Stand Density Management Diagram

Supporting Growth and Yield Decision-making

Timber Production

Developing Commercial Thinning Regimes

Craig Farnden, RPF

British Columbia
Forest Service British Columbia
Forest Practices
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More Information on SDMDs

- *Copies of SDMDs and associated training*
  Pat Martin, RPF, Stand Development Specialist
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- *Using* SDMDs *to design thinning prescriptions*
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- *A copy of the publication*
  "Stand density management diagrams for lodgepole pine, white spruce, and interior Douglas-fir" (Farnden, C. 1996. Information report BC-X-360)
  Forestry Canada, Pacific Forestry Centre, Victoria BC
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Overview

Topic

Timber Production: Developing Commercial Thinning Regimes

Objectives

To demonstrate to practitioners the use of stand density management diagrams (SDMDs) to plan commercial thinning regimes, with particular emphasis on timber production.

This document is one in a series of information booklets on using stand density management diagrams (SDMDs)

Topics planned for the series include using SDMDs to manage for timber production, forest health, wildlife habitat, and visual quality

Audience

Silviculturists responsible for developing thinning regimes.

It is assumed that users of this document have a solid understanding of the basic principles underlying SDMDs and site index.

Assumptions and Limitations

SDMDs are decision support tools. They are based on the assumptions that a stand is even-aged, predominantly of a single species, and will grow like a healthy, untreated stand.

The usefulness of an SDMD depends on the user's:

- understanding of its underlying assumptions and applications
- ability to collect stand and site data to locate stands on the diagram
- ability to interpret the range of information contained in the diagram.

The lines in the SDMDs (Farnden 1996) reflect stand conditions in the TIPSY[1] (v. 2.1) managed stand yield tables. As in those tables, the diagrams show *maximum* expected survivorship and yields for *average healthy fully stocked stands*. Under operational conditions, actual yields may be as much as 10–20% less than those suggested by the diagrams, depending on factors such as pest impacts, site occupancy by non-commercial species, or canopy gaps resulting from either poor initial stocking or unstockable ground.

[1] Table Interpolation Program for Stand Yield: a computer database and associated access program containing managed stand yield tables generated by TASS, an individual tree, distance-dependant growth model originally conceived by Dr. Ken Mitchell and further developed by the B.C. Ministry of Forests, Research Branch.

SDMDs should be considered as somewhat less precise predictors of yield than is TIPSY, which in turn is less precise than TASS[2]. SDMDs incorporate a very limited set of stand attributes to facilitate graphical presentations of stand dynamics. This simplification, however, results in a lack of sensitivity to other attributes which may affect yields. A good example of this is the assumption when using SDMDs that thinned and unthinned stands of the same top height and density will have similar development patterns. In reality, trees in these stands will have different crown characteristics and spatial distributions, leading to slightly different patterns of mortality and rates of growth.

Density management diagrams are most useful for depicting development patterns in stands that closely match the assumed structural, stocking, and health conditions noted above. For more complex stand structures, other models such as Prognosis^{BC}[3] or the Mixedwood Growth Model[4] (MGM) may be more suitable.

Acknowledgements

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Instructional format; project coordination: Cortex Consultants Inc.

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[2] TASS (Tree and Stand Simulator): An individual-tree, distance-dependent growth model developed by the B.C. Ministry of Forests. Output from this model, through managed stand yield tables in the TIPSY v 2.1 software, forms the basis for all the SDMDs discussed in this document.

[3] Prognosis^{BC} is an individual tree, distance independent growth model developed by the U.S. Forest Service and adapted for use in southern BC by the BC Ministry of Forests.

[4] MGM is an individual tree, distance independent growth model developed at the University of Alberta for use in boreal mixedwoods.

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Introduction

Stand density management diagrams (SDMDs) are powerful tools for understanding patterns of development in even-aged, single-species stands. They are useful for:

- visualizing stand development over a wide range of establishment densities
- exploring the array of potential density manipulations that can be implemented as part of a silvicultural regime
- comparing thinning regimes (timing, intensity, frequency) and their impacts on stand development
- illustrating (in a silviculture prescription or in a teaching situation) the expected changes in stand development resulting from a particular silviculture regime.

With practice, SDMDs can help silviculturists to quickly find a small set of treatment options that satisfy a specified set of management objectives. Where possible, SDMDs are best used in conjunction with other more robust models such as TASS to refine treatment regimes or undertake additional analyses (e.g., financial).

This document describes how SDMDs can be used in the development of commercial thinning regimes.

This document describes how SDMDs can be used in the development of commercial thinning regimes

Commercial Thinning Concepts

Objectives for Commercial Thinning

Commercial thinning (CT) is carried out to:

- obtain mid-rotation yields
- harvest timber that would otherwise die because of competition-induced mortality
- keep stocking at the optimum level needed to maximize volume yield (this objective applies to the frequent light thinnings practiced in some locations in Europe, but rarely—if ever—in British Columbia)
- manipulate stand structures to produce specific products and stand values.

Commercial thinning generates revenue

By definition, CT generates revenue. Whether, and how early in the rotation yields can be obtained from CT, depends largely on when enough volume can be obtained from thinning to make the operation financially viable.

Impacts of Thinning Intensity on Volume Production

Thinning frequently and lightly maximizes volume production

Thinning frequently and lightly to maintain full stocking maximizes volume recovery. In a perfect (but impractical) regime, frequent light thinnings would be used to capture both competition-induced mortality in small trees and occasional irregular mortality in large trees just prior to tree death. In this way, less volume would be lost to mortality and yield would approach maximum gross volume production.

With heavier, less frequent thinnings, yield is lower due to temporary periods of less-than-full site occupancy (following thinning) and occasional irregular mortality losses before the next thinning entry.

Frequent, light thinnings can increase yields 5–10% over an unthinned stand; infrequent heavy thinnings can reduce yields by a similar or greater amount.

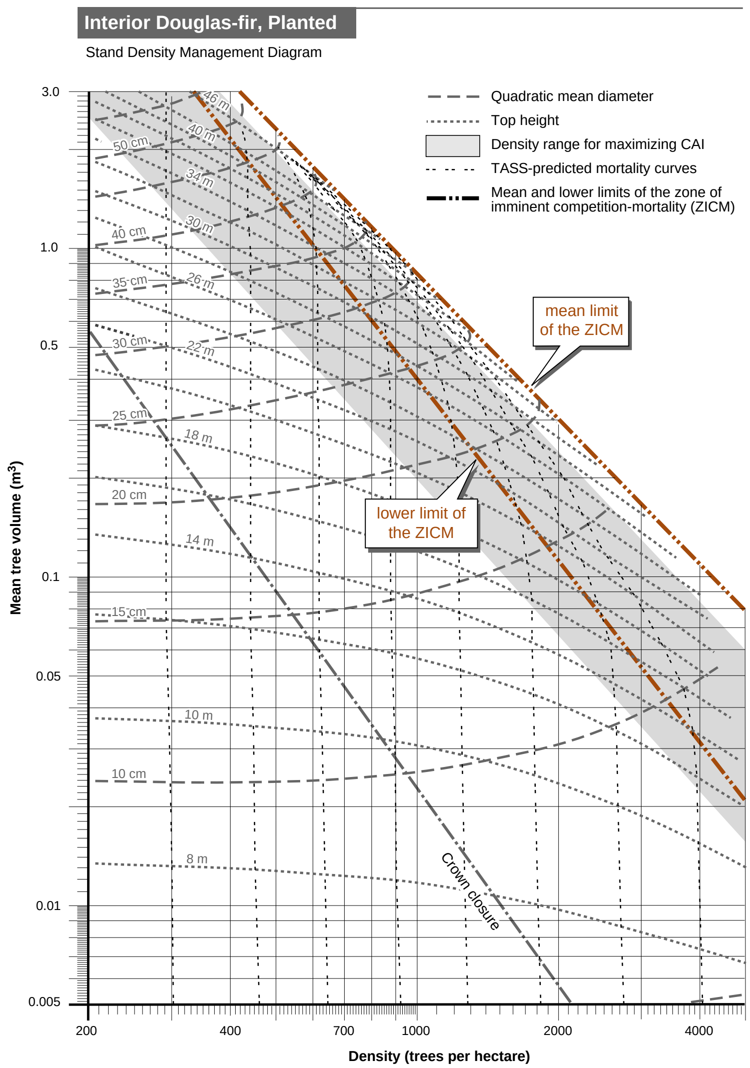
Zone of Imminent Competition-Mortality (ZICM)

As trees in an even-aged, single species stand grow they eventually get large enough that they begin to compete for growing space. With continued growth, crowding becomes more severe and the weakest individuals decline in vigour and approach death. Further expansion of the dominant crowns causes smaller trees to die and results in more growing space being occupied by fewer individuals. This process is called “self-thinning.”

On an SDMD, the zone of imminent competition-mortality (ZICM) shows where self-thinning occurs. The lower limit of the ZICM, where self-thinning first begins to accelerate, is often used as a guide for locating stand conditions optimal for CT treatments and final harvests (Figure 1).

The ZICM shows where self-thinning occurs

Figure 1 Zone of imminent competition-mortality (ZICM)



While the lower limit of the ZICM is a convenient reference point for planning density management regimes, the stage at which a particular stand begins to self-thin is neither fixed nor so clearly identifiable. The ZICM boundaries drawn on the SDMDs in this document represent the author's visual interpretation of the transition between a growth phase that is relatively free of mortality, and one in which mortality from competition is significant. This boundary is actually a broad transition phase rather than an abrupt line. Self-thinning in any given stand may begin several years before or after that suggested by the lower limit of the ZICM.

The ZICM is used as a guide to identify stand conditions for CT and final harvest

The examples in this document use the lower limit of the ZICM as a guide for identifying optimal stand conditions for commercial thinning treatments and final harvests. This assumes that it is appropriate to let stands grow at the highest stocking level possible to maximize volume growth while avoiding volume lost to mortality as a stand self-thins. It should be noted that there are many situations in which thinning guidelines other than the lower limit of the ZICM are appropriate.

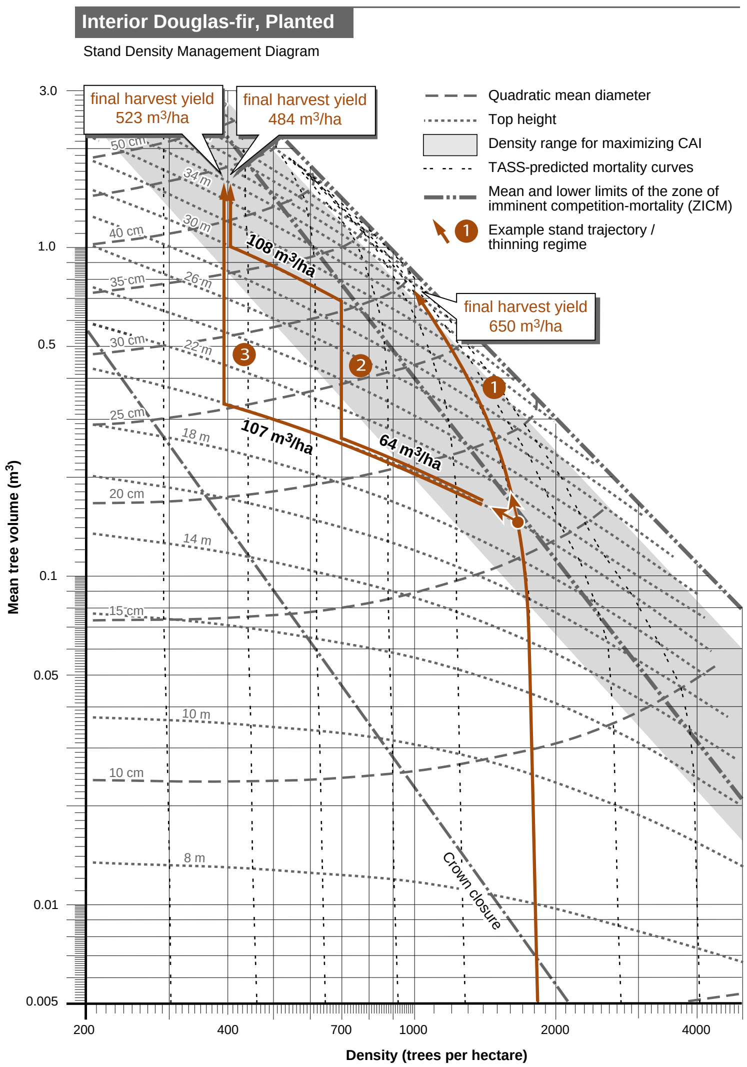
Designing a Commercial Thinning Regime

A CT regime balances revenue generation with stand management requirements

From a timber production perspective, decisions on timing, intensity, and frequency of thinning depend on factors such as total rotation financial analysis (balance of discounted costs and revenues), fibre flow requirements, and stand structural objectives. Deciding when, how frequently, and how much to thin requires balancing revenue generation and fibre flow with stand management requirements. Removing enough volume to make an operation financially viable or to meet periodic fibre flow requirements must be balanced against leaving enough residual growing stock to adequately utilize the growing space on the site. Post-thinning stocking levels should be high enough to maintain desired growth rates without being so high that self-thinning mortality occurs prior to the next entry.

Figure 2 illustrates three density management regimes for a planted stand of interior Douglas-fir with a site index (SI_{50}) of 24 m: no thinning 1 ; two moderate intensity thinnings 2 ; a single heavy thinning 3 .

Figure 2 Alternate thinning regimes, simulated by TASS and superimposed on an SDMD



Comparing thinning and final harvest volumes for three density management regimes

Table 1 shows the thinning and final harvest yields associated with each regime. The first and second regimes have very similar yields, while the yield from the single heavy entry is about 4% lower.

