2.4 Tree Site Improvement and Remedial Measures

1. General objective

This chapter guides the planning and practical performance of a revitalisation project. It will help to improve health, growth and life expectancy of elder urban trees by reducing problems with soil and poor root vitality

2. Specific objectives

A European Tree Technician is expected to be able to:

- through dialog with the client help with a preliminary problem definition and influence the content of the initial assignment. Please refer to the chapter introduction for legal and economic aspects to be aware of.
- carry out a professional diagnosis of the tree health problems. Often a specialist must be consulted for complicated soil/root interactions.
- formulate alternative solutions to improve tree health – also taking work safety, biosecurity and habitat protection into account.
- organise and implement the task
- try to invoke a monitoring of tree increment to evaluate the effects of revitalisation

3. Keywords

“root-friendly” soil horizon	Soil gas exchange	Drainage
Waterlogging	Soil acidity	Soil alkalinity
Anaerobic soil respiration	Fine root turnover	Tree sugar balance
Flaws in the carbohydrate-balance	Techniques to improve quality of the growth media	

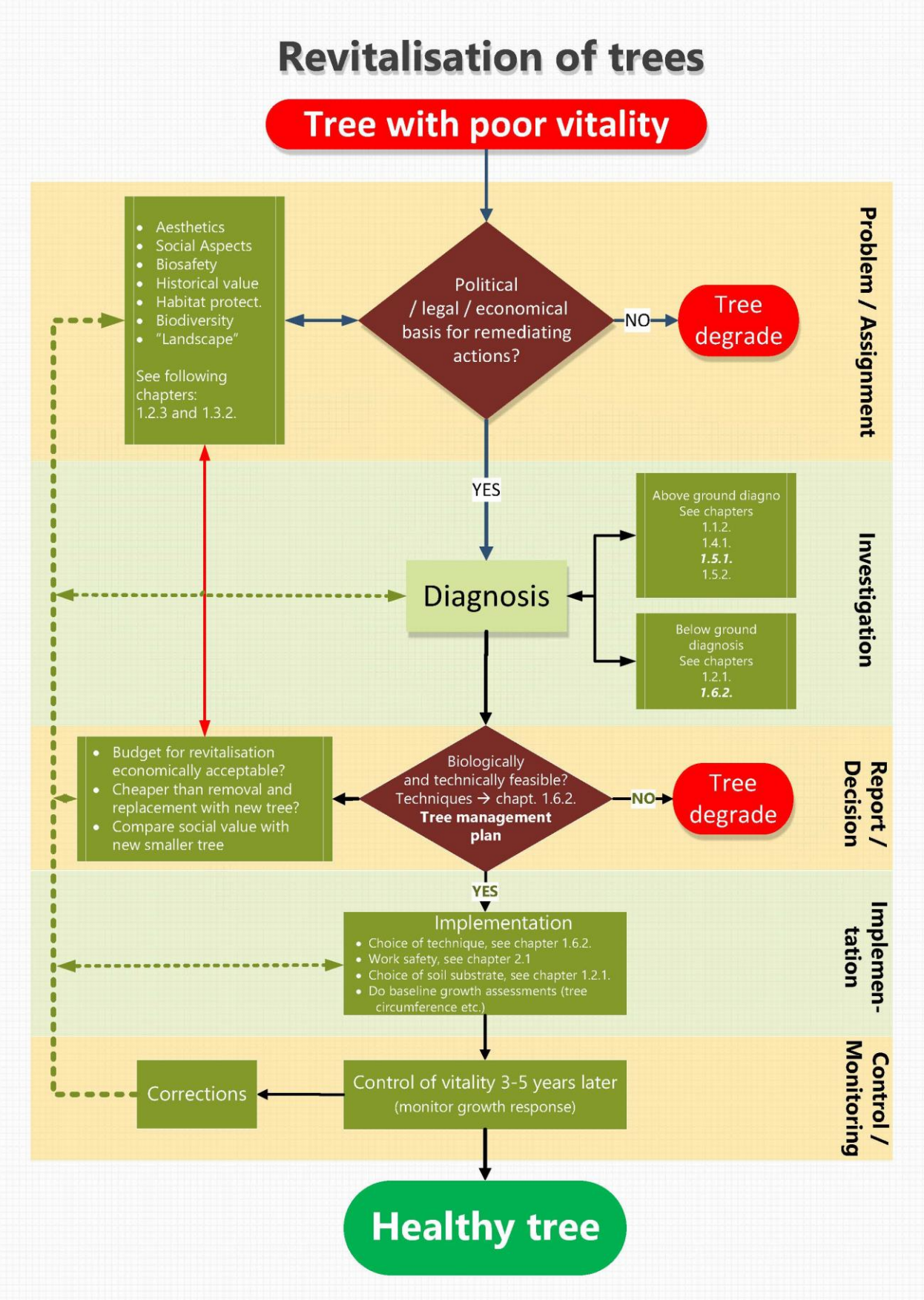
4. See together with

Chapter 1.6.2 and 1.2.1.

5. Essence of the topic

This chapter provides guidance in how to organise a tree revitalisation project from the first contact with the client through implementation and final control of the wanted results. The flow of the process is described and sketched in the shown flowchart.

6. Introduction – the process



Problem definition and assignment

The problem with poor tree vitality is commonly identified by the client (but may also be identified by an ETT during a larger survey). Most clients may recognize a vitality problem but may not have the sufficient knowledge to properly diagnose the problem. Thus, during the initial contact an ETT should stress the necessity of a thorough investigation, but also help the client to perceive the potential full extent of various remedial actions. If the client has a sufficient legal and financial basis for remedial actions, an assignment should be formulated in writing. Please note the general business rules listed at the introduction to chapter 2.

