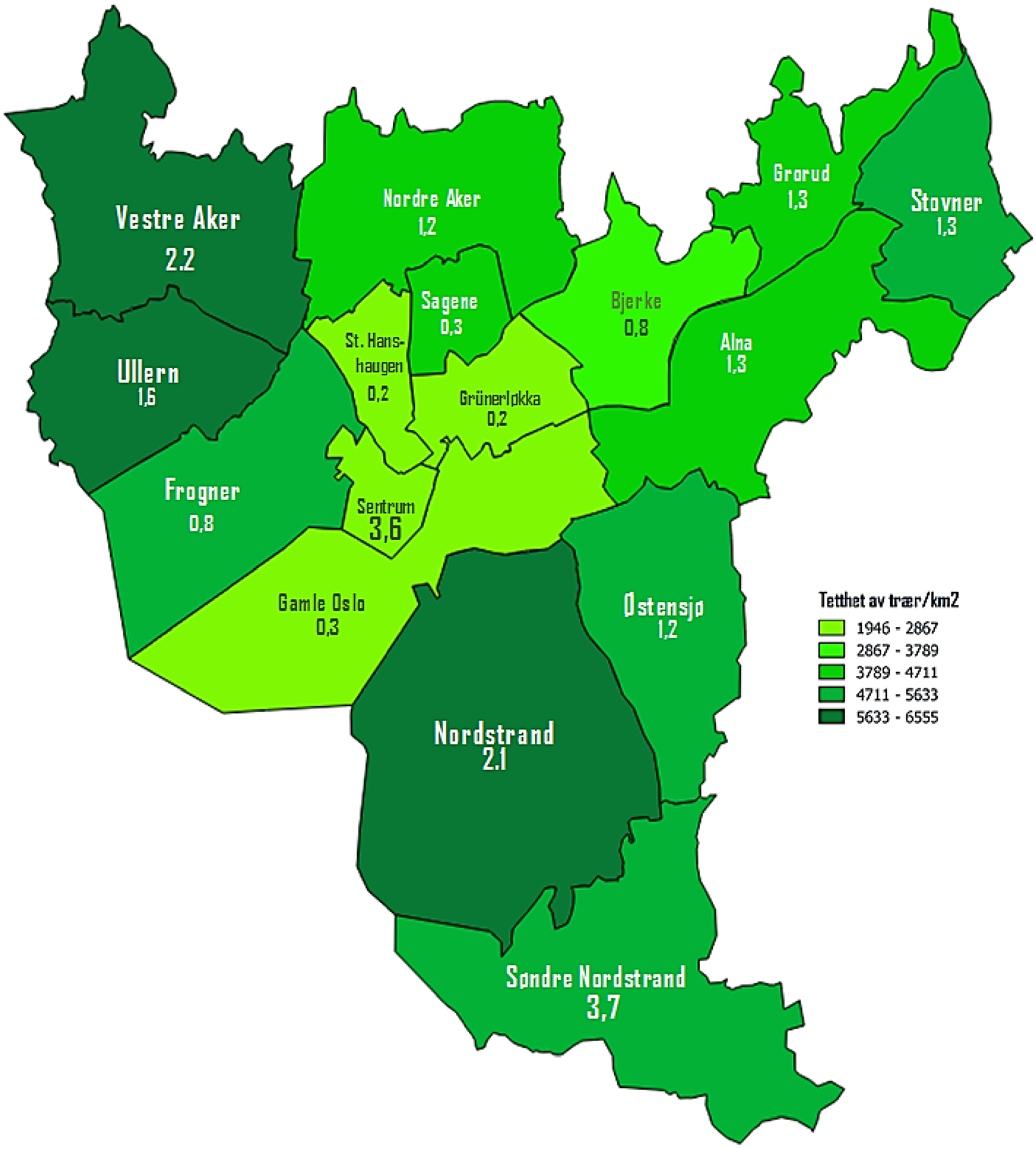


Figure A2. Tree density by area (density of green colour) and inhabitant (numbers) in districts of Oslo

We also used the inventory data to identify the greenest streets in each city district, as another approach to generating awareness about city trees, and street trees in particular. For each city district the greenest street was identified based on the highest tree density on either side of the street. Streets along public parks were not considered in the calculation, as the indicator was meant to highlight street trees maintained also on private land. Tree density was calculated based on the number per surface area of the 10-m buffer on both sides of the street, multiplied by the street length.).