Table 1 Thinning and harvesting yields for each of three density management regimes (as simulated by TASS)

	Density management regime	**Yield from thinning** (m^3/ha)	**Yield at final harvest** (m^3/ha)	**Total harvested volume** (m^3/ha)
1	no thinning	0	650	650
2	two moderate thinnings	172	484	656
3	one heavy thinning	107	523	630

Table 2 compares the periodic annual growth rates (PAI) of these three regimes. Moderate thinning 2 maintains the stand's growth comparable to no thinning 1, but heavy thinning 3 reduces the stand's growth during the first 15 years (5 m top height) following thinning. In the last 40 years (10 m top height) of the regime, PAIs are similar for all three stands.

Table 2 Periodic growth (PAI) for each of three thinning regimes (as simulated by TASS)

		PAI (m^3/ha/yr)		
Height range	**Age range**[a]	1	2	3
20–25 m	46–61 yr	10.2	10.0	8.3
25–30 m	61–79 yr	9.0	9.3	9.1
30–35 m	79–101 yr	6.9	7.1	7.2

[a] The total age for each height range was derived from site index curves.

Using SDMDs to Plan Commercial Thinning Regimes

Two examples are provided to illustrate some of the techniques that can be used in designing CT regimes using SDMDs. The reader is encouraged to view these examples as a framework for exploring options rather than as rigid steps to finding discreet solutions.

Example 1: Identify earliest commercial thinning opportunity

The earliest CT opportunity is when there is enough merchantable volume to cover the cost of thinning and enough residual stocking to maintain full volume production

Finding the earliest opportunity for a viable commercial thinning entry in a stand is often an important step in exploring a range of density management options. Such an exercise might be applied, for example, to determine the subset of current stands of suitable age for thinning at a discrete time period in the future.

The *earliest* opportunity for a CT occurs when there is sufficient merchantable volume in the stand to pay for removal of some stems and leave sufficient residual stocking to maintain full volume production.

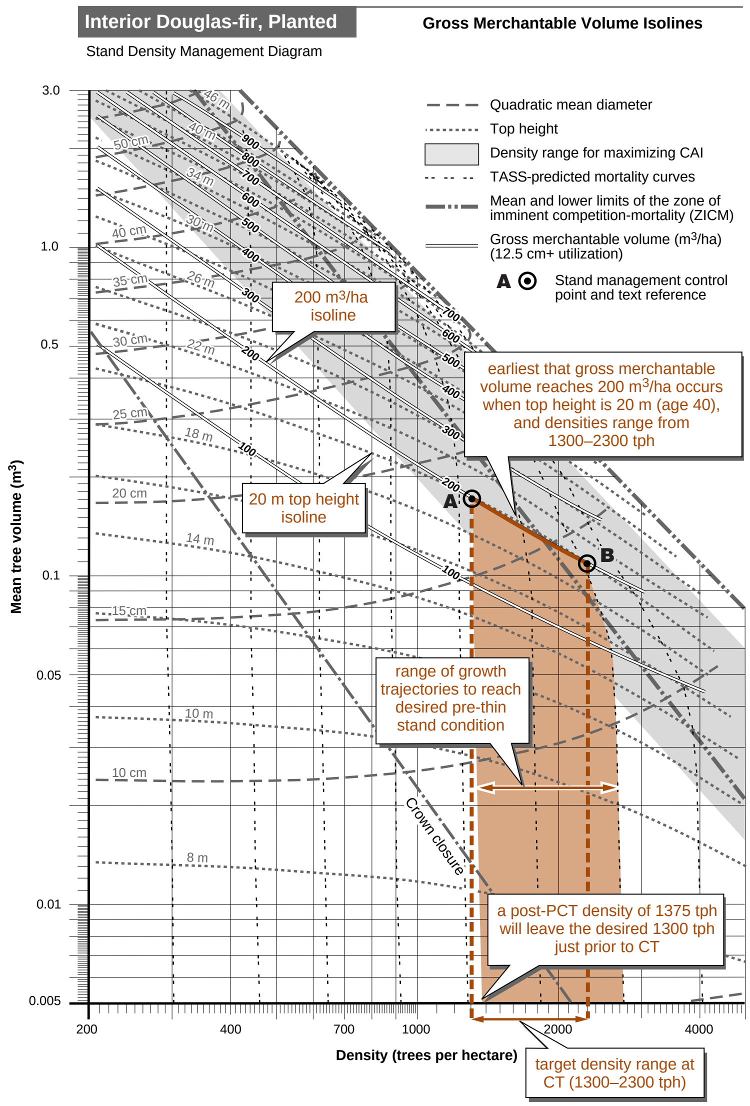
In this example, assume that the minimum volume needed for a financially viable stand entry is 60 m^3/ha, and the maximum acceptable removal is 30% of the stand's merchantable volume in one entry. Therefore, there must be a minimum merchantable volume of about 200 m^3/ha in the stand before thinning.

Merchantable volume is a poor measure of thinning intensity, particularly for a first entry when a significant proportion of the stand may still be below merchantable size. It is, however, an important factor because of its influence on the financial viability of treatments. For early thinnings of moderate intensity with a 12.5 cm merchantability limit, the percent merchantable volume removed will be approximately 10 percentage points lower than percent basal area removed (i.e., a 40% basal area removal will roughly equate in most situations to roughly a 30% volume removal). For later thinnings, these values will converge to within 3–5 percentage points.

Once the target pre-thinning merchantable volume has been determined, the matching merchantable volume isoline can be highlighted on the SDMD (Figure 3). The earliest CT opportunity occurs where the lowest top height isoline intersects this minimum merchantable volume isoline[5].

[5] While the SDMD has no time scale, top height can easily be converted to age using site index curves. See Example 2, Figure 4.

Figure 3 Maximum merchantable volume for a given height/age occurs at a range of densities



In this example, the earliest that the minimum merchantable volume of 200 m^3/ha can be reached is at a top height of 20 m (Figure 3). The 200 m^3/ha volume can be achieved over a range of densities bounded by points **A** and **B**, but declines at densities outside of this range.

Given a minimum merchantable stand condition, there will always be a distinct range of densities at which the target volume can be achieved. For higher or lower densities, it will take longer to achieve the same merchantable volume (the impact of higher densities disappears for most mid- to late-rotation CT treatments and final harvests, as a higher proportion of the total stems has passed the merchantability threshold).

For a given a minimum merchantable stand condition, there will always be a distinct range of densities at which the target volume can be achieved

In this example, the minimum volume (200 m^3/ha) is reached at the same time in the future for densities ranging from 1300–2300 tph (Figure 3). The lowest density at which the minimum volume is reached is approximately 1300 tph, point **A**. The lines bounding the brown-shaded zone (drawn parallel to the mortality lines) and approaching points **A** and **B** show the stand development patterns after planting or PCT. They indicate establishment (or post-PCT) densities of 1375 tph to achieve 1300 tph at 20 m, or 2750 tph to achieve 2300 tph at 20 m. The difference between 1375 and 1300 tph (or 2300 and 2750 tph) is the predicted mortality between the PCT and first CT entry.

Once the pre-thinning density range has been quantified, stand density can be controlled with plantation espacement or pre-commercial thinning (PCT). In many cases, factors such as CT operating costs and value of thinned materials will suggest selection of lower densities within this range (the number of pieces harvested will be lower and average piece size will be larger). Other considerations, such as habitat, pest risks, or wood quality may also influence the choice of density.

Example 2: Planning a Commercial Thinning Regime for Specific Objectives

SDMDs are useful for visualizing entire stand management regimes, and searching for potentially feasible options. They are particularly useful for identifying critical decision or "control" points when planning CT for a particular stand. Five steps are suggested in designing a stand density management regime involving CT:

1 Identify target stand condition at final harvest
2 Identify critical time periods for thinning
3 Check viability of thinning entries
4 Check potential for additional thining entries
5 Test selected thinning regimes.

An example stand is used to illustrate the steps.

The example uses a timber production emphasis and focuses primarily on volume production as the measure of success

The steps can also be used to manage for other objectives

Example Stand Description and Management Objectives

A young stand of productive Interior Douglas-fir (SI_{50}=24 m), located in a management zone with long rotations (>130 yr) to meet wildlife habitat requirements, is being considered for pre-commercial thinning. A timber supply shortfall is expected for the forest management unit when this stand is 55 to 65 years old. Thinning volumes from stands committed to long rotations could provide supplementary fibre to help fill the projected shortfall. The minimum thinning volume assumed to be financially viable is 60 m^3/ha, and the maximum acceptable removal 40% of basal area (approximately 30% of merchantable volume). The silviculturist must design a stand management regime to meet the wildlife habitat requirements of the management zone and to contribute fibre from commercial thinning during the period of projected timber supply shortage.

Step 1: Identify target stand condition at time of final harvest

Step 1 defines the control points to meet the desired management objectives

Define the parameters that control the timing of final harvest

These could include a target piece size, a need to maximize mean annual increment (MAI), time to achieve minimally acceptable harvest volumes, meeting forest-level wood flow needs, or (this example) providing a particular stand structure to meet wildlife habitat requirements.

Identify the target final-harvest stand condition

If maximizing volume production is important, then final harvest will likely take place around the culmination of MAI. In most cases, culmination age for a thinned stand will be slightly later than for an unthinned stand, so use TIPSY to obtain a preliminary estimate of culmination age for an unthinned stand and add 5–10 years.

If average stand diameter is used, it is important to evaluate the feasibility of the chosen value. A common error when using SDMDs is to set final-harvest targets based on average stand diameter without checking to see if that target can be achieved within a reasonable time. It is also important to consider the range of piece sizes, in addition to the average piece size that will be available. The largest pieces produced will often be of greater concern than the rest of the diameter range.

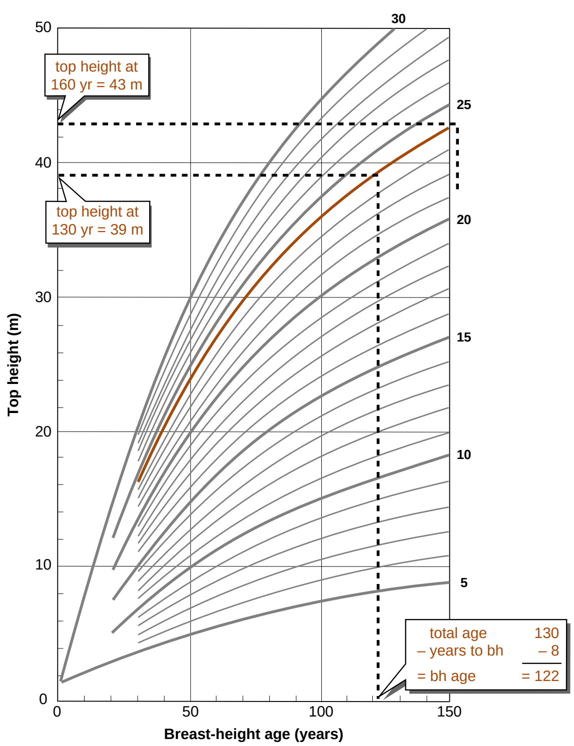
For the example stand, wildlife habitat requirements control the timing of final harvest, and the target condition of the stand at final harvest is 130–160 years old.

Since age is not shown on an SDMD, the final-harvest age must be converted to top height using the appropriate site index curves.

For the example stand (SI_{50}=24 m), the equivalent top heights at 130–160 years old are about 39–43 m (Figure 4).

Since age is not shown on an SDMD, the final-harvest age must be converted to top height

Figure 4 Converting stand age to top height using site index curves (example for Interior Douglas-fir)



Site index	5	6	7	8	9	10	11	12-13	14-15	16-18	19-22	**23-28**	29
Years to bh	24	21	18	16	15	14	13	12	11	10	9	**8**	7

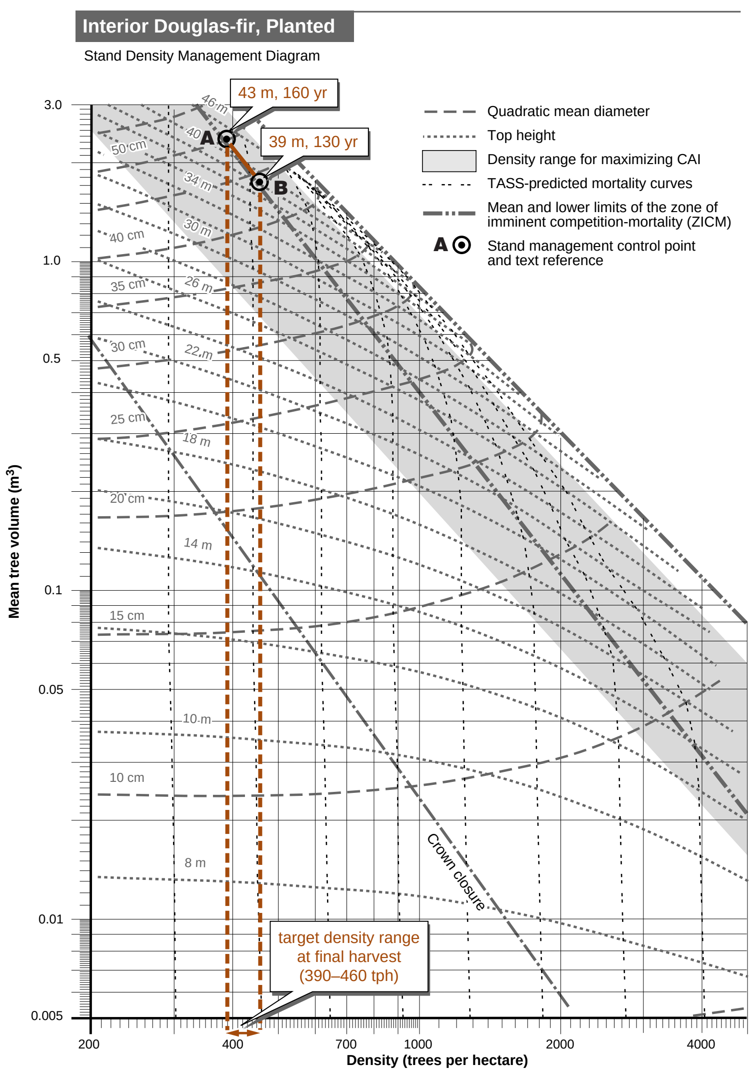
Plot target stand condition for final harvest

On the appropriate SDMD, plot the two points where the chosen top-height isolines intersect the lower limit of the ZICM (Figure 5, points **A**, **B**). These *control points* are the upper and lower ages/heights for the target final-harvest stand conditions. They define the boundaries of the range of possible trajectories under consideration.