Revitalisation is both relevant for amenity trees ***and*** for veteran trees, because no matter whether the purpose is aesthetics or biodiversity protection, a prolonged remaining life span of the tree is desirable. It is important to realise that the nature conservation value of veteran trees can be dramatically enhanced by improving the carbon-balance of the living parts of tree

Investigation / diagnosis

The tree may have many different damages or health problems. It may be unstable bifurcations in the stem, large dead, broken or pruned branches, stem hollowness, severed roots, fungi attack, crown decline symptoms etc. Many of such problems may be handled directly related to the specific symptom with specific measures (pruning, cabling, fertilisation etc.) – se relevant sections in chapter 1 and 2.

The revitalisation, however, aims at improving the carbohydrate-balance of the tree. Poor carbohydrate balance commonly induces poor vitality – see chapter 1.1.2, **1.5.1** and 1.5.2 for symptoms. An improved carbohydrate-balance will improve increment in general, enhance twig and leaf mass, improve leaf colour, enhance root regeneration and above all: improve the maintenance of barriers for decay within the living woody body. Elder trees always have more or less hidden wounds in roots, stem and crown, where the woody body degenerate and die back. A central purpose of a revitalisation actions is to slow down the speed of decay and degeneration. Or put in terms of urban forest managers: to enhance the remaining life span of the tree by several decades.

The purpose of the investigation is to identify the most critical factors and mechanisms that limits the carbohydrate-balance. This may either be flaws in carbohydrate-production (input=photosynthesis) or mechanisms that heavily consume carbohydrates (output). Sugar-production in old trees is very often limited by poor water-balance, which very often comes back to poor water uptake, which again commonly relate to poor root architecture (poor horizontally AND vertically extension of the root system). Excessive carbohydrate-consumption is not seldomly found in the fine-root turnover complex – refer to chapter 1.6.2.

A correct diagnosis is very important in order to evaluate the feasibility of a revitalisation project and in order to suggest proper measures. It will often be necessary to associate a soil/root-specialist to the project in order to ensure correct diagnosis.