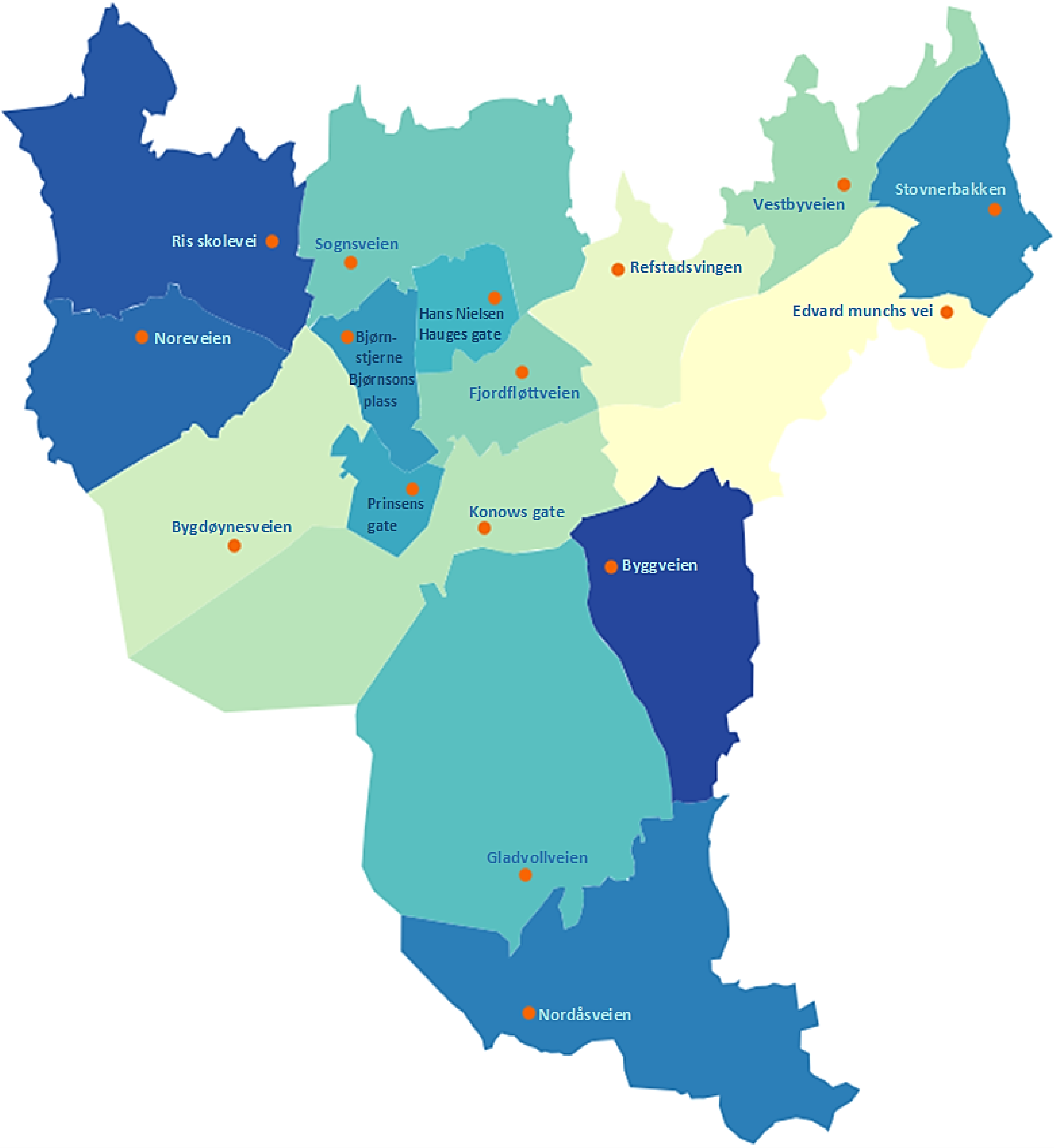


Figure A3. The orange markers indicate the centre point of the greenest street for each city district of Oslo. The greenest street measurement excluded streets along public parks, aiming to highlight conservation of street trees.

The greenest streets for each district were also used to ground truth the number of trees estimated for the whole built zone of Oslo using filtered Lidar data. The greenest streets identified in Figure A3 were visited during August-September 2016. The number of trees (>5m) within the 10-m buffer zone was counted and this ground-truthed number was compared to the estimated number using Lidar identification (Table A1). The mean error was 6% meaning that Lidar data overestimated on average the actual number of trees by 6%.

Table A1 The 16 streets with their tree density derived from the LIDAR data, the amount of trees defined by LIDAR 2011 and the actual amount of trees present today (2016) within a 10-m buffer zone. Only trees higher than 5 meter were included.

City district	Street	Tree density (trees/ 1000 m²)	Number of trees (LIDAR)	Number of trees (ground-truthed)	Deviation (%)
Grorud	Vestbyveien	23	91	82	10 %
St. Hanshaugen	Bjørnstjerne Bjørn-sons plass	22	22	11	50 %
Stovner	Stovnerbakken	22	226	224	1 %
Vestre Aker	Ris skolevei	22	77	53	31 %
Søndre Nordstrand	Nordåsveien	21	262	256	2 %
Ullern	Noreveien	19	108	92	15 %
Alna	Edvard Munchs vei	18	108	92	15 %
Frogner	Bygdøynesveien	18	201	193	4 %
Nordre Aker	Sognsveien	18	626	754	-20 %
Nordstrand	Gladvollveien	18	250	258	-3 %
Sentrum	Prinsensgate	18	12	17	-42 %
Østensjø	Byggveien	17	69	63	9 %
Bjerke	Refstadsvingen	15	59	63	-7 %
Gamle Oslo	Konows gate	14	181	179	1 %
Grünerløkka	Fjordgløttveien	14	41	34	17 %
Sagene	Hans Nielsen Hauges gate	10	66	59	11 %
Mean error (Lidar)					6%

The greenest streets in Oslo as identified by the Lidar identified tree points did not always give the subjective impression of being green streets as compared to streets along parks. Recall that streets bordering the municipal Marka forests and public parks were not included in the analysis. Furthermore, the LIDAR data from 2011 tended to overestimate tree density by on average 6%. By the time of the ground-truthing the Lidar data were already 5 years old. Also, a LIDAR scan is not always capable to distinguish between one single tree and a group of trees.

A new LIDAR was conducted summer 2017, which will shortly provide better insights in the tree data of Oslo. The data will illustrate the evolution in tree density in Oslo over a 6-years period. Following the greenest street application, the new data will provide a more accurate outcome of the greenest streets in Oslo, which might diverge less with the in situ perception at street level.

Further, LIDAR data will identify singletree locations with reference to a previous study that checked remotely-sensed imagery vs. eye-level photography for assessing tree cover densities of urban forests (Jiang et al., 2016).

Appendix 2 – Revised field form for documenting VAT03 appraisals

Locality:	**Part of an avenue**	**Tree Species:**	
Street	Yes	**Tree survey number:**	
Square	No	**Date:**	
Unbuilt Area	**Part of a forest**	**Number of stems:**	
Small park	Yes	at a hight of ....m divided into ....stems	
Large park	No	**Stem cirumference:**	
Urban residual biotope	**Single Tree**	Min:	Max:
Small forest	Yes	**Actual age:**	
Riparian area	No	Min:	Max:
Dry area		**Actual height:**	
Slope, degree:		<5m 5-10m 10-15m 15-20m 20-25m 25-30m >30m	
0-10 10-30 >30		**Crown area (diameter)**	
small hill		Min:	Max:

Health Factor			
Roots	**Lower Stem**	**Stem**	**Main branches**
Excavation	Rot / Fungi	Rot / Fungi	Deadwood / Dying of branches
Soilbulge and Soilrupture	Hollow	Hollow	1/3
Rot	perhaps	Injury of the bark	1/3 - 2/3
perhaps	Injury / Injuries	crack / cracks	> 2/3
Choking root	Dogs uric	Sloping Postion	Scars
Ants/insects	Epiphytes	Angle:	Big
Injury / Injuries		Fork	Small
Soil compaction		Resin flow	Missing leading shoot
root formation restricted		(Proliferation)	Epiphytes
in one direction		Epiphytes	
more directions			
Value: 0 - 1 - 2 - 3 - 4 - 5	**Total Value Stem: 0 - 1 -2 - 3 - 4 - 5**		**Value: 0 - 1 - 2 - 3 - 4 - 5**