In the example stand, the target height range of 39–43 m intersects the lower limit of the ZICM to indicate a final-harvest density range of 390–460 trees per hectare (Figure 5).

Identify the upper and lower top heights for the target final-harvest stand conditions

Figure 5 Identify final-harvest target stand density



Step 2: Identify critical time periods for thinning

SDMDs can be used to define a range of target stand conditions that will provide thinning yields at critical times such as periods of anticipated timber supply shortages.

In the example stand, it is desirable to thin when the stand is 55–65 years old to provide wood to help offset a projected timber shortfall in the management unit.

Determine the height range of the candidate stand during the critical period using the appropriate site index curve (as in step 1)

Converting age to top-height as demonstrated in step 1, the example stand will be 23–26 m in top height at ages 55–65 years.

The desired thinning at 55–65 years converts to 23–26 m top height

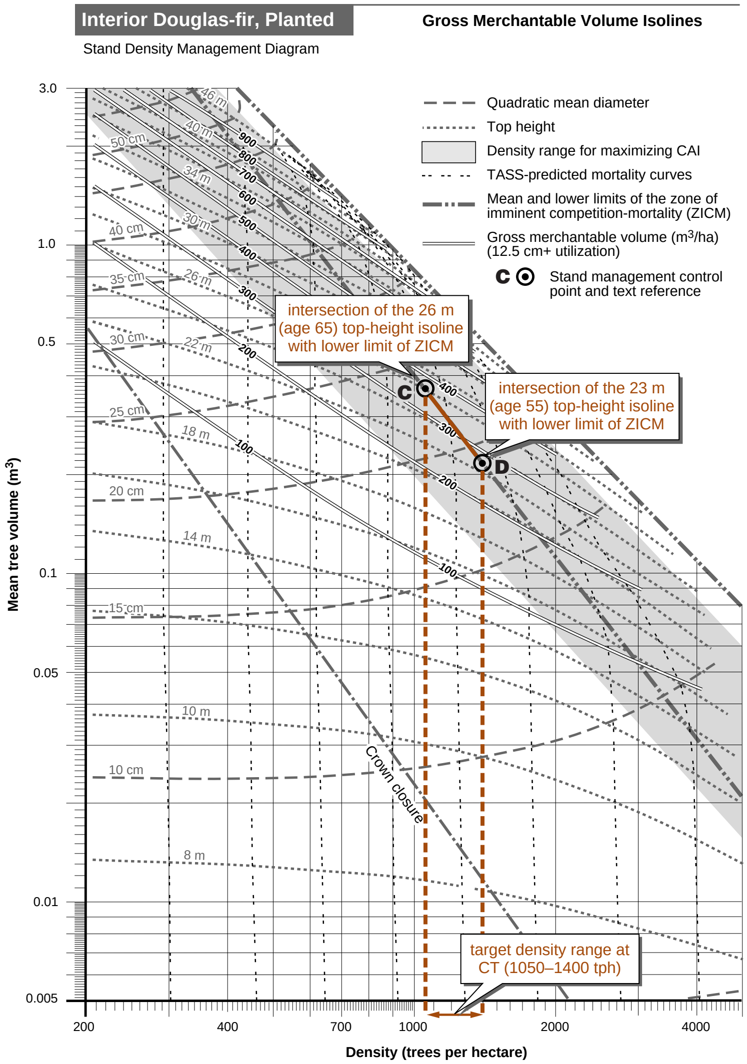
Plot the intersections of the appropriate top-height isolines with the lower limit of the ZICM (Figure 6)

These control points **C**, **D** bound the range of stand conditions (age/height and density) for which thinning could be used to generate timber yields to mitigate the projected shortfall.

In the example, thinning volumes can be generated at stand densities of 1050–1400 tph.

Figure 6 Identify a range of stand conditions that will provide yields from thinning during the desired time period

Points **C** *and* **D** *indicate the range of stand conditions that will provide the needed thinning volumes*



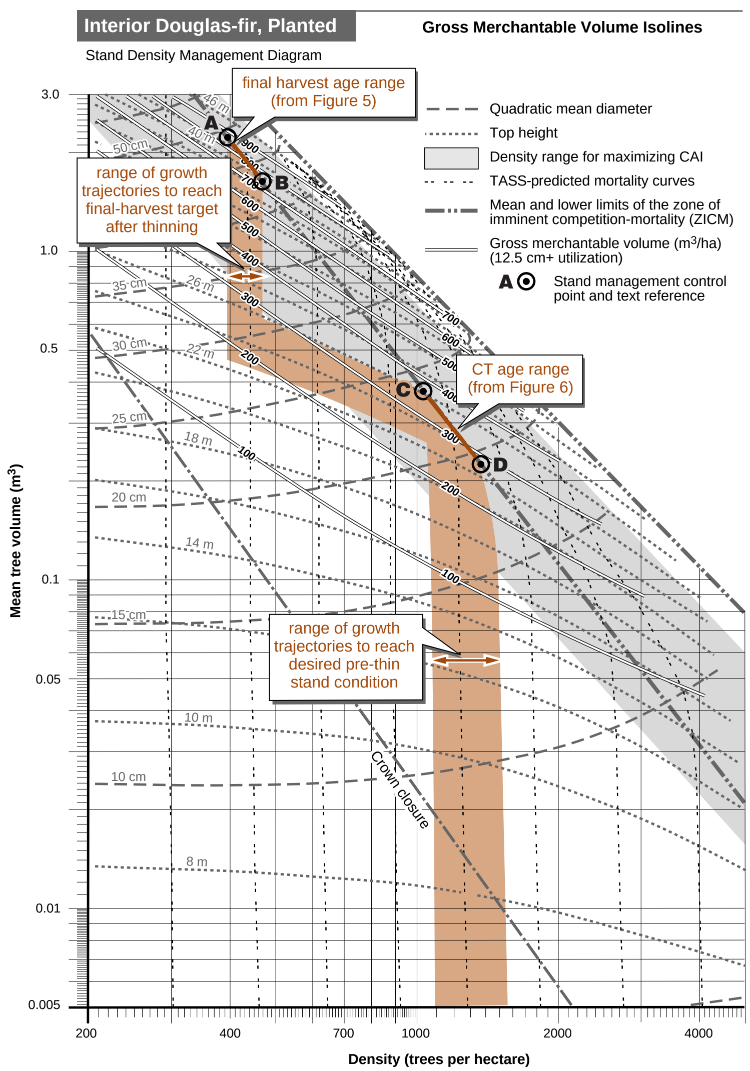
Use the control points on the SDMD to identify potential thinning treatments for the stand

This stage of the planning exercise is imprecise, and requires some exploration by trial and error.

Begin by tracing a "backwards" trajectory from each set of control points, paralleling the nearest mortality curve, and ending at the top-height isoline associated with the next (lower) set of control points (Figure 7a). Join the vertical trajectories along the common top-height isolines. These trajectories describe the boundaries of potential growth trajectories that meet the specified management objectives.

In the example, there are two sets of control points (Figure 7a). Set **A**, **B** indicates the final-harvest stand conditions. Set **C**, **D** indicates the pre-CT stand conditions during the period of timber supply shortage. Each set of control points describes the range of stand densities that meet a specifically desired condition. The shaded bands describe the range of growth trajectories that the stand can take to meet the CT and final-harvest conditions.

Figure 7a Identify a range of potential management trajectories that satisfy the timing needs specified by the management assumptions

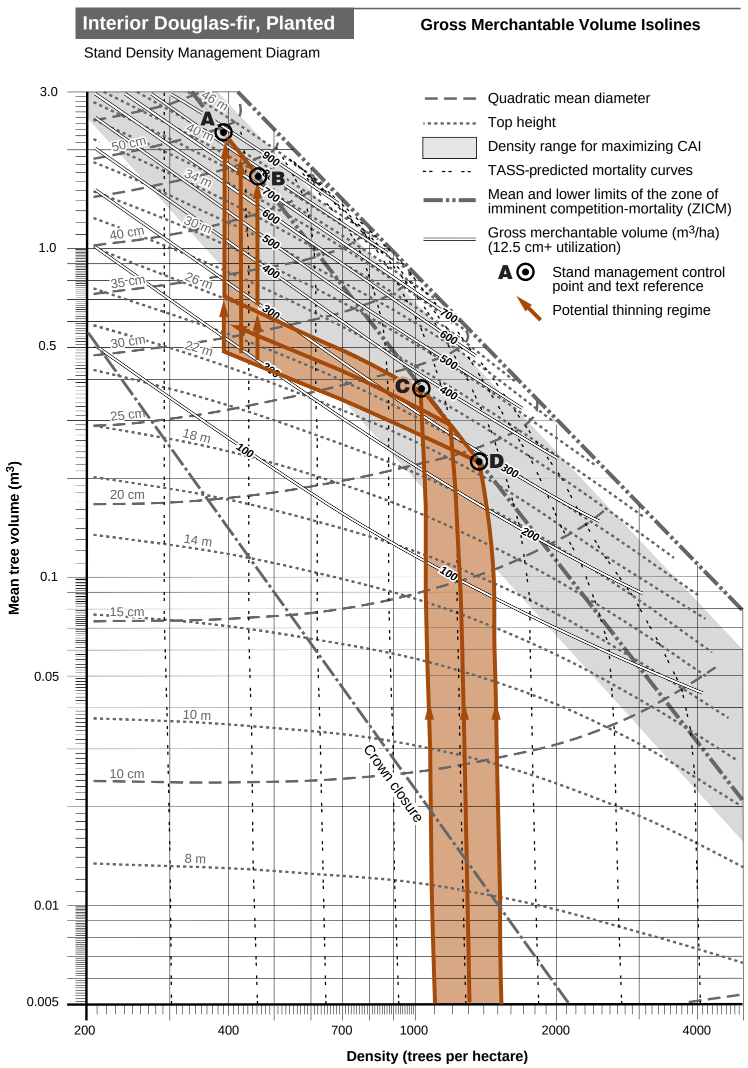


The shaded band indicates the range of stand growth trajectories that meet the CT and final-harvest conditions

Once the range of growth trajectories that meet specified management objectives have been identified, other options for stand treatment can be explored. Figure 7b identifies several thinning trajectories that can be taken to reach the target final-harvest conditions.

Figure 7b Explore various options for stand trajectories within the range of potential solutions

The lines within the shaded band indicate potential thinning trajectories to reach the final-harvest conditions



Step 3: Check viability of the potential thinning entries

Not all potential trajectories (management regimes) will be viable. Eliminate thinning trajectories that do not meet the specified criteria (e.g., timing, minimum financially viable harvest volume, sufficient residual volume).

Potential trajectories must be checked against specified criteria (e.g., financial viability, sufficient residual volume)

While SDMDs are not very precise tools for estimating harvest yield, there are several ways of assessing whether the removal volumes plotted on the diagram are appropriate.

Volume Calculation

Merchantable yield in thinnings can be estimated by using total volume as a proxy. Calculate the total volume of the pre-thinned stand by multiplying density times mean-tree volume (read these values from the horizontal and vertical axes of the SDMD). Subtract the estimated total volume for the thinned stand, calculated by multiplying the post-thinning density times the mean-tree volume on the same age-height isoline as the pre-thinned stand. The difference will be a reasonable, though slightly low (5–10%) estimate of merchantable thinning volumes.

In the example, use total volume as a proxy to calculate the merchantable volume that would be generated by thinning the stand at point **C** (1030 tph) to 460 tph (the highest possible post-CT density from Step 1) (Figure 7b):

pre-thinning volume = 391 m^3/ha (1030 tph * 0.38 m^3/tree)
post-thinning volume = 294 m^3/ha (460 tph * 0.64 m^3/tree)
CT volume = 97 m^3/ha (391–294)

Thinning from point **C** to a density of 460 tph would be financially viable, based on the 60 m^3/ha minimum that was assumed in Example 1.

This method works best for light to moderate thinnings done early in the rotation. For heavy or very late first thinnings, this approach underestimates thinning yields by as much as 20%. Errors may be greater for second and subsequent entries than for first entries.

Proportion of Stems Cut

When thinning from below, the number of stems to be removed is always a considerably larger proportion of the pre-thinning condition than is the basal area or volume to be removed, but with some practice the number of stems to be removed can be used as a guide. For example, between 55 and 75% of stems must be removed to achieve a 33% volume removal, depending on the stem size distribution and how closely the “smallest first” rule is followed when cutting. At the very least this type of guide can help identify some of the more wildly impractical scenarios.