Tools:

- Mallet
- Binocular/drone for study of crown structure and foliation (example: https://www.skovbykon.dk/images/videos/ginkgolav2.mp4, https://www.skovbykon.dk/images/videos/rot_investigation_drone_skovbykon.mp4

- Iron rod for analysis of stem hollowness and for detection of soil compression (test horizontally or oblique in every major soil horizon)
- Spade and hand shovel
- Camera and measuring tape, pen, paper etc. for documentation
- Field tools for pH assessment of major soil horizons
- Brush to clean root samples
- Botany magnifying glass (10x) for study of root surface

Reporting / decisions

Improvement of a tree's biology is always possible. Question is but: Is it possible within an acceptable economic scale. The answer relies on several steps of analysis:

a) Describe the biological/technical measures. Can you formulate alternative measures?
b) Can you provide rough cost levels for each alternative? Do not forget to include the long-term monitoring of effects.
c) The costs for improving the trees remaining life span should be compared with the monetary and social values of the tree. This evaluation may also include the costs for replacement of the old tree with a new one including costs for site improvement.

The report should also be formulated in a way (or at least contain a summary) that it is suitable for dialog between your client and other stakeholders (politicians, community etc). One alternative is always "continue as usual" or removal of the tree.

Implementation

Signs and symptoms that support, contradict or extend the original diagnosis are likely to show up during implementation of the revitalisation operations. Please register such observations.
After ended operation, it is good practice to carry out a baseline-assessment of stem circumference for later simple control of the remedial measures carried out.

Control

It is good praxis to control that the anticipated positive effects on tree vitality are achieved. Visible effects of the revitalisation will often not show up until 3-5 years after implementation, but improved foliage density/colour may show up as the first.
If the tree does not respond to the revitalisation as expected, explanations for this should be searched for. A revised diagnosis and supplementary actions might be necessary.

7. Hints regarding diagnosis / investigation

Before attempting any improvements, carry out a diagnostic analysis including: A) Above ground factors involved in tree degenerations (se chapter 1.5.1. and 1.5.2.), B) Below ground problems. Below ground problems are commonly related one or both of the following factors:

A) Limited root space
B) Poor soil quality

A) Determination of a tree's root space – horizontally and vertically – is very difficult in an urban environment. Not at least because tree roots tend to exploit every found macropore and therefore "run wild" in all different unexpected directions. Such a job is for specialists. However, obvious limitations to root expansion close to the tree should be acknowledged. Root spread in park soils *may* be less complicated.
B) But an attempt should be made to evaluate the soil quality. However, this also constitutes a challenge, because practically all available theories and text books on soil assessment relates to more or less natural soils in forestry or agriculture. Good instructions for assessment of urban soils are missing. Urban soils are affected and often deteriorated by humans and are exposed to different problems compared to "natural soils". The texts of Urban (2008, chapter 7) and EPA (2011) provides some inspiration, but they are not sufficiently "hands on". Great care should be taken not to "copy-paste" guidelines: table 14 in Cappiella et al (2006) is an example of guidelines which should only be followed after thorough analysis. Thus, a few concentrated guidelines are given below.

Former land-use should be noted if possible – particularly with respect to contamination of the soil with pollutants and heavy metals. If the soil is polluted, soil exchange could be a relevant option.
Is the soil recipient for deicing salt from nearby streets or pedestrian paths? Does the soil have a sufficiently course texture and structure to "wash out" salt from the soil column?
The hydrology of the site should be considered. Does the site seem to have a natural vertical drainage through the soil or is surface runoff the primary mechanism of rain water disposal? Will the site be suitable for storm water management? Can the site receive roof water for improved growth conditions?
The soil assessment is always a "must". This job is not easy, because the soil as growth media for tree roots is complicated ecosystem (refer to chapter 1.6.2.).