Minor branches	**Twigs and buds**
Deadwood / Dying of branches	Dead
1/3	a little
1/3 - 2/3	a lot
> 2/3	Injury of leaves
Big Scars	Injury of buds
Epiphytes	few leaves
	some twigs are cut
Value: 0 - 1 - 2 - 3 - 4 - 5	**Value: 0 - 1 - 2 - 3 - 4 - 5**

SUM / 25:

Place of Growth Factor			
Adaption, care	**Architecture**	**Aesthetic**	**Environment**
Stress factors:	fits together with tree	residence whithin tree height distance	darkens the area
de-icing salts	doesn't fit together		Habitat function for:
trampling	Contact with built structures		
few light		impressive because of	protection against
restricted infiltration area	tree as a mark for traffic	height	wind
		growth form	dust
.............%	no visible link to architecture	aesthetic in a group	sun
old / historically / cultural important tree			rain
Value: 0 - 1 - 2 - 3 - 4 - 5	**Value: 0 - 1 - 2 - 3 - 4 - 5**	**Value: 0 - 1 - 2 - 3 - 4 - 5**	**Value: 0 - 1 - 2 - 3 - 4 - 5**

Visibility
public space
private space
distance from public space:
frequency
high
medium
few
visible from:
all directions
.....direction(s)
Value: 0 - 1 - 2 - 3 - 4 - 5

SUM / 12.5:

Notes / Complements:

Form 3. First update of the VAT03 scheme

Appendix 3 Growth factor worksheet

How old is that tree? If you don't want to cut it down to count the annual rings of growth, or if you don't have an increment borer, you can get a fairly good estimate of a tree's age by using a simple technique developed by the International Society of Arboriculture.

Instructions
1. Determine the tree's diameter (inches) at a height of 4.5 feet from the ground.
Diameter = circumference / 3.14 inches
2. Use the table below. The table assigns a growth factor to various tree species.
Multiply the diameter (inches) by the appropriate growth factor.

Example: Your cottonwood tree has a diameter of 18 inches at 4.5 feet from the ground.
18 inches x 2 = 36 years (estimate)

Note: Growth factor numbers are most accurate for trees grown in healthy forests. Street and urban trees often are exposed to stressors such as poor soils, damage from machines and equipment, restricted growing areas, etc. Street and urban trees have different growth factors and they tend to grow more slowly and be weaker than healthy forest-grown trees.

Tree species and	**Growth Factor**
Aspen *spp.*	2
American elm	4
Austrian pine	4.5
Basswood	3
Birch, paper	5
Black cherry	5
Black maple	5
Black walnut	4.5
Colorado blue spruce	4.5
Cottonwood	2
Green ash	4
Ironwood	7
Kentucky coffee tree	3
Northern red oak	4
Norway maple	4.5
Red maple	4.5
Red pine	5.5
River birch	3.5
Scotch pine	3.5
Shagbark hickory	7.5
Silver maple	3
Sugar maple	5.5
White oak	5
White pine	5

Minnesota Project Learning Tree www.mndnr.gov/plt

Appendix 4 Life expectancy of park trees

Table 1. Life expectancy and relation between stem circumference and age phase of trees in Oslo (Source: Bymiljøetaten, Oslo Kommune)

Tree species	Life expectancy in urban envrionment	Average stem circumference in establishment phase	Average stem circumference in half part of growing phase	Average stem circumference in half part of climax phase	Termination phase
Lind	300	27 cm	after 50 years 125 cm	250 cm	376 cm
Maple	200	27 cm	after 40 years 100cm	200 cm	251 cm
Birch	120	27 cm	after 30 years 94 cm	188 cm	226 cm
Elm	200	27 cm	after 40 years 126cm	252 cm	314 cm
Horse chestnut	150	27 cm	after 30 years 94 cm	188 cm	235 cm
Cherry tree	100	27 cm	after 25 years 62 cm	124 cm	125 cm
Oak	500	27 cm	after 70 years 176 cm	352 cm	628 cm
Ash	300	27 cm	after 50 years 125 cm	250 cm	376 cm
Willow	100	27 cm	after 30 years 113 cm	226 cm	251 cm
Alder (black)	100	27 cm	after 30 years 94 cm	188 cm	188 cm
Cottonwood	100	27 cm	after 30 years 94 cm	188 cm	251 cm
Beech	200	27 cm	after 40 years 126cm	252 cm	376 cm
Larch	250	27 cm	after 40 years 100cm	200 cm	314 cm

Table 2. Life expectancy and relation between stem circumference and age phase of urban trees in Oslo (Source: pers. com Anders Often, NINA)

	Forventet alder		Snitt omkrets i ulike aldersfaser			
	Relativ	År	1.Etableringsfase (cm)	2.Vekstfase (cm)	3.Klimaksfase (cm)	4.Avviklingsfase (cm)
Lind	****	450	40	130	250	450
Lønn	***	250	50	120	200	250
Bjørk	**	200	60	120	160	200
Alm	****	450	40	120	300	450
Hestekastanje	***	350	40	120	250	350
Kirsebær	**	160	50	80	130	160
Eik	*****	500	200	400	450	500
Ask	*****	550	250	300	450	550
Pil	***	300	100	200	250	300
Or (svart)	**	200	70	130	170	200
Poppel	****	450	150	250	350	450
Bøk	***	300	80	140	270	300
Lerk	***	250	70	130	190	250
Ikke registrert	ukjent					

Table 3. Suggested life expectancy for urban trees in Oslo based on the average of the suggestions by Anders Often and BYM. The suggested life expectancy of other common species in Oslo are added.

Suggested life expectancies for other tree species in Oslo

English name	Norwegian name	Latin name	Life expectancy (years)
Lind	Lind	Tilia cordata	375
Maple	Lønn	Acer sp.	225
Birch	Bjørk	Betula sp.	160
Elm	Alm	Ulmus sp.	325
Horse-chestnut	Hestekastanje	Aesculus hippocastanum	250
Cherry tree	Kirsebær	Prunus avium	130
Oak	Eik	Quercus sp.	500
Ash	Ask	Fraxinus sp.	425
Willow	Pil	Salix sp.	200
Alder (black)	Or (svart)	Alnus sp.	150
Cottonwood	Poppel	Populus sp.	275
Beech	Bøk	Fagus sp.	250
Larch	Lerk	Larix sp.	250
Blue spruce	Blågran	Picea pungens	150
Pine	Fur	Pinus sp.	250
Douglas fir	Douglasgran	Pseudotsuga menziesii	500
Lawson cypress	Lawsonsypress	Chamaecyparis lawsoniana	500
Norway spruce	Gran	Picea abies	500
Swiss pine	Sembrafuru	Pinus cembra	500

Appendix 5 Common species in Norway

In this section the common tree species in Norway, more specifically Oslo, are listed and described below.