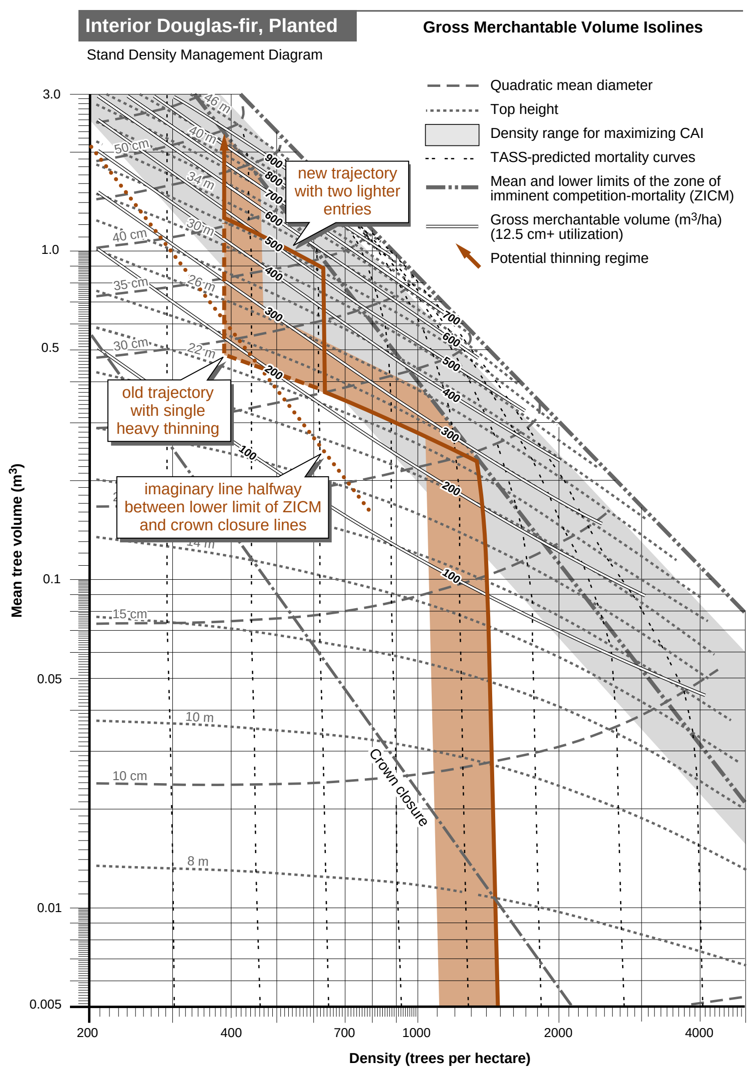
Where a heavy entry has been identified, consider using one or more light entries instead to maximize total volume producion

Step 4: Check potential for additional thinning entries

Where a heavy entry has been identified, consider using one or more light entries instead. Removals of greater than about 30% of merchantable volume, 40% of basal area, or 60% of total stems are likely to create excessive unoccupied growing space, leading to reduced cumulative volume production (thinnings plus final harvest). These values are general approximations and may vary for different pre-thin stand conditions. Heavy thinnings also increase the risk of wind or snow damage.

As a quick check to assess the need for additional CT entries, draw a line halfway between the lower limit of the ZICM and the crown closure line (Figure 8). A thinning trajectory that crosses this line will almost certainly be subject to losses in volume production, with the risk of losses increasing the closer the trajectory approaches this line. A set of comparative TASS runs can be used to test for possible growth differences resulting from different thinning intensities.

Figure 8 Check potential for additional thinning entries

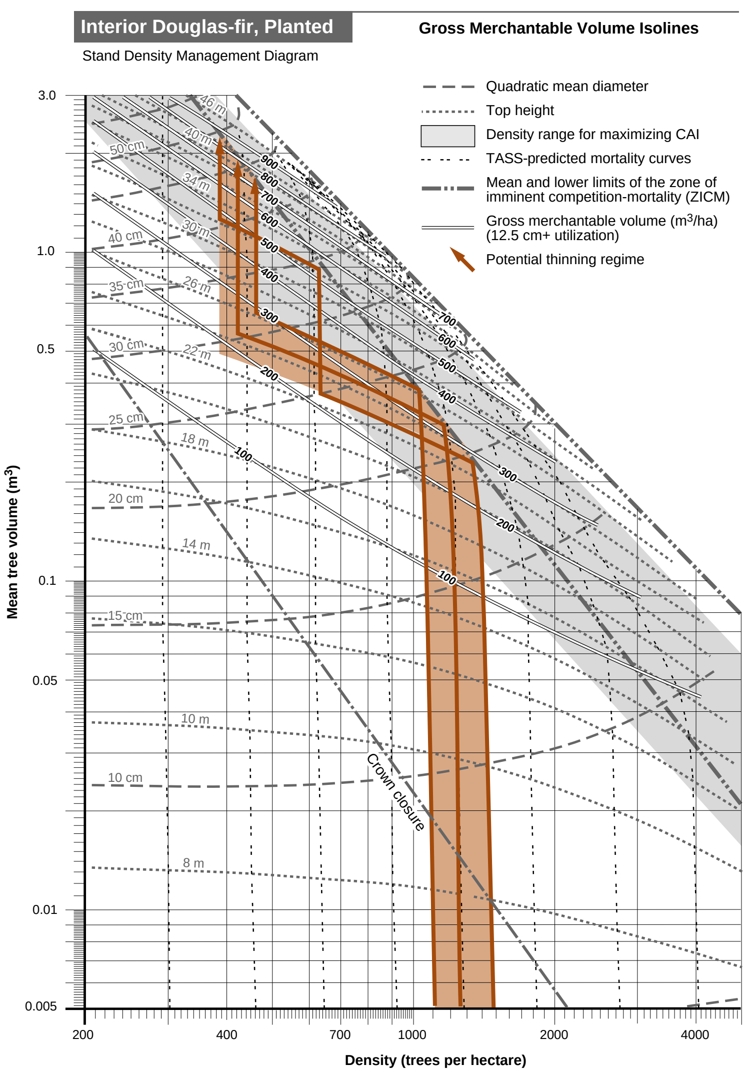


Step 5: Test selected thinning regimes

When a set of potentially feasible thinning regimes has been identified (Figure 9), TASS should be used to evaluate each regime and to identify needed adjustments to the number, timing, or intensity of thinning entries. Output from a TASS run is sometimes used to document stand prescriptions.

TASS should be used to evaluate each CT regime and to identify needed adjustments to the number, timing, or intensity of thinning entries

Figure 9 Select a limited set of possible thinning regimes for further exploration with TASS



TASS requires the following information for each proposed thinning regime:

- species, site index, and establishment density
- degree of stand clumpiness—usually one of the two clumpiness assumptions (or three for some species) used in TIPSY will be sufficient; in some cases stand clumpiness may require the use of an operational adjustment factor (OAF); see the TIPSY help files for information about using a particular class of OAF (OAF1) to represent clumpiness
- timing of thinnings, most commonly specified in terms of age or top height
- type of thinning rule—thinnings planned using an SDMD must involve "thinning from below," but TASS permits deviating from this absolute rule to maintain uniform spacing if desired.

Closing Remarks

The strength of SDMDs lies in their graphic portrayal of stand dynamics and density management decision-making. This presentation makes it possible to visualize growth trends, treatments, and their interactions in a single framework, thereby enhancing understanding of the critical processes that affect density management crop planning.

The strength of SDMDs lies in their graphic portrayal of stand dynamics and density management decision-making

Silviculturists developing commercial thinning regimes should not rely solely on SDMD predictions of stand volume. Many of the measurement parameters used in the example may suggest a level of precision that is not warranted. For many reasons, not every stand will develop exactly as suggested by an SDMD, which creates some uncertainty in the outcome.

Glossary

Commercial thinning (CT): A thinning entry in which the cut trees are extracted from the stand and used to generate revenue. All thinnings in this publication are assumed to be "thinnings from below," where the cutting rule is "smallest first."

Control point: A point on the SDMD representing stand conditions that meet the requirements of stated management objectives. These requirements will usually be expressed in terms of when a profile of specific products will be produced (e.g., volume, piece size, and time of availability).

Cumulative yield: Merchantable volume of final harvest and all commercial thinning entries.

Density: In the context of this report, density refers to the count of all trees in the stand deemed to be in the primary cohort. Trees that are distinctly in the understorey should not be included, but suppressed trees which were once part of the canopy should be counted.

Gross volume: All stemwood production from stand inception to a given measurement date, including that of both live and dead trees (i.e., gross volume = total volume + thinning volume + volume lost to mortality).

Growth trajectory: On an SDMD, a curved line showing changes in stand density with increasing stand age. Growth trajectories generally follow the curved shape of the TASS-predicted *mortality curves*. Values for other stand parameters (e.g., diameter, height) are determined from the value of corresponding isolines intersected by the trajectory.

Irregular mortality: Tree deaths for which the probability is not readily predicted by competition theory (i.e., self-thinning). Irregular mortality is generally attributed to random or periodic factors such as pests, wind, snow breakage or inclement temperature extremes. Irregular mortality may affect trees of any size class and may be distributed uniformly or in clumps.

Isolines: Lines connecting points on the SDMD having the same values (e.g., diameter, height, merchantable volume).

Mean tree volume: The average volume of all trees in the stand, including non-merchantable trees but not including understorey trees.

Merchantable volume: A measure of "usable" or "recoverable" volume which deducts from total volume the volume of trees below a certain dbh limit, the volume of stumps, and the volume of the tops of trees with diameters too small to use. All merchantable volumes in this report (and the accompanying SDMDs) are gross merchantable volumes—they assume a stump height of 30 cm, a minimum usable top diameter of 10 cm, and a minimum dbh of 12.5 cm. No deductions have been made for decay, waste, or breakage.

Operational adjustment factors (OAFs): Deductions made to growth model predictions to account for real-world conditions not reflected in the model. Common reasons for applying OAFs include deductions for proportions of a stand that are not stocked (or are stocked with non-commercial species) when the model assumes full and uniform stocking, and reductions to yields resulting from pest impacts. The yield values in this report assume full site occupancy and healthy stand conditions—no OAFs have been applied.

Pre-commercial thinning (PCT): A thinning entry in which the cut trees are not extracted from the stand—also referred to as "thinning to waste" or "juvenile spacing."

Regime: A stand development plan incorporating both natural processes and intentional interventions (e.g., thinnings). On an SDMD, a regime is illustrated as a set of connected lines showing the growth trajectories from stand initiation to each thinning and then to final harvest.

Regular mortality: Tree deaths predicted by competition theory, i.e., caused by stand self-thinning. Trees succumbing to regular mortality are generally the smallest in the stand and are more or less evenly distributed.

TASS (Tree and Stand Simulator): An individual-tree, distance-dependent growth model developed by the B.C. Ministry of Forests. Output from this model, through managed stand yield tables in the TIPSY v 2.1 software, forms the basis for all the SDMDs discussed in this document.

Top height: The average of the heights of the largest diameter tree in each of a set of 0.01 ha plots, providing the tree is suitable (i.e., the tree is healthy, does not have a broken or damaged top, and its height growth is not affected by a competitor). This roughly equates to the average height of the largest 100 trees per hectare.

Total volume: All living stemwood volume at a given measurement date.

TIPSY: A Windows-based computer application that produces variable density yield tables for a range of coniferous tree species common to British Columbia. Tables produced are based on output from the TASS model.

Zone of imminent competition-mortality (ZICM): A zone on an SDMD indicating the probable occurrence of competition-based mortality in stands. The lower limit of the ZICM approximates the point at which self-thinning starts to occur at noticeable levels. The mean limit of the ZICM is the maximum density line for average stands—roughly half of all stands may have growth trajectories that lie above this line.

Sources of More Information

Commercial Thinning

Anonymous 1999. Guidelines for developing stand density management regimes. BC Min. For., Victoria, B.C. 94p.

Contains good discussion of stand dynamics relative to density management, and a broader array of factors affecting density management decisions than are presented in this document. Particularly appropriate relative to conditions in British Columbia.

Davis, L.S. and Johnson, K.N. 1987. Forest management. 3rd Edition. McGraw Hill Book Company.

Chapter 3 contains a discussion of stand-level growth and yield. Chapter 4 discusses methods of density regulation.

Nyland, R.D. 1996. Silviculture concepts and applications. McGraw Hill Book Company.

Oliver, C.D. and Larson, B.C. 1996. Forest stand dynamics. Update Edition. John Wiley & Sons Inc.

Currently the most comprehensive North American text on stand development from both qualitative and quantitative perspectives.

Smith, D.M., Larson, B.C., Kelty, M.J. and Ashton, P.M.S. 1996. The practice of silviculture: applied forest ecology. 9th Edition. John Wiley & Sons Inc.

Contains several chapters on the theory and application of thinnings in even-aged stands.

Stone, M.S. 1992. An economic evaluation of commercial thinning Douglas-fir in the coastal region of British Columbia. For. Can. and BC Min. For., Victoria, B.C. WP-6-002.

Stone, M.S. 1996. Commercial thinning lodgepole pine: an economic analysis. BC Min. For., Economics and Trade Br., Victoria, B.C.

SDMDs

Drew, T.J. and Flewelling, J.W. 1979. Stand density management: an alternative approach and its application to Douglas-fir plantations. For. Sci. 25(3):518-532.

Farnden, C. 1996. Stand density management diagrams for lodgepole pine, white spruce and interior Douglas-fir. Can. For. Ser., Pacific For. Cent., Victoria. BC-X-360. 37p.