8. Some technical aspects

Soil biodiversity and old root channels – particularly valuable in deep clay horizons

Deep clayey soil layers may contain old root channels (macropores), which are extremely important for drainage, gas exchange and new root expansion. Such soil horizons are created over 1000's of years and are crucial for the soil biodiversity and soil health. Please take care not to ruin such deeper soil layers.

Rough or gentle techniques for soil work

1. Pneumatic tools (air pressure and vacuum): When the old soil is loosened with an air spade and removed by vacuum, it is possible to work close up to the trees with comparatively little damage to the root

system. Roots below 1-2 mm will be lost, but they regenerate quickly. However, please be careful not to damage the root bark by close up air pressure.

2. Backhoe / ripper / drainage plow etc: When using tools that sever roots, the “critical root zone” (CRZ) should be respected (see chapter 1.6.3). This reduces the possibility to work close to the tree, but may still have a significant effect.
3. Combination of backhoe and manual shovelling: Combining the backhoe work with careful manual soil removal around roots makes it possible to remove soil closer to the tree.

Before the use of technique 2 and 3, gather data about root distribution in order to formulate the “critical root zone” (CRZ).

General root protective measures:

By root work, please note the following: A) Always keep exposed roots moist and protected against sun and light – e.g., with wet burlap, B) try not do damage roots thicker than 30-40 mm, C) whenever such larger roots are severed, they should be treated with a clear cut in order to stimulate regrowth and prevent decay, and D) fine roots will commonly get lost during root exposure, which is a minor problem as fine roots regenerate vigorously given the right growth conditions.

“Critical root zone” (CRZ)

When using one of the rough methods, that sever roots, the “Critical root zone” (CRZ) must be considered (Please refer to chapter 1.6.3. for references to CRZ). Either by doing a prior analysis of root spread or by starting the work at greater distance from the tree and gradually approaching the tree. When digging or ripping, the “Critical root zone” is defined by no (or very few roots) being thicker than 3-4 cm. Please note that the “Critical root zone” varies a lot among tree species and strongly depends on how deeply rooted the soil is.

Correction of soil chemistry

During soil work, low or high pH may be corrected – although this is not an easy job. Ideally soil samples should be titrated in a soil lab to provide us with an idea of the pH buffer in the soil, but in the real world it is very difficult to hit the right dose and get the dose correctly mixed with soil particles. Furthermore, it may take time for the soil to achieve a new pH-balance after addition of either lime or sulphur. One way of minimizing the risk from chemical amelioration is to add our corrective material on spatially limited spots, lines or section. Another method for reducing risk of “running wild chemistry” is to use course material of e.g. course lime instead of common agricultural fine textured lime. An unbalanced nutrient situation may be corrected through use of proper fertilizers. Please also consider the risk of killing roots with overdoses of fertilizers.

9. Technical solutions

Deep ripping

Soil compression in the topsoil is easier dealt with: Mechanical tilling, frost and thaw and root activity will commonly counteract compression of the topsoil. But vehicles with an axle load of more than 5 tons will compress the soil to a depth of 60-70 cm. Loosening of the subsoil is a much larger challenge. Loosening with a backhoe is commonly very effective. Ripping with a 70-100 cm deep “ripper tines”/chisel may also be effective. Soil should be dry during the treatment. Created macropores in soils with a high clay content may close again when clay particles during water infiltration are leaked

downwards. Sandy soils are more likely to gain from deep ripping on the long term. On clay soils deep rooting crops may be considered (canola, alfalfa, lupin) to enhance the creation of deep macropores.

Soil drainage

Water input in large parts of northern Europe is between 600- and 1000-mm precipitation per year. Between 300- and 450-mm water is commonly lost from forest ecosystems via evapotranspiration. Thus, between 300- and 600-mm rain must drain off urban landscapes. This may happen in three ways: A) surface runoff (e.g., to sewer systems), B) horizontal drainage within the soil to low positioned recipients or C) vertical drainage through the subsoil. At any site, where trees are growing, it is useful to spend a few considerations to these basic hydrological issues – not at least to consider how much water will be available for the trees at various soil depths.

