Using quantitative forest structure targets: the good, bad, and ugly

Kevin R. Gehringer, Ph.D.
Biometrics Northwest LLC
Redmond, WA
Email: krg@biometricsnw.com

Abstract

The effective use of quantitative forest structure targets in forest management requires three components. The first is a data set that specifies a reference condition representing the desired forest conditions from which quantitative assessment criteria are derived. The second is either observed forest structure data or output from a credible forest growth model used to generate projections of forest management scenarios that are under consideration. The third is a statistically and biologically consistent assessment procedure used to determine whether the forest structure target has been, or is likely to be, achieved. Four quantitative forest structure targets are compared within the context of the Forests and Fish Law of Washington State. The comparisons are performed using two reference data sets and several management scenarios projected using two versions of the ORGANON forest growth model to highlight several issues that can arise when using quantitative forest structure targets and forest growth models.

Key Words: Quantitative target, nonparametric assessment, forest structure

1 Introduction

Quantitative forest structure targets can help to reduce both management and regulatory uncertainty by clearly specifying desired forest structures and the associated assessment criteria used to determine regulatory compliance. In an environment with tight financial margins and increasing regulatory pressure, it is critical for all stakeholders to know exactly what the forest management objectives are and what the assessment criteria for regulatory compliance are, and to document them. The effective use of quantitative forest structure targets in forest management requires the careful consideration and selection of a reference data set that is representative of the desired forest structures, the selection of relevant target attributes, and the selection of a statistically and biologically consistent assessment procedure.

A common approach used to specify quantitative forest management targets is to compute upper or lower bounds, as appropriate, for one or more forest structure attributes of interest, e.g., trees per acre, volume per acre, or basal area per acre, and then to use these as box-constraints to assess the suitability or regulatory acceptability of forest management scenarios that are under consideration. The upper or lower bounds are typically computed from a selected data set by using simple summary statistics or quantiles obtained from the distribution of a single attribute or from the marginal distributions for multiple attributes.

Simple box-constraint approaches are problematic for two reasons. First, they can dramatically reduce the size of an acceptance region for a quantitative target relative to the distribution of the attribute(s) of interest, and second, they can miss the mode for skewed distributions. For example, using a median value for a single attribute as a lower bound (a procedure that appears frequently) rejects 50% of the representative data *a priori*, and if median values are used as lower bounds for multiple attributes, the reduction in the acceptance region can be even more dramatic, for example, rejecting 75% of the representative data for a two-dimensional, symmetric distribution. In these situations the effectiveness of the targets can be negatively impacted by the removal of significant portions of the region surrounding the mode of the underlying attribute distribution from the acceptance region.

While simple box-constraints may be used effectively to define quantitative forest management targets, their use requires the direct consideration of the underlying distribution of the targeted attribute(s), but alternative approaches that make direct use of this distribution exist (Gehringer, 2006) and may be more effective. The alternative methods, while more complex than the simple box-constraints to use, are derived directly from estimates of the underlying distribution of the targeted attribute(s), including the variability of the targeted attributes. Quantitative targets directly derived from the distribution of values for the targeted attribute(s) are expected to be more robust than simple box-constraints, by including variability and the curvature inherent in these distributions, and they should also increase the likelihood of obtaining the desired forest structures, particularly when multiple attributes are used to specify the forest structure target.

1.1 Quantitative target definition and components

A *quantitative target* consists of numerical assessment criteria derived from a reference data set that has been selected to represent a desirable outcome or set of conditions described by the distribution of numerical values for a specified set of attributes. The distribution of attribute values in the reference data set may be used directly or indirectly to define assessment criteria. A direct use of an attribute distribution from the reference data set could derive assessment criteria using the probability contours of an approximation to the distribution of the selected attribute(s) (Gehringer, 2006), or use a nonparametric estimate of the probability density function (Silverman, 1986, Gehringer and Redner, 1992). An indirect use of an attribute distribution from the the reference data set could derive assessment criteria using summary statistics, e.g., the mean or median, or quantiles.

A quantitative forest structure target for forest management requires three components. The first is a data set that specifies a reference condition representing the desired forest conditions from which quantitative assessment criteria are derived. The target data set should be clearly and unambiguously defined, be pedigreed, having a minimum of peer review of the data selection, sampling, or analysis methods, be representative of the desired forest structure conditions, and be multidimensional to more completely specify the forest structure target.