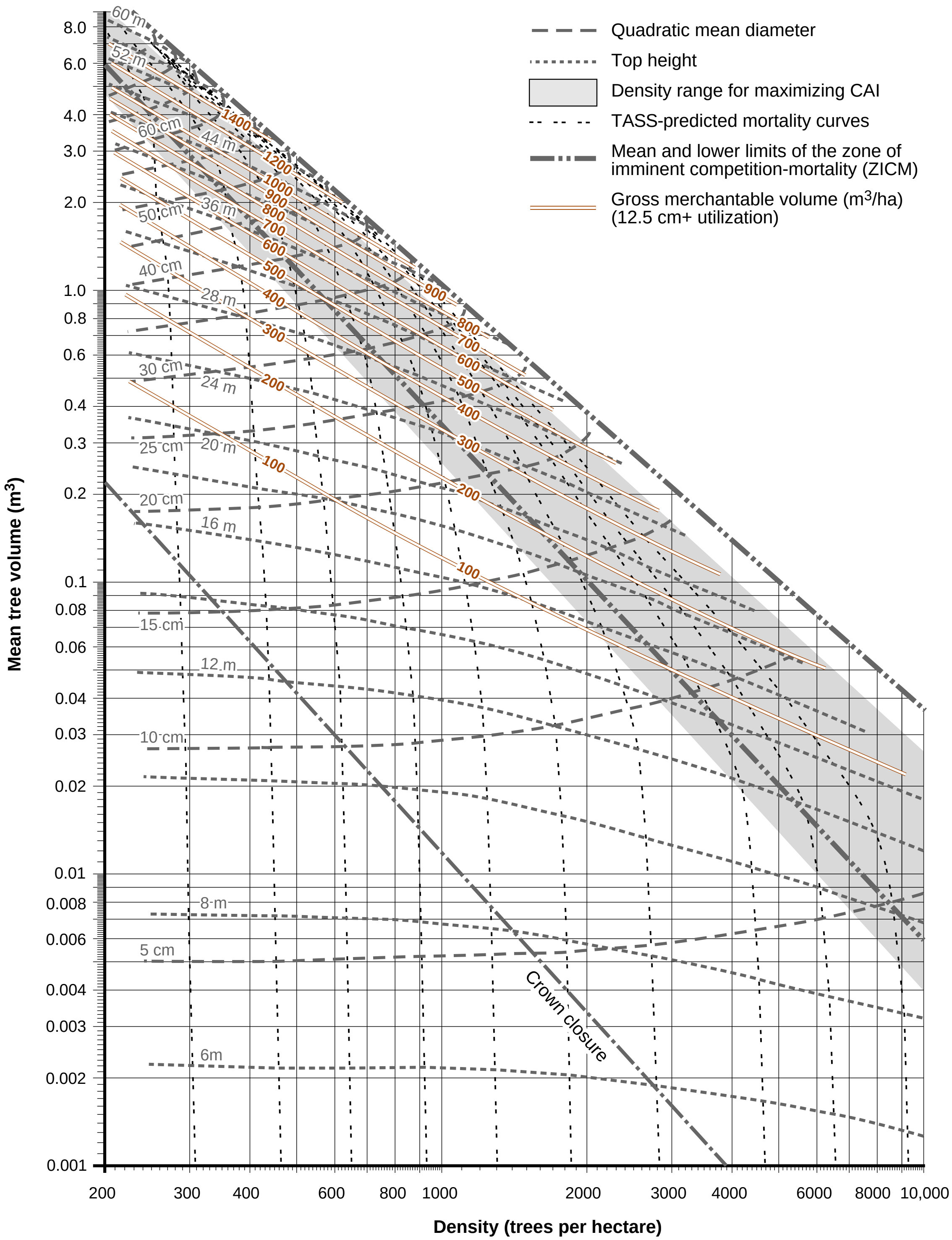
Farnden, C. 1998. Stand density management diagrams: a silvicultural planning tool. In: Bamsey, C. (Ed.) Stand density management: planning and implementation. Proc. of conf. Nov. 6&7, 1997, Edmonton AB. Clear Lake Ltd., Edmonton. pp.131-139.

Appendix 1
Stand Density Management Diagrams with Gross Merchantable Volume Isolines

Coastal Douglas-fir, Natural

Stand Density Management Diagram

Gross Merchantable Volume Isolines

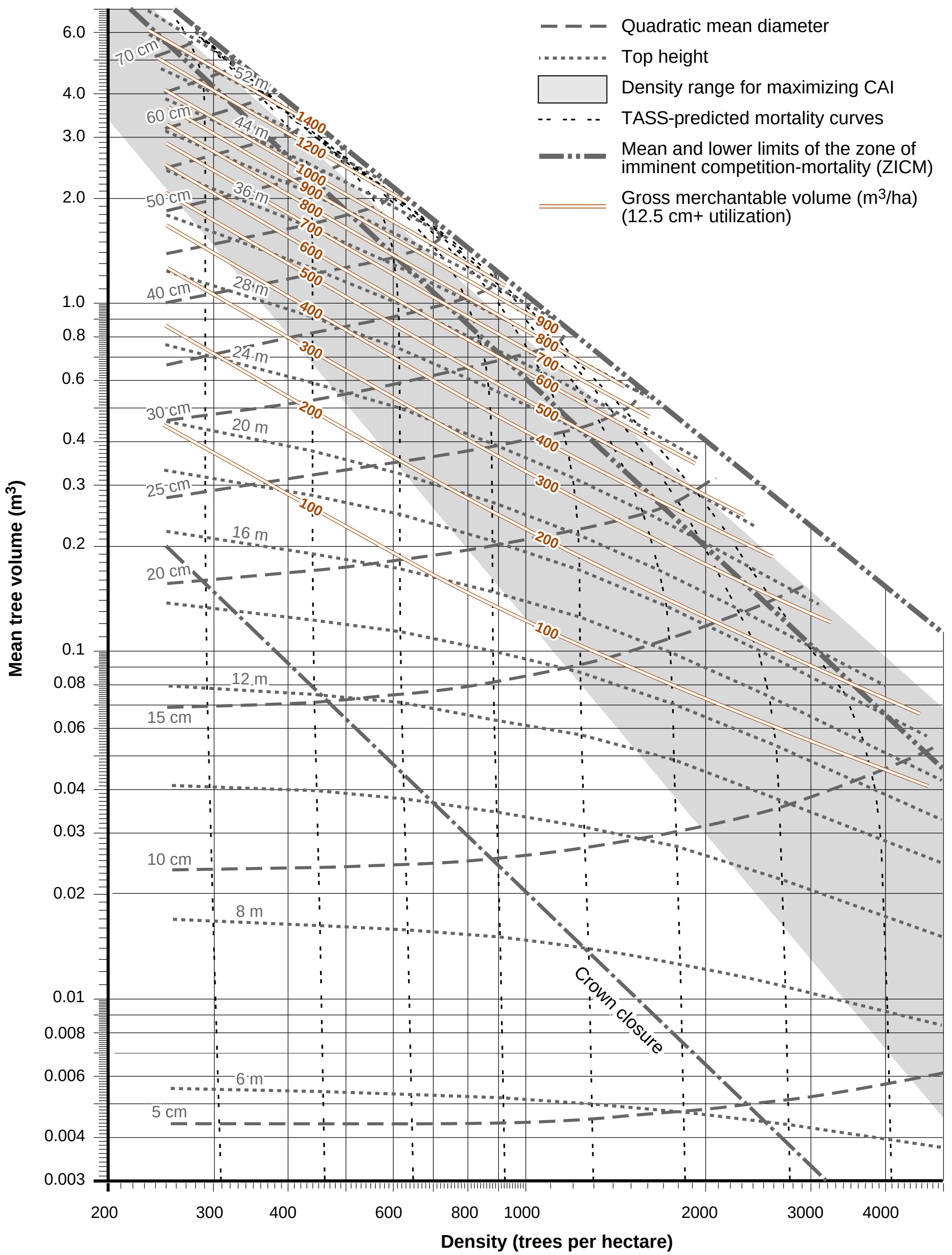


Merch. Volume Isolines: Craig Farnden, RPF for BC Ministry of Forests, Forest Practices Branch with funding from Forest Renewal BC; data source WinTIPSY 2.1, 2000
Base SDMD: Craig Farnden, RPF for BC Ministry of Forests, Forest Practices Branch with funding from Forest Renewal BC; data source WinTIPSY 1.3, 1996
Layout: Rich Rawling, Cortex Consultants Inc. with funding from Forest Renewal BC

Coastal Douglas-fir, Planted

Stand Density Management Diagram

Gross Merchantable Volume Isolines



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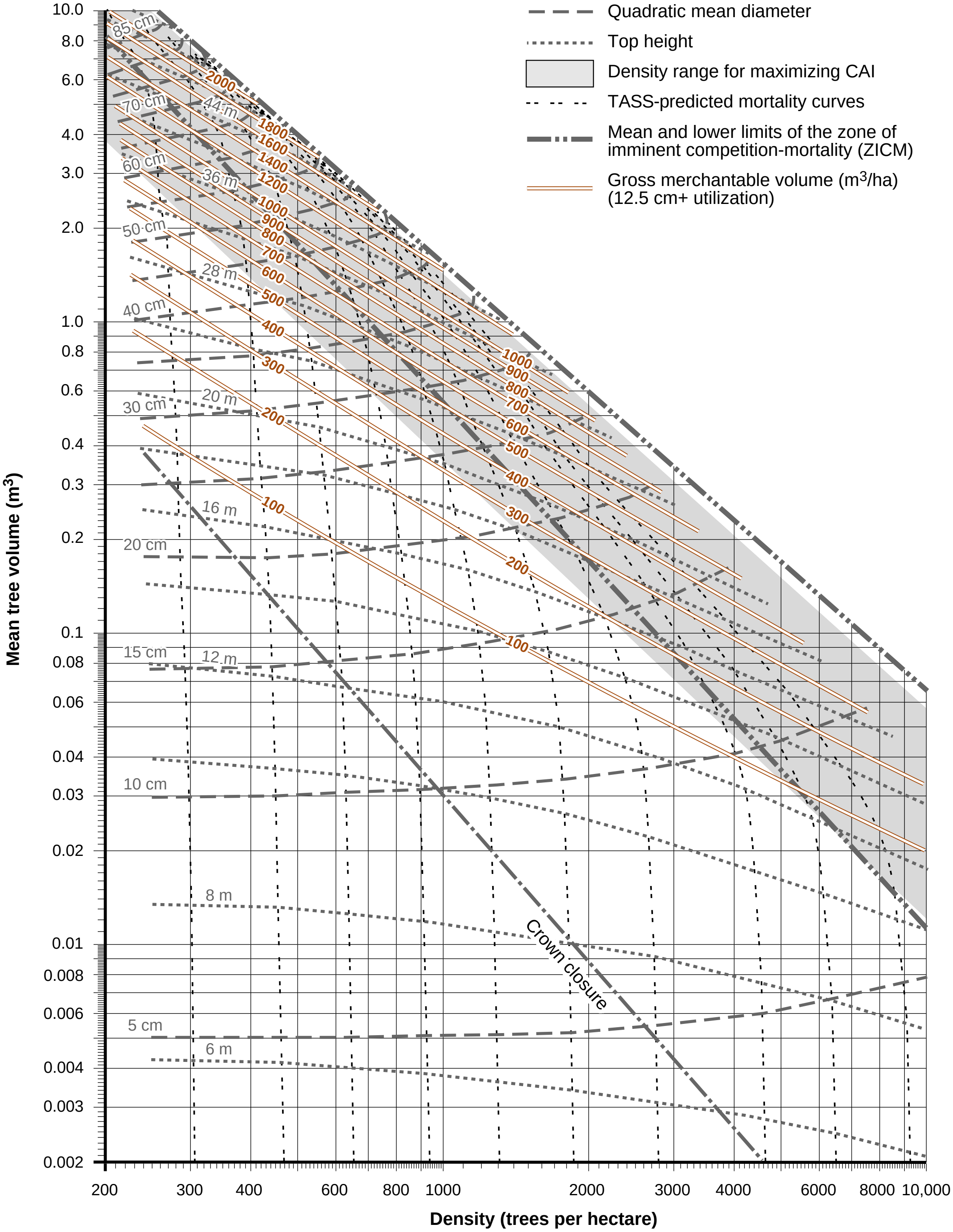
Sitka Spruce, Natural