Where water stagnates and accumulates in the subsoil, the soil becomes waterlogged. Rain water contains oxygen, but the content of oxygen in soil water is gradually reduced to a critical low level within few days (max within a week). Thus, stagnating soil water quickly becomes anaerobic and toxic to fine roots. After being waterlogged for months also woody roots tend to die, but resistance to waterlogging varies tremendously between tree species.

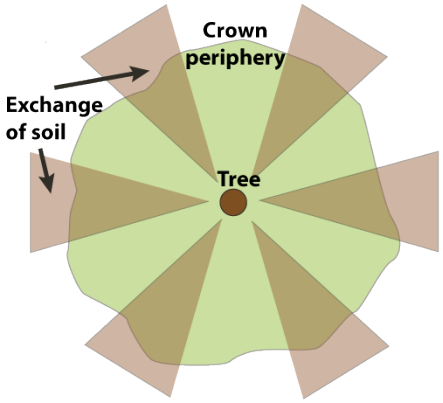
Accumulated free water in the root zone is commonly detrimental to tree health. Where a risk for waterlogging in the subsoil is present, drainage of the subsoil is necessary for good tree growth. Besides, where the outlet of drain tubes is not under water, drain tubes also enhances gas-exchange to the subsoil and we do see that root growth is particularly intensive close to drain tubes in such situations. Trenches with course gravel covered with geotextiles may be used instead of drain tubes. Finding a recipient for the drain water often constitutes a challenge for drainage of urban soils.

Soil profile rebuilding (backhoe treatment)

Where urban soils contain different layers of varying root friendliness, remixing the soil may be useful. This is efficiently carried out with a backhoe. At least this operation may break up compressed soil layers. Please refer to Day (2016). Before carrying out such a profile rebuilding, it should be carefully considered whether the soil texture and structure will be suitable after a remixing. Sometimes supplementary supply of soil materials may be beneficial (e.g. course sand if too clayey, clay if too course material, addition of compost or mull in the upper 25 cm, aeration tubes etc).

Replacement of soil

Poor urban soils are commonly replaced by a specific urban tree soil substrate before establishment of new trees. But soil replacement may also be an option around elder standing tree. When done close to the tree where intensity of course roots (>3 cm) is high, removal of the soil must be carried out using pneumatic tools (Fite 2016). Where replacement is carried out at larger distances from the trees normal digging equipment may be used for removal. Please consider the CRZ. Beside the common root protection guidelines above, please note the following:



1. Please notice that the anchorage/stability of the tree must be maintained during the operation. Therefore, only replace the soil in sections of the root zone (see picture). Best time for this kind of operations is late winter / early spring, in order to provide the roots with a growing season for root regrowth in the new soil.
2. Use refill material that is suitable for the site with regard to traffic load etc.
3. Actions should be taken to ensure proper soil moisture at least during the first growing season after soil exchange.

Air tilling

This method can be used to loosen a compressed topsoil. May be used also to mix down compost into the upper soil. Please refer to Fite (2016).

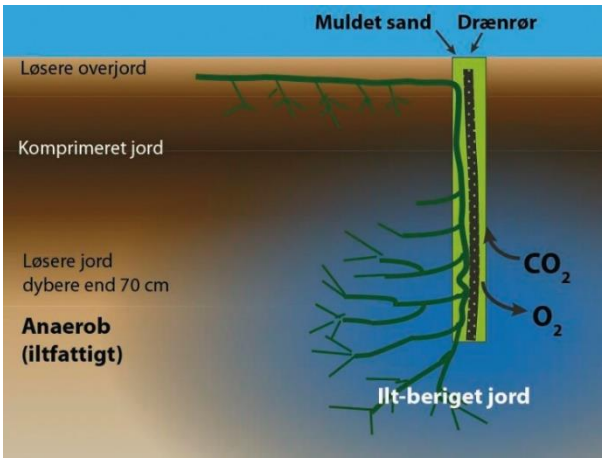
Pneumatic creation of and filling of macropores with compost or other material