The second is a data set of observations that are to be assessed relative to the assessment criteria derived from the target data set. The observation data set may contain observed forest structure data or output from a credible forest growth model used to generate projections of forest management scenarios that are under consideration. In this context, a credible forest growth model is simply one that produces output consistent with reality for the attributes of interest.

The third is a statistically and biologically consistent assessment procedure that is used to determine whether the forest structure target has been, or is likely to be, obtained for the observed data or model output. Statistical consistency is achieved by emphasizing the underlying distribution, or joint distribution for multiple attributes, of the forest structures from the target data set when developing the assessment criteria. Biological consistency is achieved by using actual data to derive the assessment criteria, by using relevant forest structure attributes, and by aiming for the relevant part of the distribution, e.g., the mode. In addition, biological consistency may be improved by considering the state space of the attribute values, that is, the attribute values independent of time, since similar forest structures can occur at different times.

1.2 The Forests and Fish Law of Washington State

With the listing of salmon and other anadromous fish species in the Pacific Northwest as threatened under the Endangered Species Act, Washington State passed its Forests and Fish Law in 1999 and the Washington State Forest Practices Board adopted permanent rules implementing the Forests and Fish protection measures in 2001. The primary objectives of the Forests and Fish Law are to: (1) provide compliance with the Endangered Species Act for aquatic and riparian-dependent species; (2) restore and maintain riparian habitat to support a harvestable supply of fish; (3) meet the requirements of the Clean Water Act for water quality; and (4) keep the timber industry economically viable in the state of Washington. These objectives are to be achieved through management practices that create or retain forest stands that will develop characteristics similar to mature, unmanaged, conifer dominated or mixed riparian stands when they reach an age of 140 years. An adaptive management monitoring program was also established to provide feedback on the effectiveness of the implemented Forests and Fish rules, and to allow modifications to the rules as necessary based upon accumulated scientific evidence. The Forests and Fish rules are different for eastern and western Washington due to their different biogeographic characteristics, and only the rules for western Washington are considered here.

The Forests and Fish rules specify a riparian management zone (RMZ) on each side of potentially fish bearing streams having a total width based on the site potential tree height or site class for Douglas-fir (*Pseudotsuga menziesii*). Each RMZ is then subdivided into three subzones parallel to a stream. The first subzone, adjacent to a stream, is the *core zone*, and it is a 50 foot wide no harvest zone. The second subzone, the *inner zone*, where limited harvest may be permitted subject to leave tree, shade, and other constraints. The third subzone, the *outer zone*, where harvest is permitted subject to leave tree and other constraints. The widths of the inner and outer zones vary depending on Douglas-fir site class and stream size. Two stream size classes are used: streams < 10 feet in bankfull width and streams ≥ 10 feet in bankfull width.

Assessments to determine whether any inner zone harvest is permitted under the Forests and Fish rules are performed in two steps. First, the current forest conditions are projected to an age of 140 years using a forest growth model. Second, the basal area per acre (BAPA) for the combined core and inner zones is compared to a threshold at 140 years. If the BAPA value is less than the threshold, then no inner zone harvest is permitted. If the BAPA value is greater than or equal to the threshold, then inner zone harvest is permitted subject to shade and other constraints, provided the residual trees allow the combined core and inner zone BAPA value to meet or exceed the threshold when projected to 140 years.

The Forests and Fish rules provide two leave tree options, Option 1 and Option 2 for inner zone harvest when permitted and outer zone harvest. Under Option 1, the inner zone harvest must be from below and at least 57 conifer trees per acre (TPA) with diameter at breast height (DBH) values of at least 12 inches, or the largest diameter trees must be left in the harvested area. Outer zone harvest under Option 1 must leave 20 conifer TPA with DBH values of at least 12 inches. The number of leave trees in the outer zone may be reduced, on a basal area for basal area basis, by placing large woody debris in a stream or by tallying trees within channel migration zones. Trees designated as leave trees under Option 1 are required to be left uncut in all future harvests.

Under Option 2, the simpler option, the no harvest zone adjacent to the stream is extended from the core zone into the inner zone for an additional 30 feet for streams < 10 feet in bankfull width and 50 feet for streams ≥ 10 feet in bankfull width. In addition, trees furthest from the stream must be removed first, leaving 20 conifer TPA having DBH values of at least 12 inches, or the largest diameter trees in the harvested area. Outer zone harvest under Option 2 must leave 20 conifer TPA with DBH values of at least 12 inches. The number of leave trees in the outer zone may, however, be reduced to a minimum of 10 TPA if the combined core and inner zones have a projected BAPA surplus at age 140 on a basal area for basal area basis. Trees designated as leave trees under Option 2 are required to be left uncut in all future harvests.