Gross Merchantable Volume Isolines

Stand Density Management Diagram



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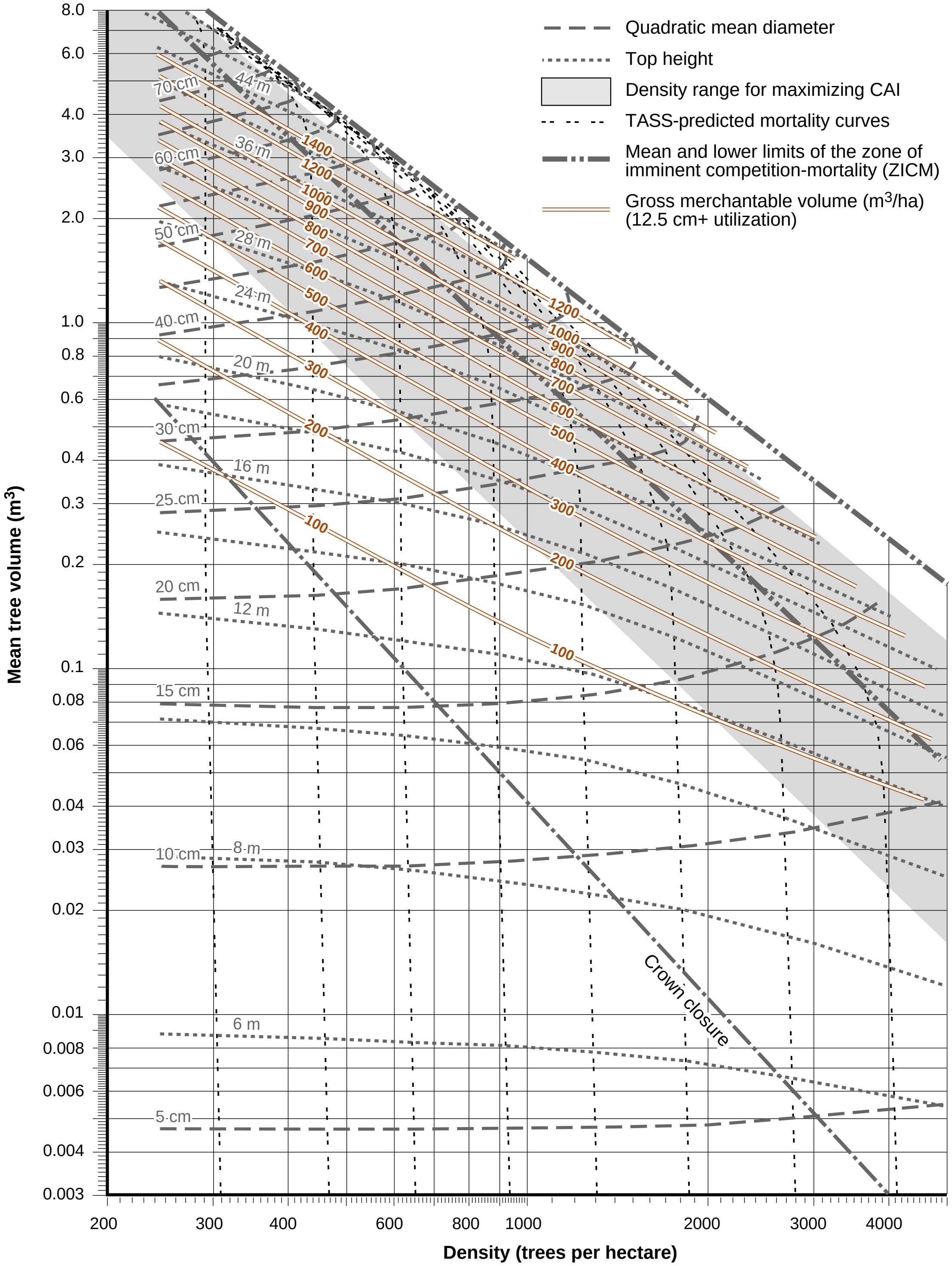
Sitka Spruce, Planted

Stand Density Management Diagram

Gross Merchantable Volume Isolines



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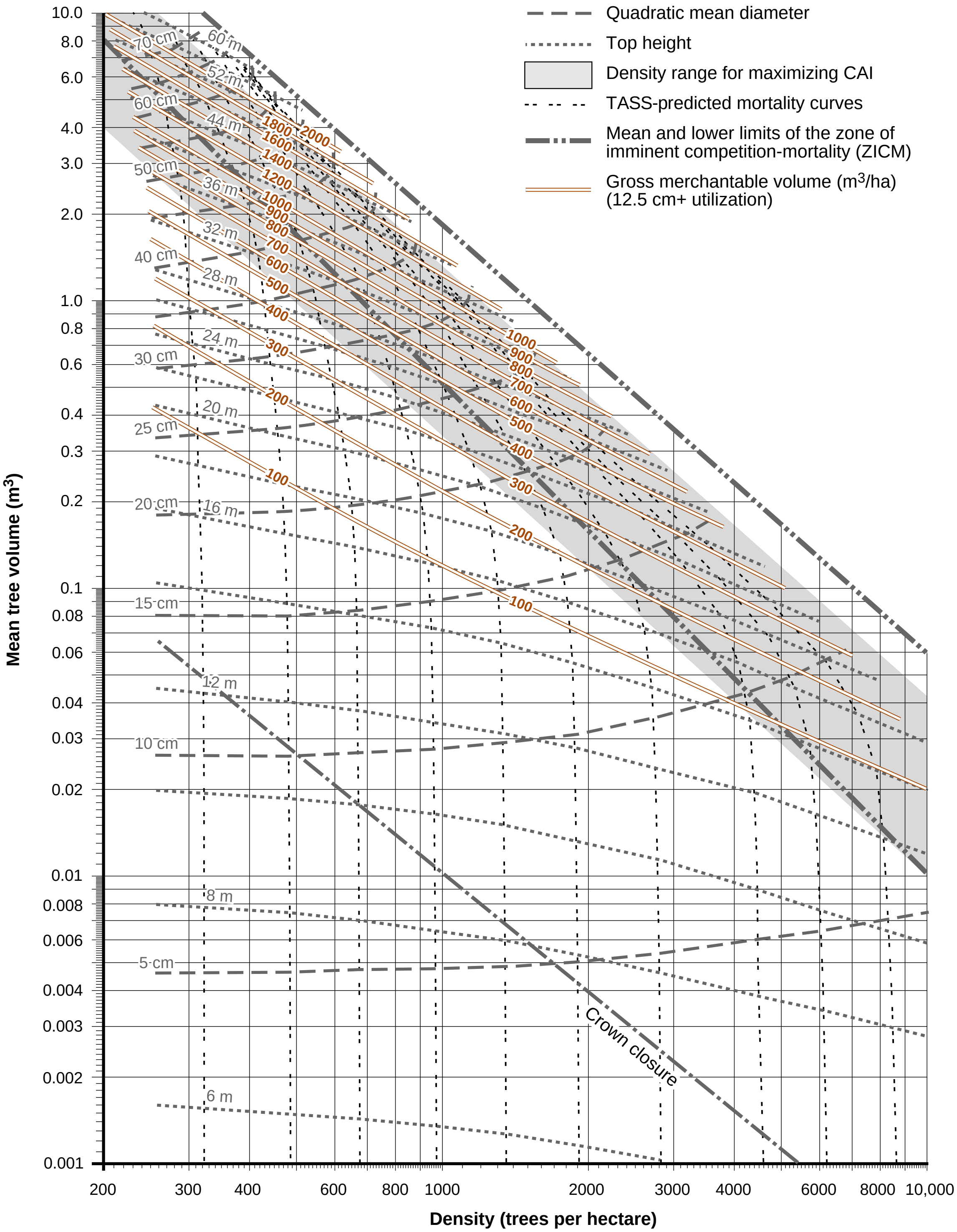
Western Hemlock, Natural

Stand Density Management Diagram

Gross Merchantable Volume Isolines



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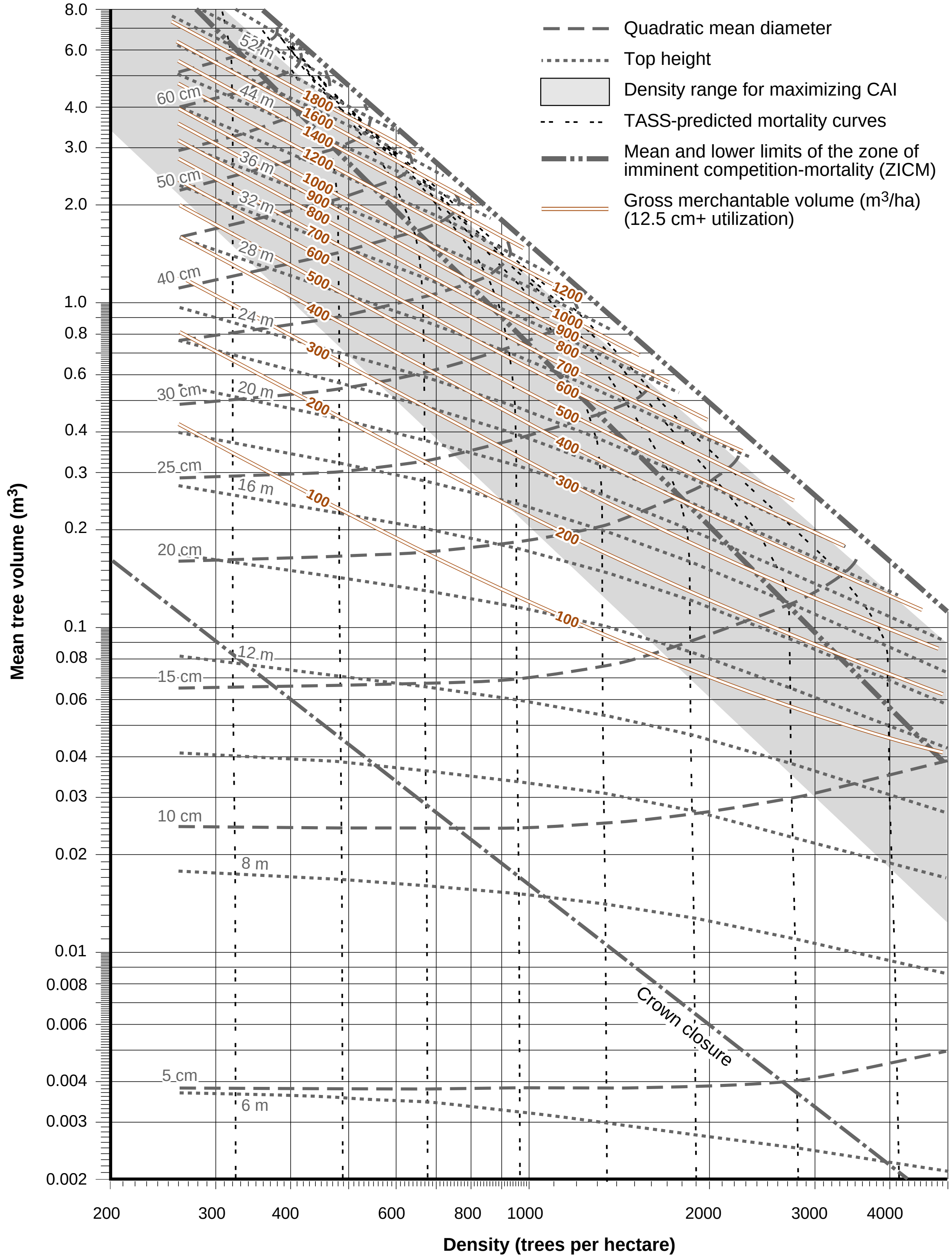
Western Hemlock, Planted

Gross Merchantable Volume Isolines

Stand Density Management Diagram



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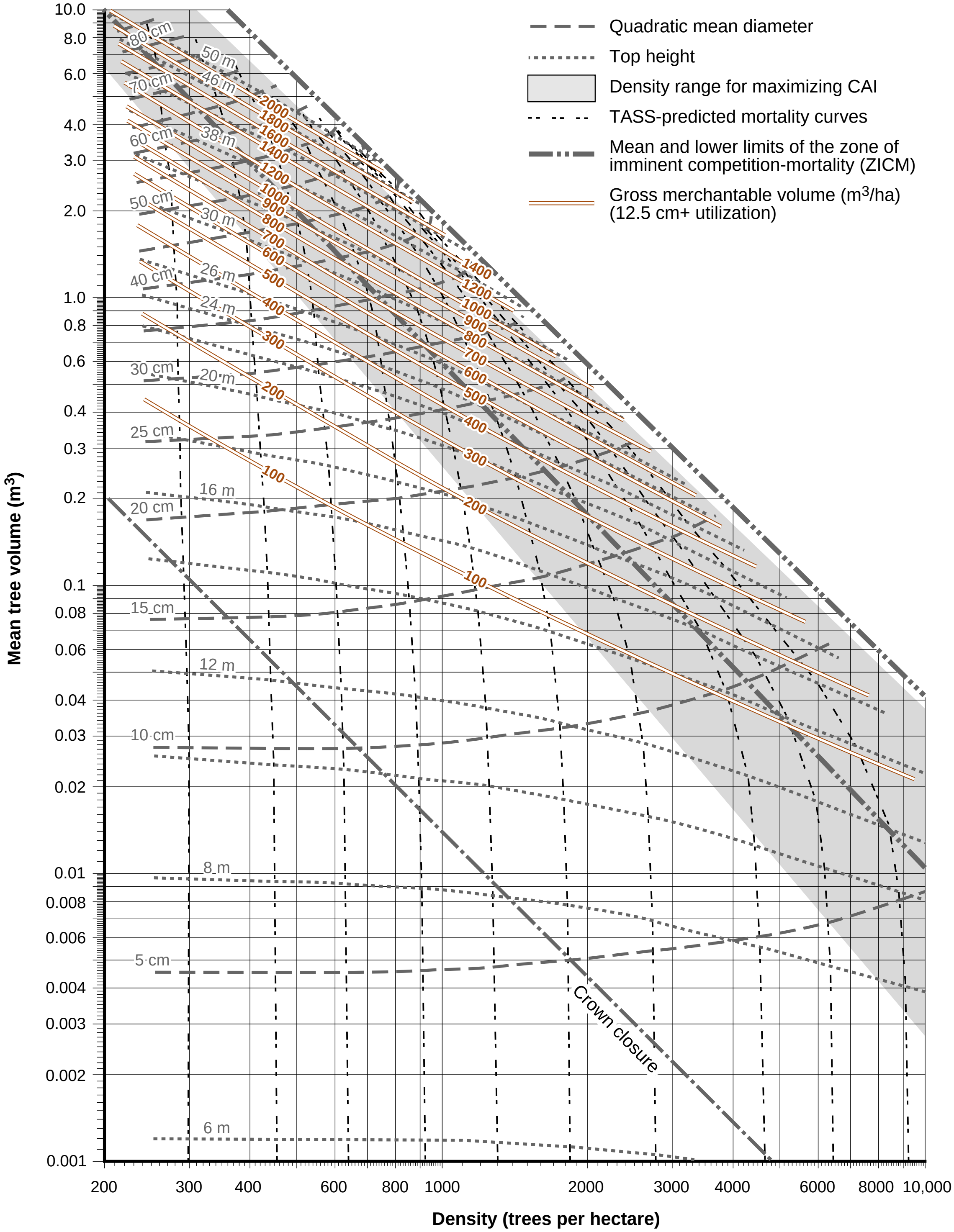
Western Redcedar, Natural