A method now widely used in Holland and Belgium is the attempt to loosen up a compressed soil by the means of soil picks (air spade similar tools) and high air pressure. Particularly in soils with high clay content, this operation must be accompanied by insertion of a material, that prevents the created macropores from closure after mud filling. Air pressure creates widespread but most likely only few macropores. This method does not resolve and loose a compressed soil, but it improves the drainage and gas-exchange in the soil to an unknown depth. Depending on the character of the inserted material (crushed lava, biochar, compost) the macropores may be more or less permanent.

Radial trenching

This is either an air tilling or a soil replacement in radial trenches going radially outwards from the tree. Depending on the depth and width of the trenches, this concept is an intermediate technique between the real "soil exchange" and "air tilling" and "vertical mulching". Please refer to Fite (2016).

Vertical mulching (with or without aeration tubes)



Vertical mulching is the creation of vertical holes in the soil, which – after refill – serves both as channels for vertical root growth and as ventilation channels for O_2 (down) and CO_2 (up). Vertical mulching may be appropriate where roots are restricted to grow in a shallow topsoil. However, vertical mulching is not helpful in all cases.

In anthropogenically compressed soils, the major limitation to vertical expansion of the root system is lack of oxygen in the subsoil. In such situations compression may be restricted to the upper 60-80 cm of the soil. If the subsoil below this compressed layer is "root friendly" (or is enhanced in root friendliness by e.g., liming or fertilisation), roots may expand below the compressed layer and thus improve the water balance and health of the tree. However, vertical mulching is not always a proper solution. If the subsoil is waterlogged or otherwise not root friendly, the benefits from vertical mulching may be limited. Some effect may arise from the improved soil gas exchange in the proximity of the vertical borings.

It is recommended to always insert a low diameter plastic drain tube (plugged at both ends) into the bored hole before refilling with a course textured but humus rich material. The top of the drain tube should be lowered about 5 cm below the soil surface and covered with a soil material.

Root collar excavation / studies of root health

One common problem in Arboriculture is "too deep planting". This commonly leads to poor root expansion and not infrequently infections by fungi. Health of the root flare may be improved by a "root collar excavation". Please refer to Fite (2016). Health of supporting horizontal roots after attack by Meripilus giganteus or Armillaria mellea may also be clarified by air spade removal of the top soil around the stem base.

10. Self-check questions

1. Mention typical signs for poor water- and carbohydrate-balance (carbohydrate=sugar, starch etc)
2. At what distance from the tree will you investigate the soil profile in order also to evaluate vertical root distribution?
3. Are you capable of carrying out a diagnosis of the "root friendliness" of soil horizons down to ~1-meter depth?
4. List technical methods for replacing urban soils close to trees and present pros and con's
5. List methods to loosen or drain an urban soil and discuss pros and con's
6. Consider availability and costs of various tools in your region for root work (air spade, vacuumer, backhoe etc.)
7. Which type of mulching is most suitable in your situation?
8. Do you know how to protect exposed roots after soil removal?
9. Can you define the criteria for "critical root zone" (CRZ)?
10. Describe artificial urban tree soil substrates that are suitable for soil replacement around trees.
11. Discuss pro and cons by using vertical mulching versus radial trenching

11. Terminology

Revitalisation	Improvement of trees vitality (carbohydrate-balance)
Critical root zone (CRZ)	The area around the tree containing roots essential for tree health and stability. *The minimum of roots for tree survival*. The CRZ should be defined for every individual tree by a root specialist, but the following diameter limits for roots to be severed may provide some guidance: 25 mm in BSI, 30-50 mm in Östberg and 30 mm in Dworniczak and 30-40 in SkovByKon. This diameter limit should be set individually and much lower for veteran trees. Please refer to chapter 1.6.3 for references.
Deep soil ripping = Sub soiling	Loosening the subsoil with deep tines to break soil compression in deeper soil layers
Aerial digging	Removal of soils with vacuum

12. Reference list

UK	Watson GW, Kelsey P, Woodtli K (1996): REPLACING SOIL IN THE ROOT ZONE OF MATURE TREES FOR BETTER GROWTH. Journal of Arboriculture 22(4), p 167-173.	