Deciduous trees

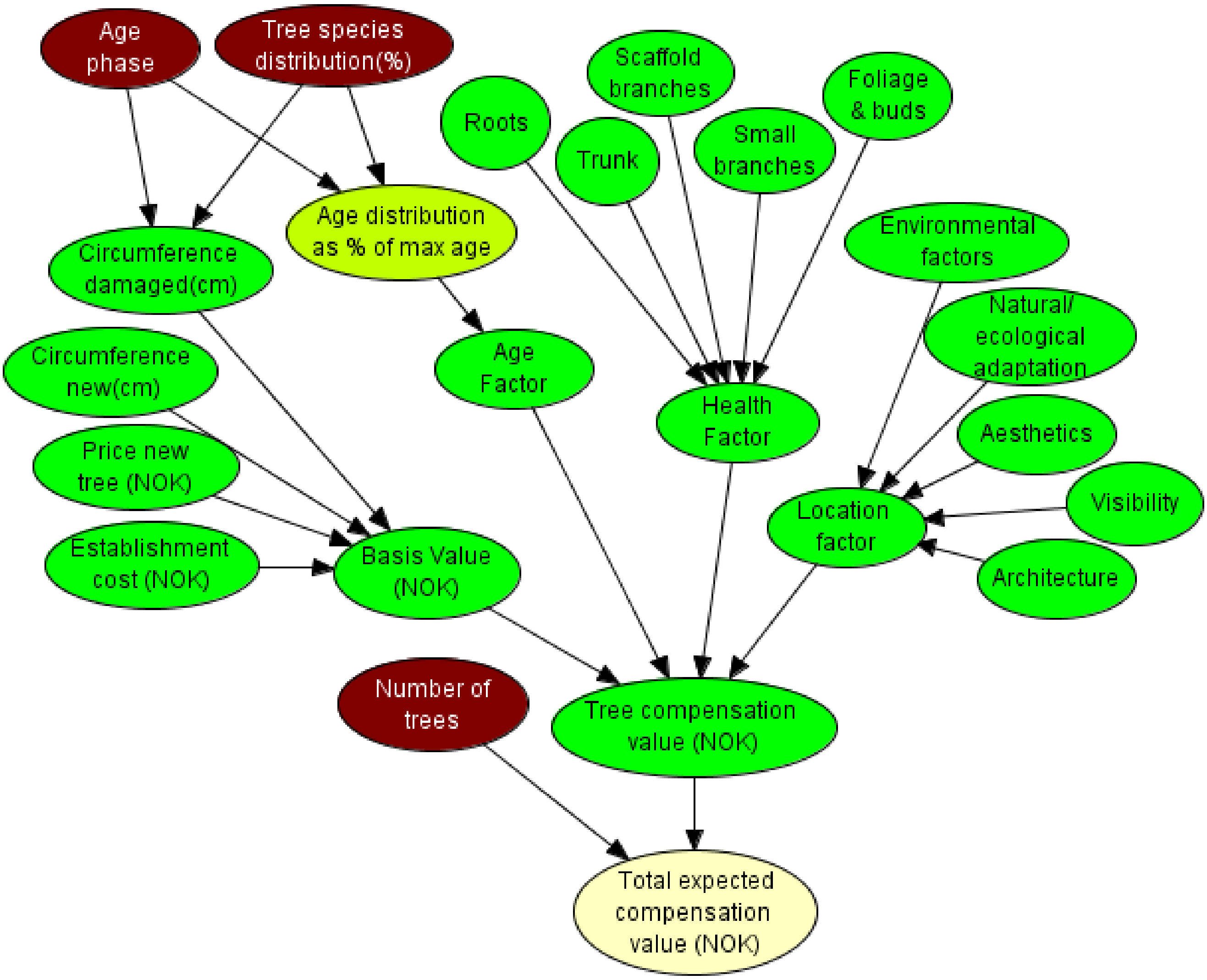
- *Aesculus hippocastanum*: Chestnut tree with a green spiky shell containing one nut.
- *Acer platanoides (cult. Atropurpurea):* Maple with hand-shaped leaves with pointed ends, the cultivar has purple colored leaves and twigs. The leaves are often covered with Mildew during the autumn without severe health effects.
- *Acer pseudoplatanus*: Maple with hand-shaped leaves with rounded ends
- *Alnus glutinosa*: Alder growing on moist soils, for example close to a river. The female catkins are short, oval and brown-reddish, but turn dark brown-black during autumn. The male catkins are long, cylindrical and reddish. The bark has often a lot of cracks.
- *Alnus incana*: Alder that has quite similar catkins as *A. glutinosa,* but distinguishes in bark pattern. The bark is often white spickled and smooth.
- *Betula pendula (rucosa)*: Birch with hanging branches. The twigs feel a bit rough and the leaves are double-toothed.
- *Betula pubescens*: Birch without hanging branches. The twigs contain hairs and the leaves are more rounded and not double-toothed.
- *Corylus avellana*: Common hazel with the well-known eatable hazel nuts. *C. avellana* is considered as a shrub with its multi-stemmed form.
- *Fagus sylvatica*: Common beech with hairy nuts that open through four transversal lines.
- *Fraxinus excelsior*: Ash with composite leaves and black winter buds.
- *Larix decidua*: Larch with soft green needles that are grouped, and turn bright before falling in autumn.
- *Malus sylvestris*: Wild growing apple tree
- *Populus tremula*: Poplar with young heart-shaped to triangular leaves and adult round coarsely toothed leaves.
- *Populus trichocarpa*: Poplar with heart-shaped leaves, but also observed with more triangular leaves. The leaves differ from the young leaves of *P. tremula* as they are glossy. The buds are reddish-brown and sticky.
- *Prunus avium*: Sweet cherry with red glands on the petioles.
- *Prunus padus*: Cherry with small black fruits, eaten by birds.
- *Quercus robur*: Oak with lobed and very short stalked leaves.
- *Quercus petraea*: Oak with less deeply lobed leaves and longer stalks.
- *Salix caprea*: Willow, new shoots sprouting around main stem (proliferation)
- *Salix alba* x *fragilus var. vitellina*
- *Sorbus aucuparia*: Mountain ash with white flowers and red fruits. The leaves are pinnate.
- *Sorbus hybrid*a: Hybrid between *S. aucuparia* and *S. intermedia* with a leaf-shape of *S. intermedia*, but the leaves are pinnate as *S. aucuparia*.
- *Sorbus intermedia*: Whitebeam that distinguishes from *S. aucuparia* by having oval lobbed leaves instead of pinnate leaves. The flowers and red fruits are very similar.
- *Sorbus mougeotii*: Whitebeam that distinguishes from *Sorbus intermedia* by having less deep- lobed leaves, with the lobs more forward pointing instead of spreading.
- *Sorbus rupicola*: Whitebeam with non-lobed, but toothed leaves. The underside of the leaves are densely haired.