Stand Density Management Diagram

Gross Merchantable Volume Isolines



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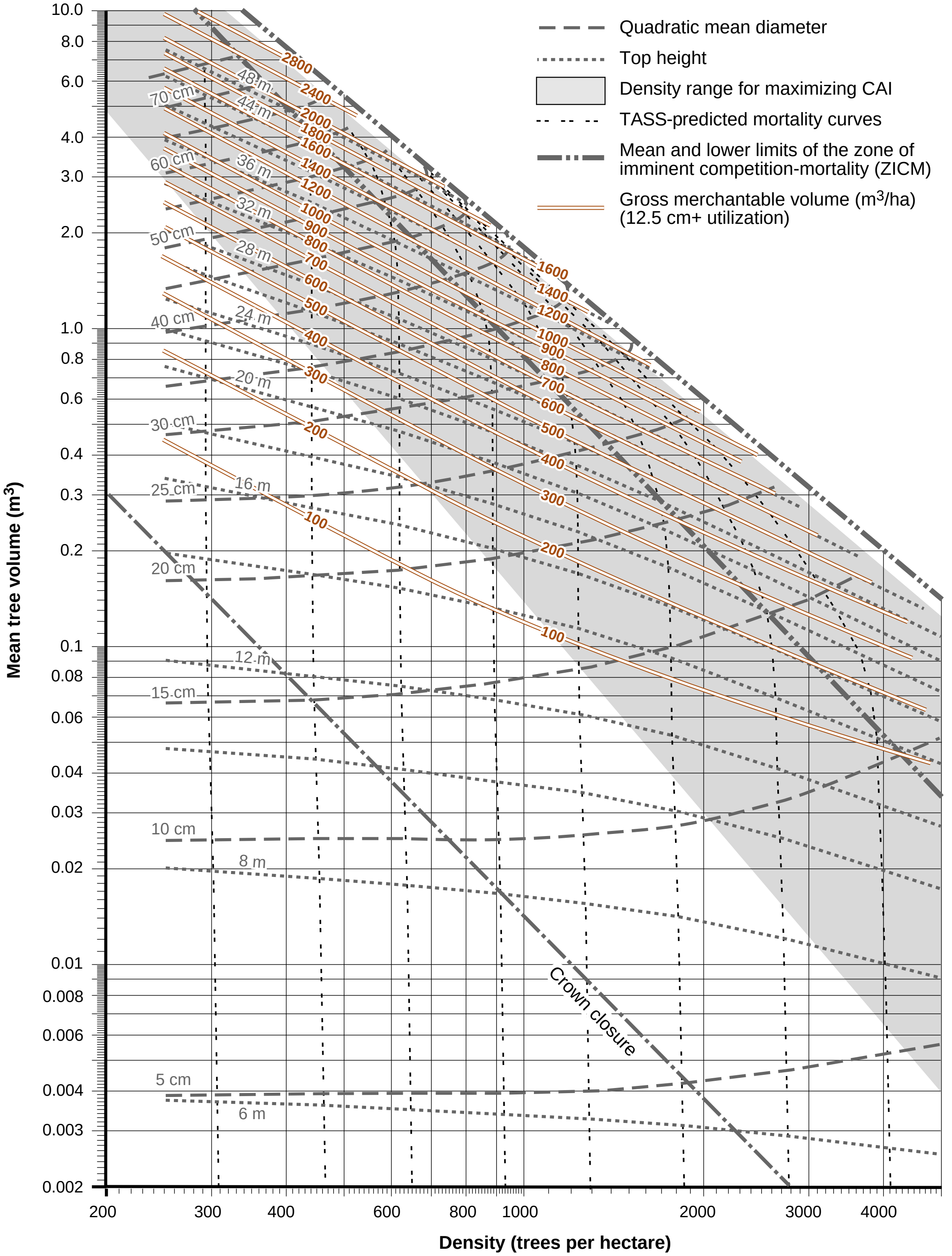
Western Redcedar, Planted

Stand Density Management Diagram

Gross Merchantable Volume Isolines



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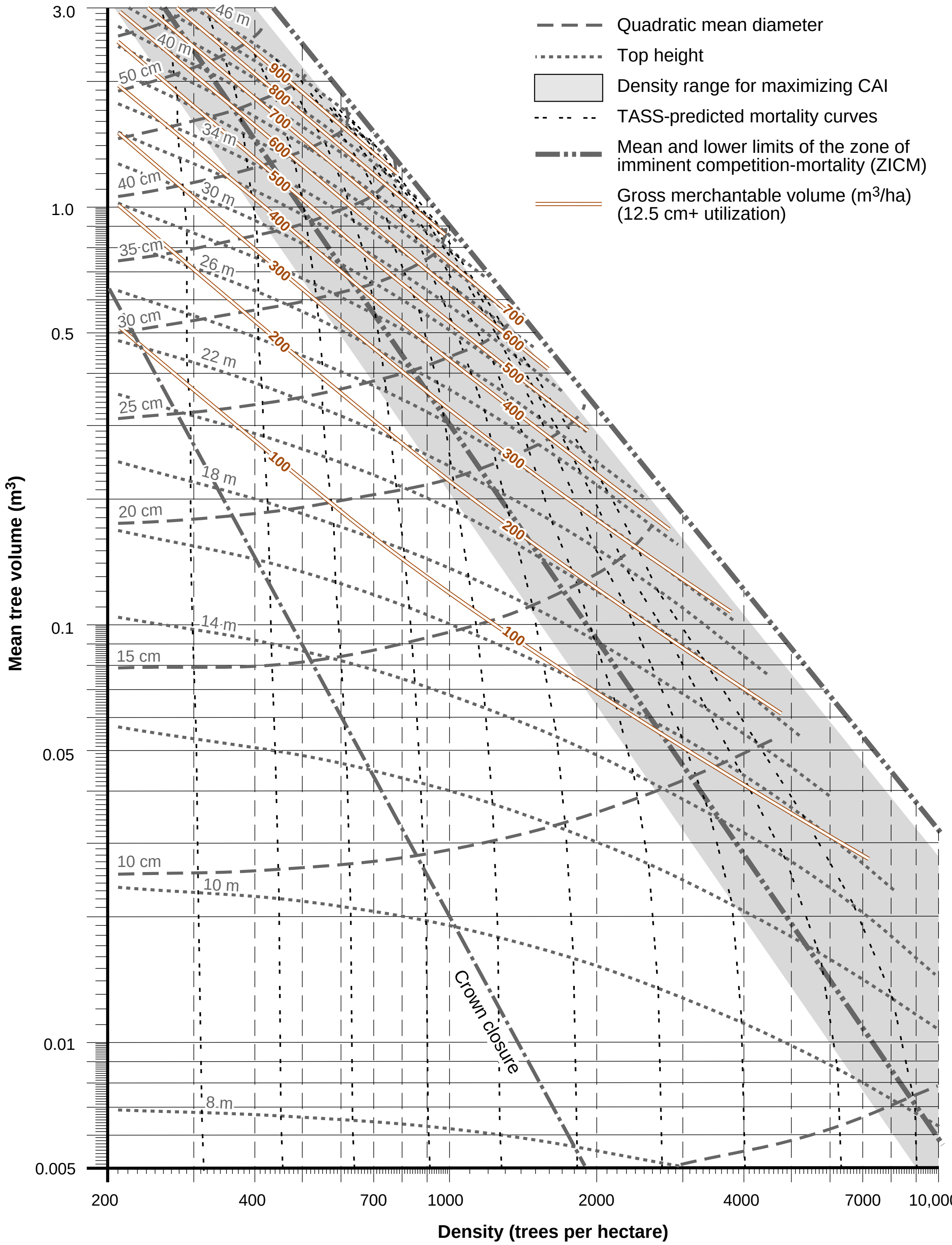
Interior Douglas-fir, Natural

Stand Density Management Diagram

Gross Merchantable Volume Isolines



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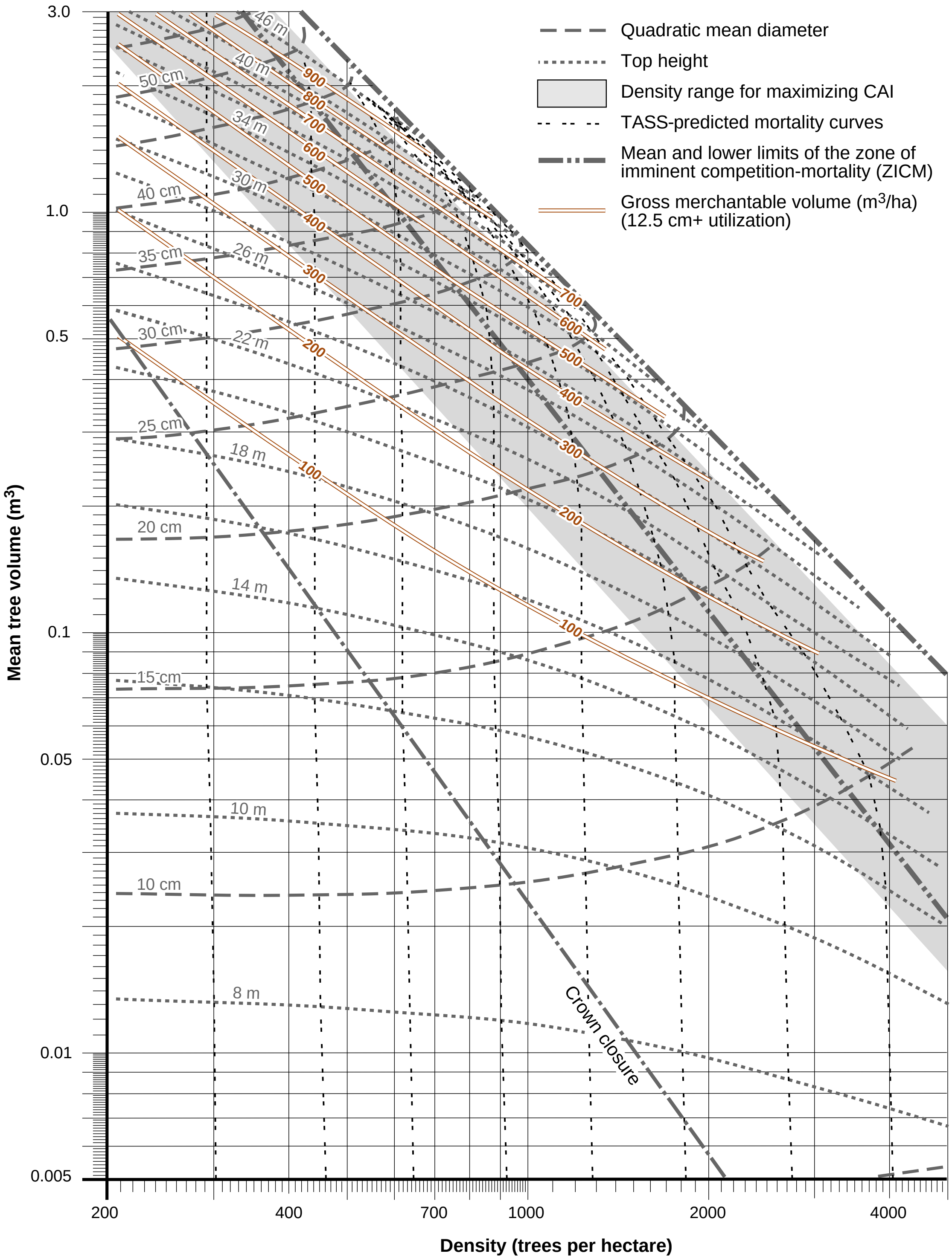
Interior Douglas-fir, Planted