UK	Fite K et al. (2016): AirSpade, Technical Applications Bulletin, Use of Compressed Air-powered Excavation for Arboricultural Site Works. Bartlett Tree Research Laboratories	
UK	Day, SD. (2016): Soil Profile Rebuilding: An Alternative to Soil Replacement. City Trees. Sept/Oct 2016.	
UK	Urban, J (2008): Up by Roots. ISA	
UK	EPA (2011): Evaluation of urban soils. Suitability for green infrastructure or urban agriculture. EPA Publication No. 905R1103 https://nacto.org/docs/usdg/evaluation_of_urban_soils_epa.pdf	
UK	Cappiella K, Schueler T, Tomlinson J, Wright T (2006): Urban Watershed Forestry Manual, Part 3: Urban Tree Planting Guide. USDA forest service. https://www.in.gov/dnr/forestry/files/fo-UrbanWatershedForestryPart_3.pdf	
UK	Texas A&M, Forest Service (?): Technical Tree Solutions: Vertical Mulching/Composting, https://tfsweb.tamu.edu/	
DK	Nielsen, C.C.N. (2016b): Træernes indbyggede forældelse. Grønt Miljø 10/2016. Websource: https://www.skovbykon.dk/images/stories/PDF_skovbykon/Traers_ontogenetiske_aeldelse.pdf	
DK	Nielsen, C.C.N. (2017): Revitalisering: Lidende bytræer i kompakt jord får nyt liv. Grønt Miljø 1/2017, p. 4-8. Websource: https://www.skovbykon.dk/images/stories/PDF_skovbykon/Revitalisering_af_bytraeer_ved_daarlig_vaekstjord.pdf	

13. Essential reading

UK	Fite K et al. (2016): AirSpade, Technical Applications Bulletin, Use of Compressed Air-powered Excavation for Arboricultural Site Works. Bartlett Tree Research Laboratories	
UK	Day, SD. (2016): Soil Profile Rebuilding: An Alternative to Soil Replacement. City Trees. Sept/Oct 2016.	
UK	Urban, J (2008): Up by Roots. ISA	
GE	Trafikkontoret Stockholm (2009): PFLANZGRUBEN IN DER STADT STOCKHOLM. EIN HANDBUCH. Chapter PFLANZGRUBENRENOVIERUNG. Websource: https://www.skovbykon.dk/images/stories/PDF_skovbykon/TK_Pflanzgruben_in_der_Stadt_Stockholm_Ein_Handbuch.pdf	
SE	Trafikkontoret Stockholm (2009): VÄXTBÄDDAR I STOCKHOLM STAD. EN HANDBOK. Chapter “VÄXTBÄDDSRENOVERING”. Websource: https://www.skovbykon.dk/images/stories/PDF_skovbykon/TK_Vaxtbaddar_StockholmsStad.pdf	

14. Additional reading

UK	EPA (2011): Evaluation of urban soils. Suitability for green infrastructure or urban agriculture. EPA Publication No. 905R1103 https://nacto.org/docs/usdg/evaluation_of_urban_soils_epa.pdf	
DK	Nielsen, C.C.N. (2016b): Træernes indbyggede forældelse. Grønt Miljø 10/2016. Websource:	

	https://www.skovbykon.dk/images/stories/PDF_skovbykon/Traers_ontogenetiske_aeldelse.pdf	