- *Tilia cordata*: A linden with rather small heart-shaped leaves. Often forming epicormics shoots.
- *Tilia platyphyllos*: A linden with large heart-shaped leaves. Often forming epicormics shoots.
- *Ulmus glabra*: Elm with composite leaves with a tippy ending.

Evergreen trees

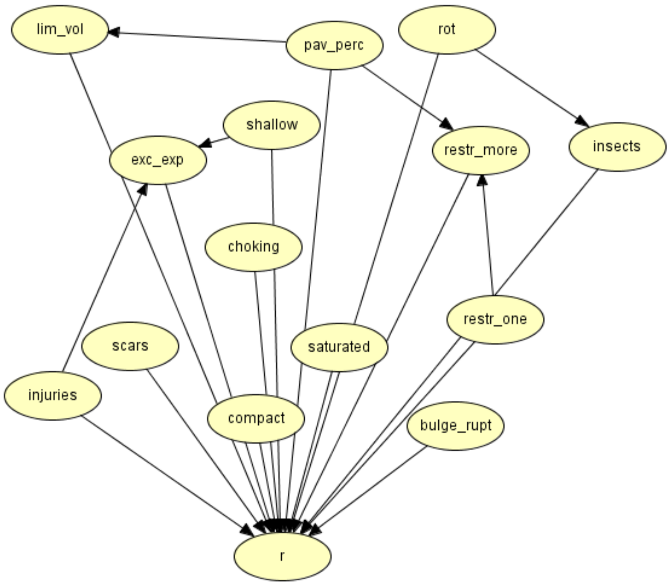
- *Chamaecyparis lawsoniana*: Cypress with feathery foliage in flat sprays, often blue-green coloured. During spring, male red cones are formed on the ends of the foliage. Female cones are small, round and green and become woody and brown when mature.
- *Ilex aquifolium*: Holly with easily recognizable spiny, dark-green glossy leaves and red fruits.
- *Juniperus communis*: Conifer with short stiff needles in rows of three. The fruits are berry-like cones that have a green coating that becomes blue and waxy.
- *Picea abies*: Spruce with short, stiff needles. The cones are long, brown and have pointed scales, though the tip becomes more truncated when older.
- *Picea pungens*: Spruce with a blue-green appearance. The cones have outward spreading scales with a crenate edge.
- *Pinus cembra*: Pine with long soft needles in groups of five. The cones are small and have pointing scales.
- *Pinus sylvestris*: Pine with soft needles, attached in pairs. Reddish stem. Naturally not covered with a lot of epiphytes.
- *Pseudotsuga menziesii var. glauca*: Heighest growing tree in the world. Only few in Norway. Soft long individually planted nails, silvery-green color. The cones are easy recognized by the long pitchfork-shaped bracts.
- *Taxus baccata*: Conifer with flattened dark green needles arranged in a spiral. Seed cones are modified to one seed surrounded by a fleshy scale which develops into a soft, bright red berry-like structure called an arillus.

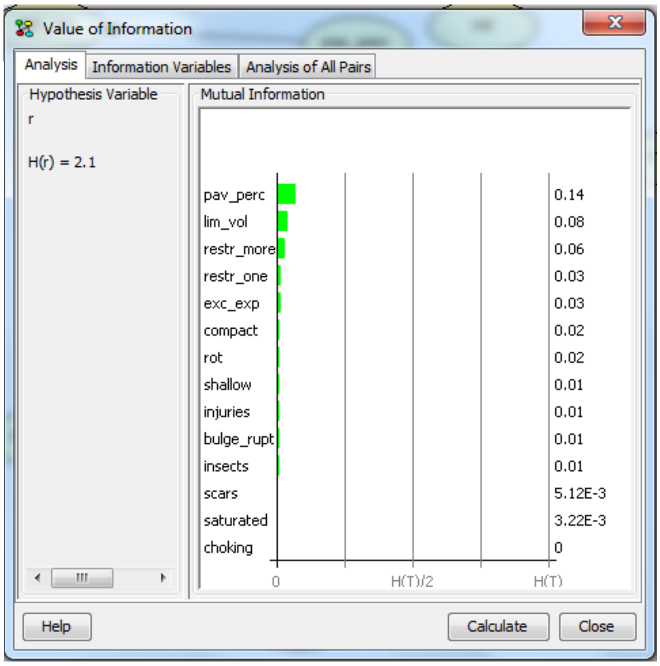
Appendix 6 Network for estimating aggregate compensation value



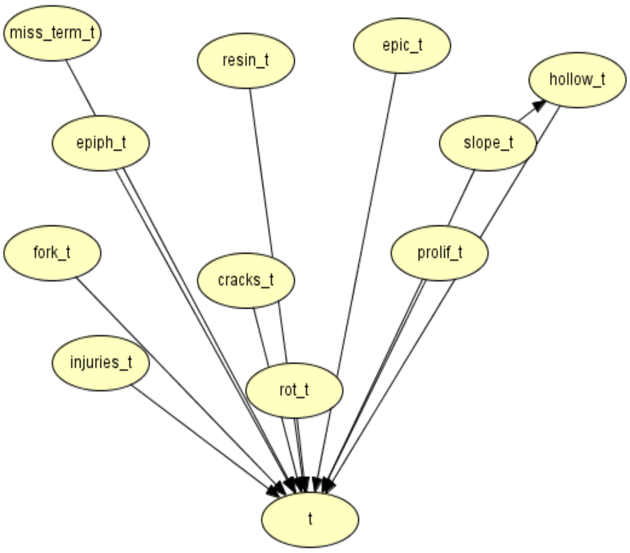
Appendix 7 Value of information analysis of tree features