Stand Density Management Diagram

Gross Merchantable Volume Isolines



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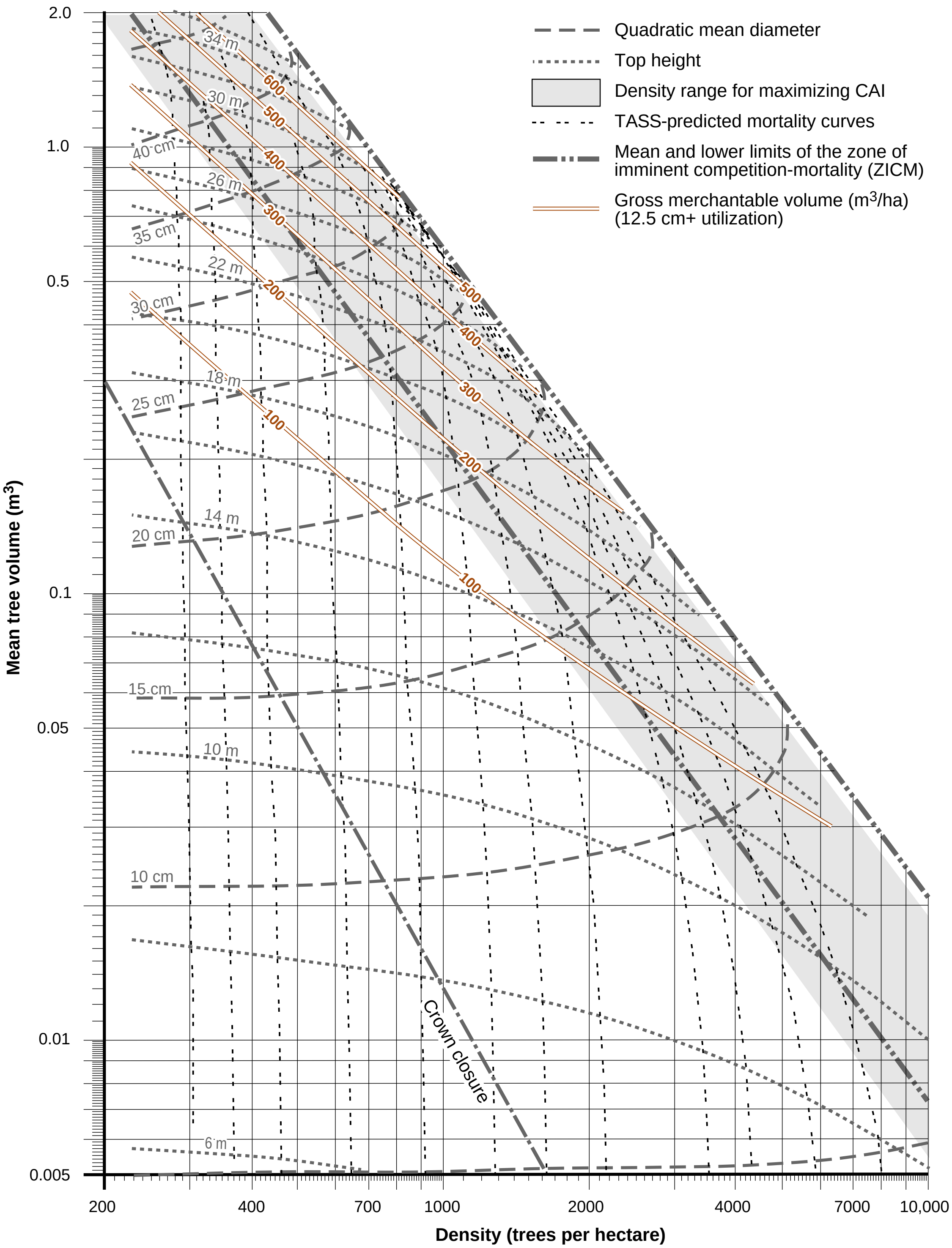
Lodgepole Pine, Natural

Stand Density Management Diagram

Gross Merchantable Volume Isolines



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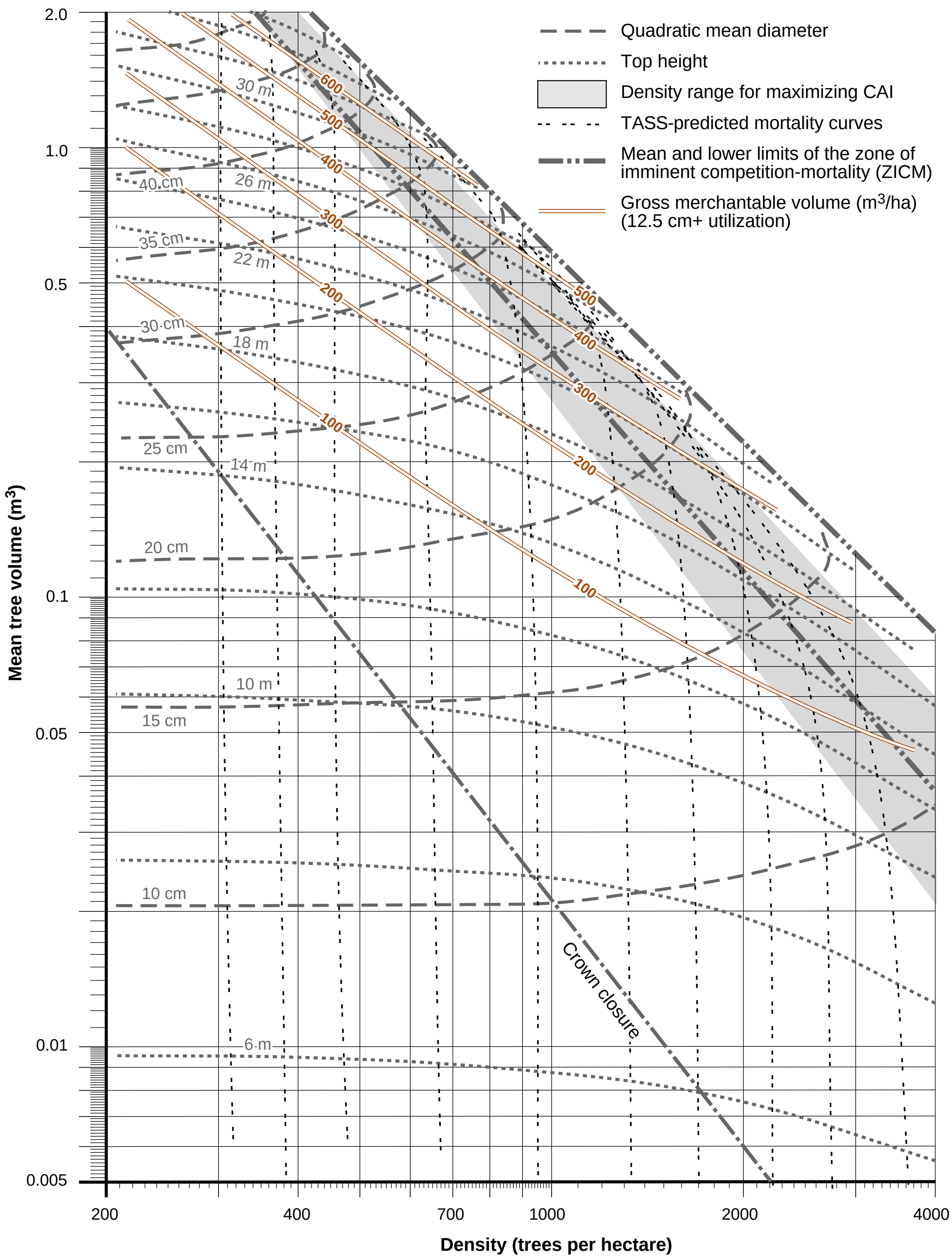
Lodgepole Pine, Planted

Stand Density Management Diagram

Gross Merchantable Volume Isolines



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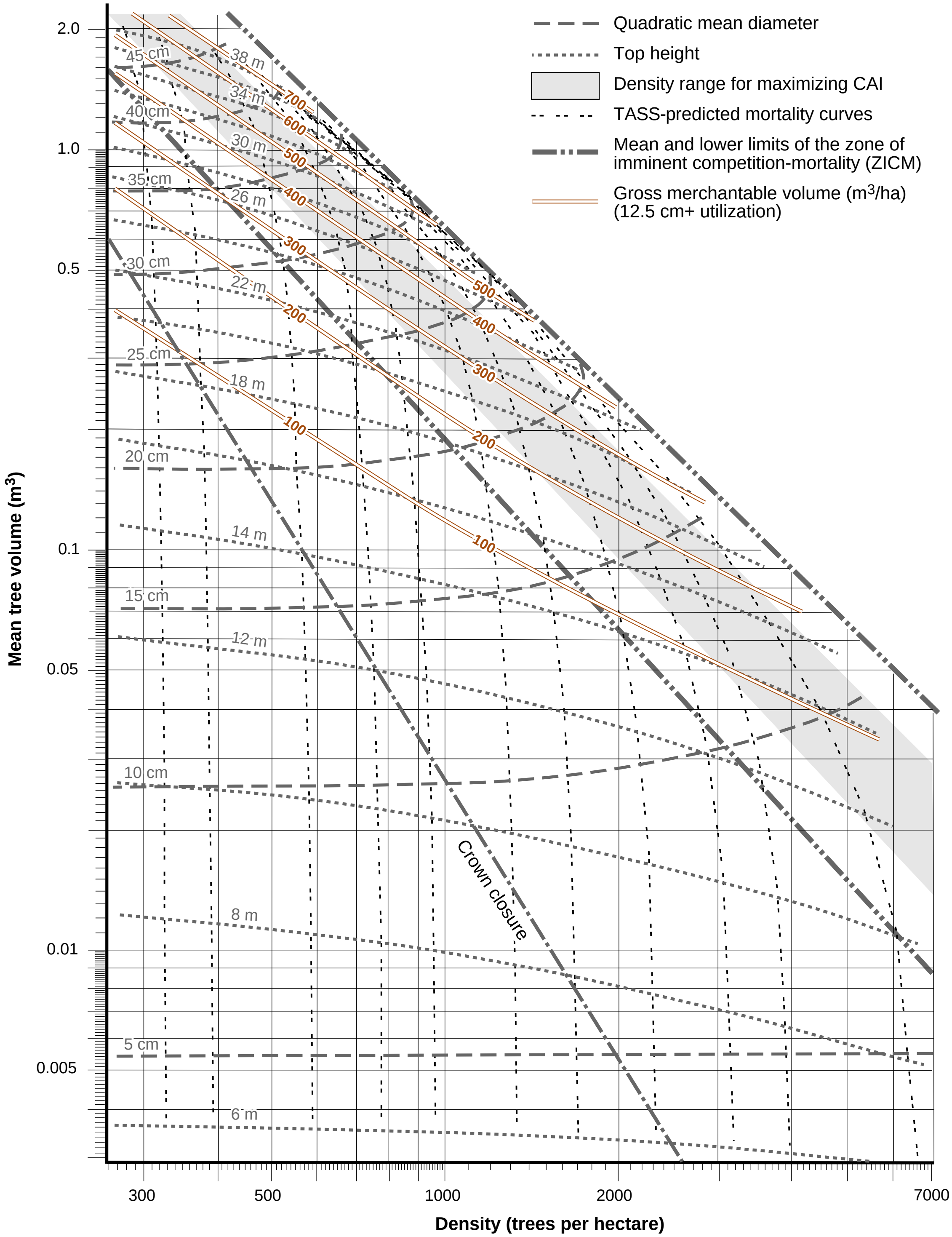
White Spruce, Natural

Stand Density Management Diagram

Gross Merchantable Volume Isolines



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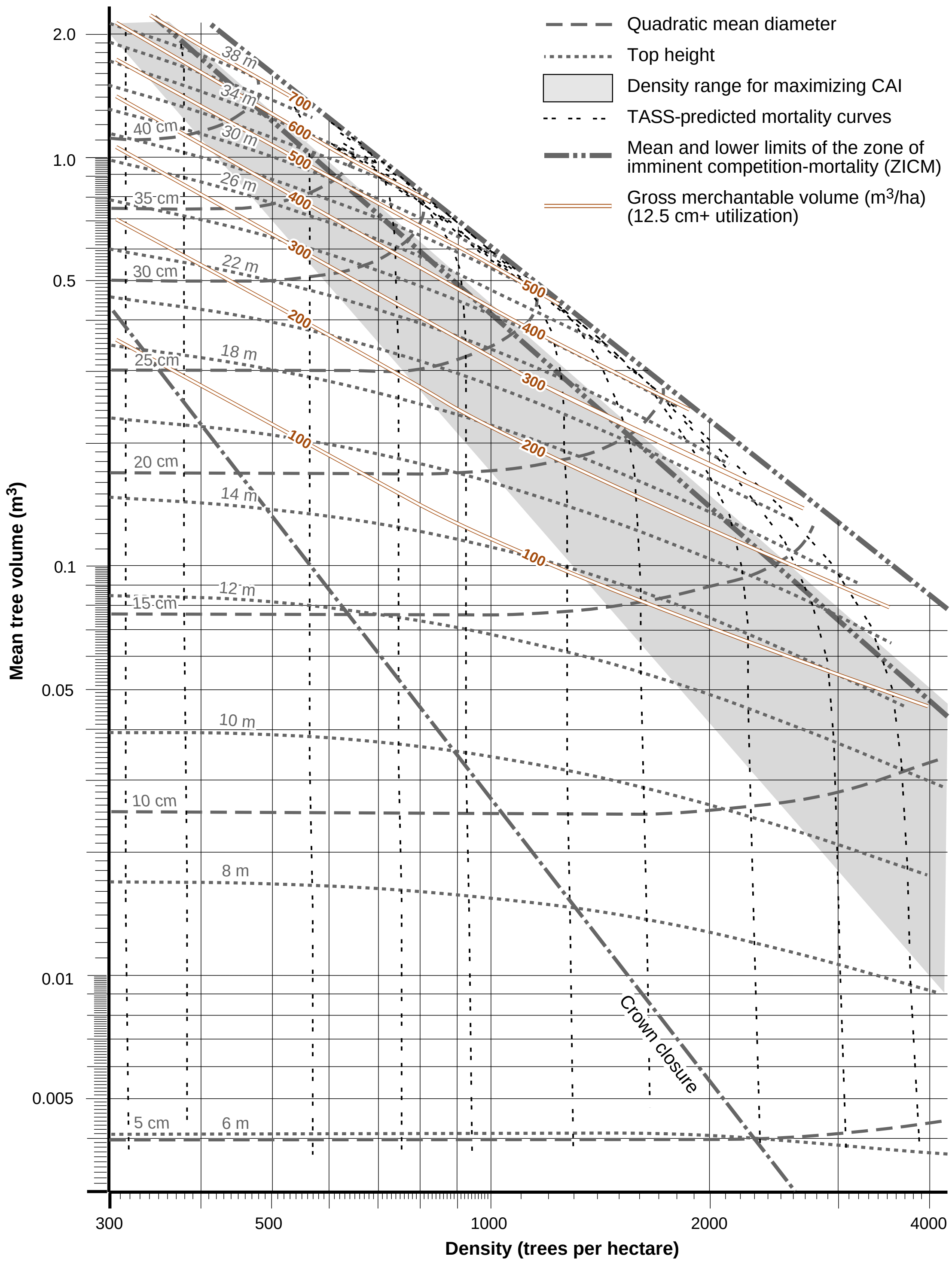
White Spruce, Planted

Stand Density Management Diagram

Gross Merchantable Volume Isolines



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