The BAPA thresholds are referred to as the desired future condition (DFC) target. The initial DFC BAPA targets were site class dependent, based on Douglas-fir site classes, and were negotiated based on a "found" data set pieced together from several sources. The initial DFC BAPA targets were: 285 ft^2ac^{-1}, 275 ft^2ac^{-1}, 258 ft^2ac^{-1}, 224 ft^2ac^{-1}, and 190 ft^2ac^{-1}, respectively, for Douglas-fir site classes I – V. These values were assumed to be interim values, to be used until a data set representative of 140 year old, unmanaged, conifer dominated and mixed riparian forests in western Washington could be collected and used to validate the DFC BAPA targets or identify alternative DFC targets. Such a data set, the desired future conditions validation data set (DFCVDS), was collected and analyzed (Schuett-Hames et al., 2005). Based on an analysis of this data set, a new, one-size-fits-all (OSFA) BAPA value of 325 ft^2ac^{-1} was established as the new DFC target for all site classes in the Fall of 2009.

Given the complexity of the Forests and Fish rules, a DFC model was developed to provide an easy to use tool to perform the projections to an age of 140 years and the necessary BAPA computations and assessments. The DFC model consists of thousands of growth model runs for a wide variety of initial stand conditions and thinning treatments that have been converted into lookup tables for interpolation. Users of the DFC model input the necessary information, including the locations of trees relative to a stream, tree sizes, species, and other information, and the model provides as output information describing the potential for harvest in the inner zone, leave tree requirements for the inner and outer zones, estimates of surplus BAPA and various other details related to the stand projection and assessment.

This section was intended to provide only a brief overview of the Forests and Fish Law of Washington State and the specific rules related to the quantitative management targets and assessment procedures developed for basal area per acre at 140 years. More complete descriptions of the Forests and Fish Law can be found at the following web sites.

`http://www.forestsandfish.com`
: This is the main web portal for information about the Forests and Fish Law in Washington State.

`http://apps.leg.wa.gov/WAC/default.aspx?cite=222`
: The Washington Forest Practices rules, published in Title 222 of the The Washington Administrative Code.

`http://apps.leg.wa.gov/RCW/default.aspx?cite=76.09`
: The Washington Forest Practices Act, Chapter 76.09 of the Revised Code of Washington.

1.3 Objectives

Given the dependence of the Forests and Fish Law on the use of a data set to define a forest structure target for managed stands and the use of a forest growth model to project forest conditions into the future, four quantitative targets and two versions of the ORGANON forest growth model (Hann et al., 1997) are compared within the context of the law. The quantitative target comparisons are performed using two independent reference data sets and several management scenarios projected using the two versions of the ORGANON forest growth model to highlight several issues that can arise when using quantitative forest structure targets.

2 Methods

2.1 Reference data set descriptions

Two reference data sets are used to define quantitative forests structure targets and to provide observations for assessments relative to those targets. The first reference data set is the desired future conditions validation data set (Schuett-Hames et al., 2005) collected by Washington State, and it will be referred to as the DFCVDS reference data. The second reference data set is derived from the PNW-FIA Integrated Database version 2.0 (Hiserote and Waddell, 2004) but emphasizes Douglas-fir dominant and mixed stands, which are among the dominant managed forest stand types in western Washington, and it will be referred to as the FIAREF reference data.

The data collection objective for the DFCVDS data was to "collect data on stand characteristics from a random sample of mature [140 year old], unmanaged conifer and mixed composition riparian stands in western Washington" (Schuett-Hames et al., 2005) that were representative of areas managed under the Forests and Fish rules. The DFCVDS reference data consists of 113 sample plots with a targeted map-based age range of 120 to 140 years and a field verified age range from 80 years to over 200 years. The majority of sampled plots were in the Cascade and Coast Mountain Ranges, 98 plots, with the remainder in the Puget Sound lowlands. Plots were selectively filtered by rejecting potential sample plots having less than 30% canopy closure and plots having "unsuitable stand age or composition, or conditions unsuitable for tree growth," such as, "rock outcrops, talus slopes, landslide scarps or standing water," among other criteria (Schuett-Hames et al., 2005). This *selectivity* has the potential to introduce a selection bias toward forest stands having greater stocking levels, i.e., stands having greater numbers and sizes of trees relative to average or typical stand conditions. This issue will be examined in more detail later.