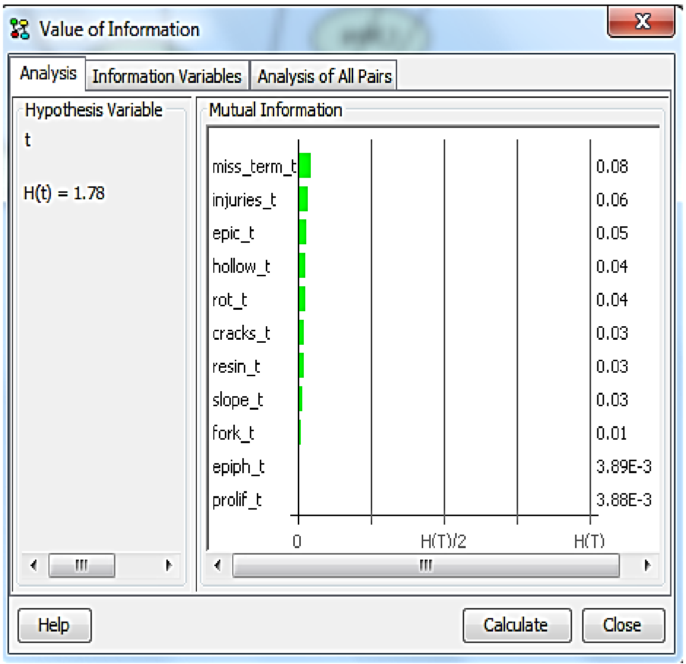
Roots



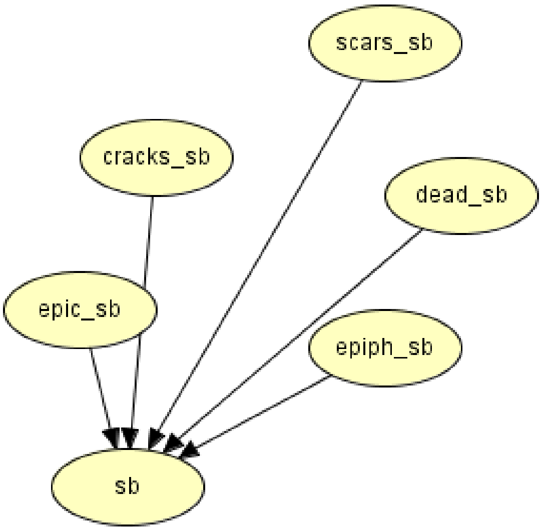


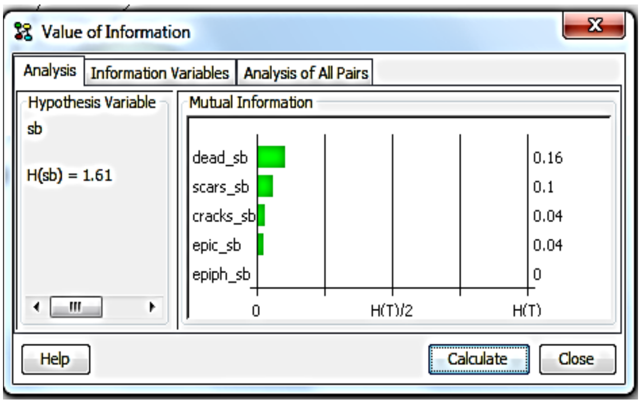
Trunk



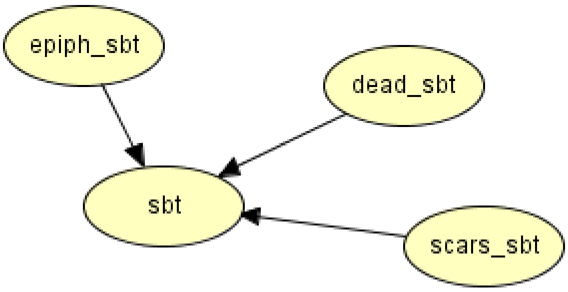


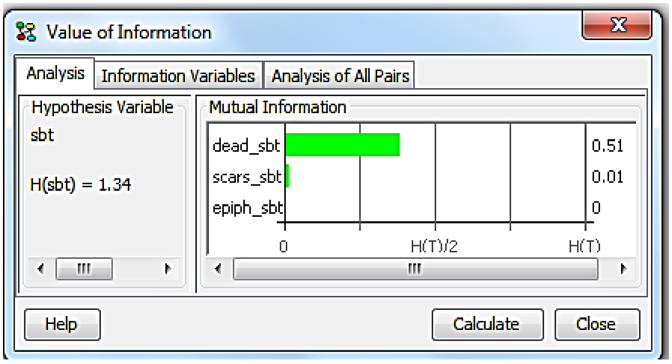
Main Branches



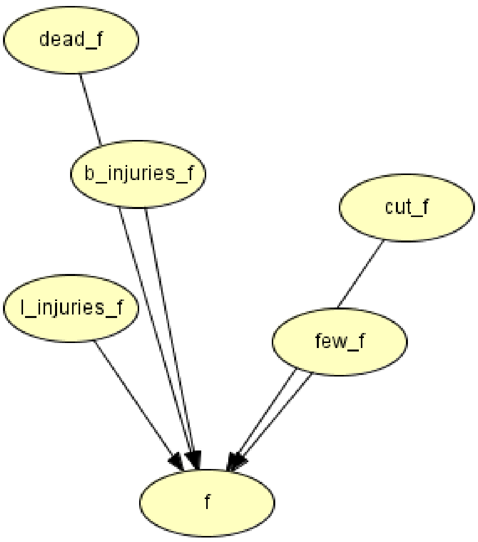


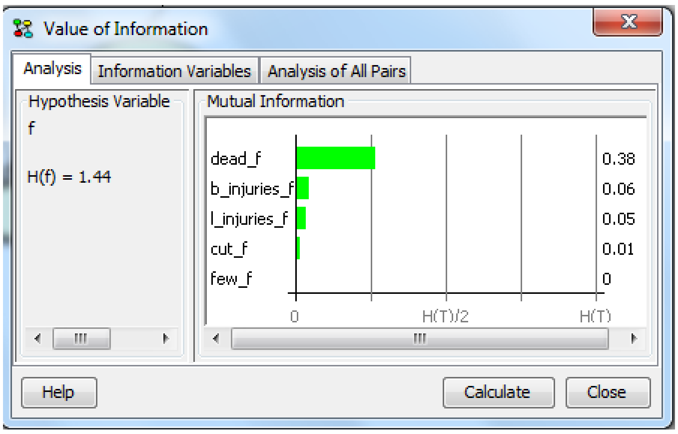
Minor Branches



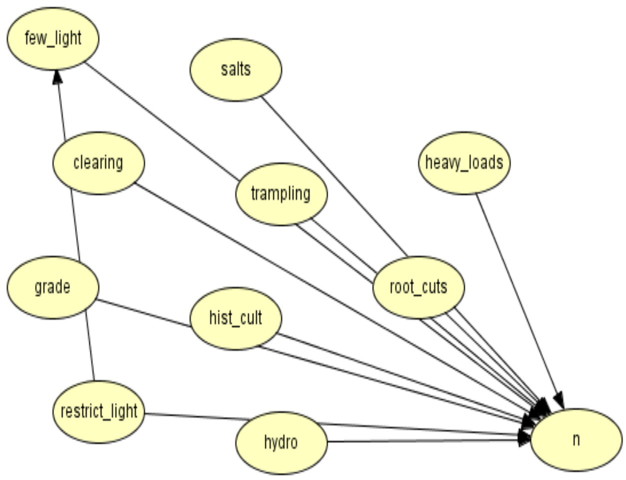


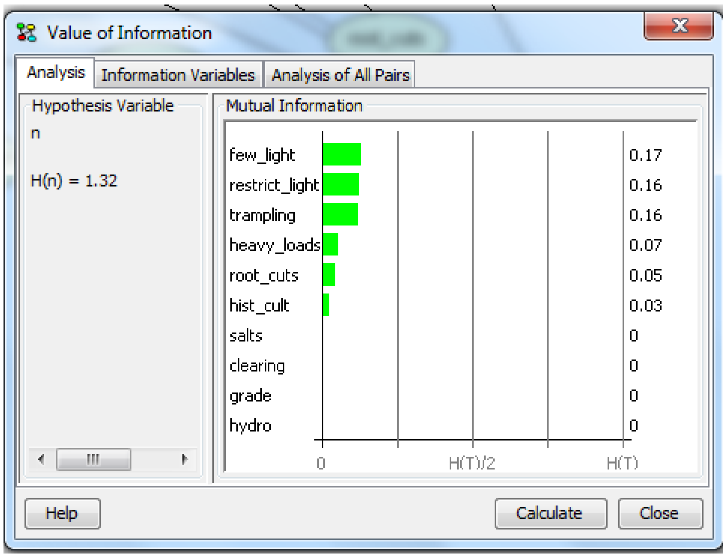
Twigs and Buds



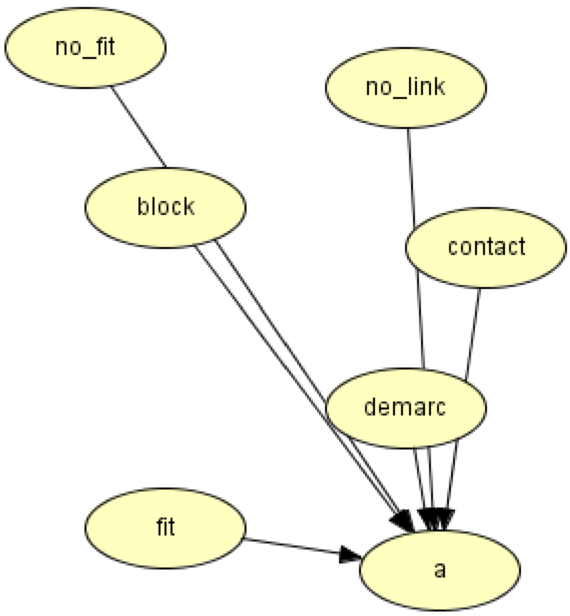


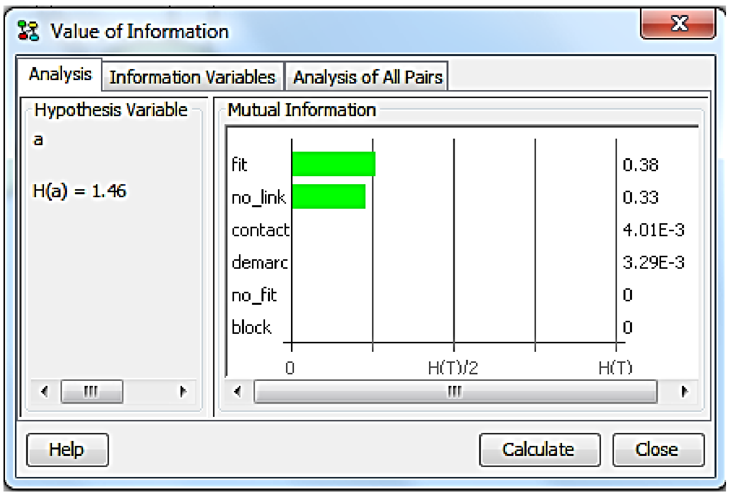
Adaptation and Care



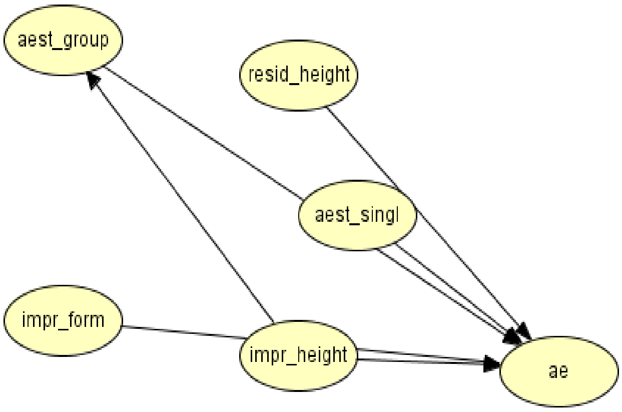


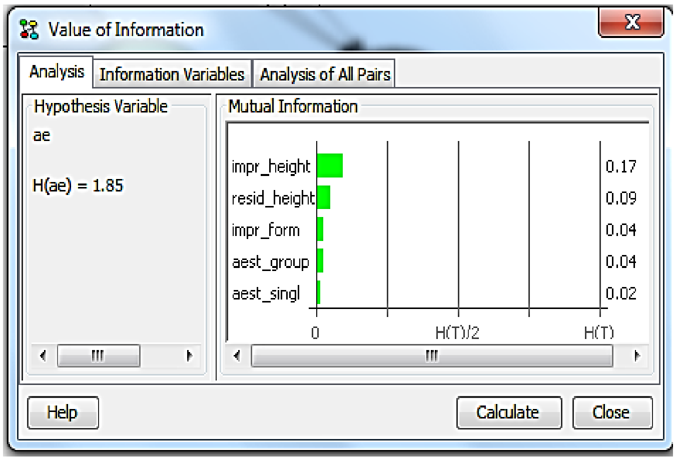
Architecture



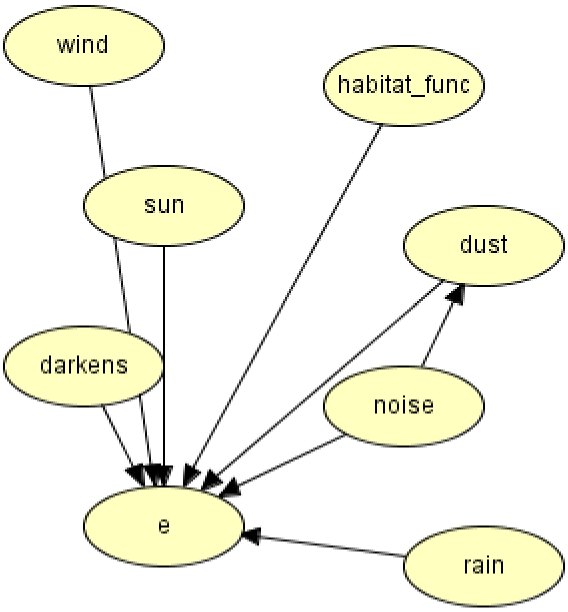


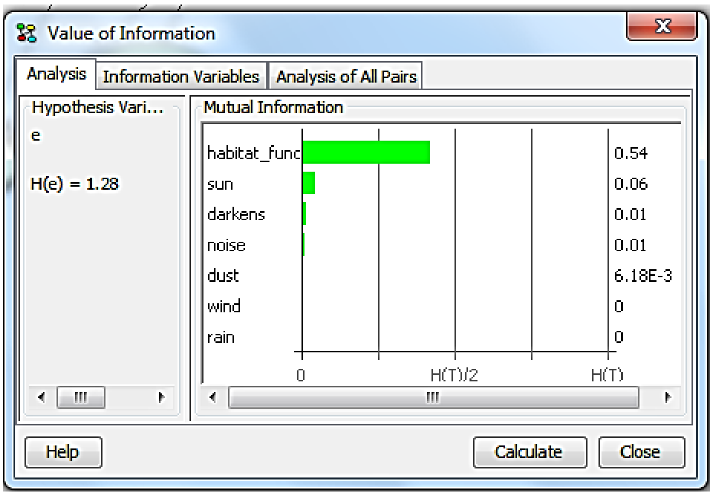
Aesthetics



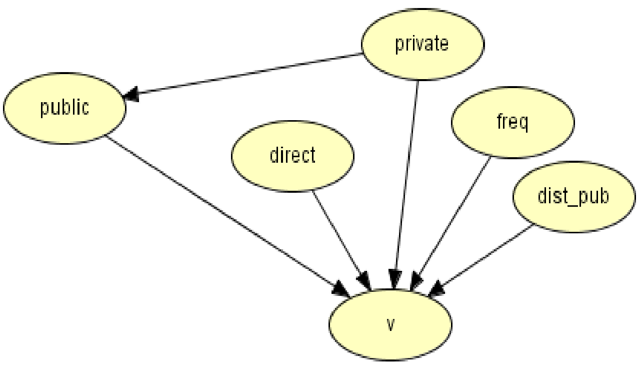


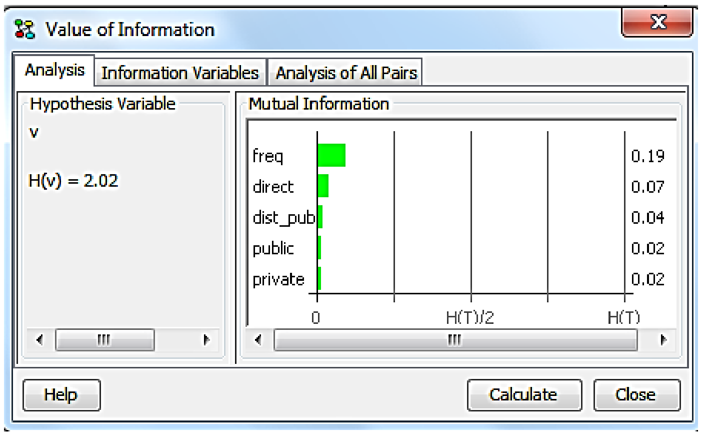
Environmental factors





:Visibility





www.nina.no

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NINA Report

The Norwegian Institute for Nature Research, NINA, is as an independent foundation focusing on environmental research, emphasizing the interaction between human society, natural resources and biodiversity.

NINA was established in 1988. The headquarters are located in Trondheim, with branches in Tromsø, Lillehammer, Bergen and Oslo. In addition, NINA owns and runs the aquatic research station for wild fish at Ims in Rogaland and the arctic fox breeding center at Oppdal.

NINA's activities include research, environmental impact assessments, environmental monitoring, counselling and evaluation. NINA's scientists come from a wide range of disciplinary backgrounds that include biologists, geographers, geneticists, social scientists, sociologists and more. We have a broad-based expertise on the genetic, population, species, ecosystem and landscape level, in terrestrial, freshwater and coastal marine ecosystems.

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Norwegian Institute for Nature Research
NINA head office
Postal address: P.O. Box 5685 Torgarden,
NO-7485 Trondheim, NORWAY
Visiting address: Høgskoleringen 9, 7034 Trondheim
Phone: +47 73 80 14 00
E-mail: firmapost@nina.no
Organization Number: 9500 37 687
http://www.nina.no

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