The data selection objective for the FIAREF data was to mimic the stated objectives of the DFCVDS, but to emphasize Douglas-fir dominated and mixed stands. A total of 553 plots were selected from the FIA-IDB version 2.0 for the FIAREF reference data. The plots selected were classified as timberland with an FIA forest type of Douglas-fir, had at least 50% of their BAPA represented by Douglas-fir, and had ages in the range from 100 to 180 years, and were from Oregon and Washington west of the Cascade Mountains. The FIA-IDB sample plots are on a regular grid throughout the region, and should, therefore, provide a more consistent sample of the forest structures throughout the region, relative to, for example, the DFCVDS sample which was mostly contained within the Coast and Cascade Ranges. Two issues, however, do arise when using plots from the FIA-IDB.

First, using only information contained within FIA-IDB version 2.0, it is not possible to definitively determine whether a particular plot has had some sort of harvest activity. It is, however, possible to obtain plot notes from the inventory surveys directly from the FIA for review. Two steps were taken to address this issue: (1) plots identified as having trees associated with a residual overstory were removed to reduce the potential impact of plots that may have been subject to some harvest activity; and (2) field notes for site classes I, II, and III were available from a different project and were used to definitively identify a subset of unmanaged plots for comparison to the overall FIAREF data set.

Second, and again using only information contained within FIA-IDB version 2.0, it is not possible to determine whether plots were riparian plots located near a stream. If,however, stands are selected based on dominant species and site quality, as was done here for the FIAREF data, issues relating to whether a stand is riparian or not become moot: riparian and upland stands having the same dominant species and site class are assumed to have, on average, the same level of productivity and similar stand structure. There is also some evidence indicating that differences between upland and riparian forests dominated by the same species may be small (Macdonald et al., 2004), providing credence to using upland stands as surrogates for riparian stands.

Given that gross forest structure attributes are being used for the target definition and assessment criteria, e.g., TPA, QMD, and BAPA, and that the natural variability of these attributes is large, the use of stands from the FIA-IDB that have not been definitively determined to be unmanaged and riparian should have minimal impact. To lend support to this statement, the TPA and QMD values for the DFCVDS reference data, the FIAREF reference data, and a known to be unmanaged subset of the FIAREF data set (FIAREFU) are plotted in Figure 1. Note in particular that the three data sets have a large region of overlap within which the distributions of their points are very similar. Several notable exceptions to the overlap region are, however, present.

First, the FIAREF data set has more points to the left and below the overlap region. This may be explained by the inclusion of site classes IV and V in the FIAREF data set, relative to the FIAREFU data set. The less productive site classes would be expected to appear below and to the left of the more productive site classes. Second, the DFCVDS data set has a relatively greater number of points above the apparent self-thinning curve than the FIAREF or FIAREFU data sets. This may be an indication that the DFCVDS data set has sampled a disproportionate number of stands with greater stocking, relative to the number of such stands in the overall population. This could also be related to differences between stocking levels of Douglas-fir relative to other conifer species, or biogeographic differences in the samples, e.g., mountain *vs.* lowland. Third, the DFCVDS data set has no points in the lower left of the distribution. This may be an indication of selection bias in the DFCVDS, particularly since the FIAREFU subset has several data points that appear in this region of the distribution. From this examination of the data sets, there is no compelling reason to disqualify the FIAREF reference data as being representative of unmanaged forest conditions within riparian areas.

2.2 Forest structure target descriptions

Four quantitative forests structure targets are compared. The targets represent both the indirect and direct approaches to using an attribute value distribution to derive quantitative assessment criteria. The first two targets use the indirect approach and are based on the Forests and Fish Law, and are the original, interim site class dependent minimum BAPA DFC target and the current one-size-fits-all minimum BAPA DFC target of 325 $\mathrm{ft}^2\mathrm{ac}^{-1}$. The third and fourth targets use the direct approach via nonparametric approximations to the joint distributions of TPA and quadratic mean diameter (QMD) from the two reference data sets coupled with a multivariate assessment procedure (Gehringer, 2006). The third target uses the FIAREF reference data set, and the fourth target uses the DFCVDS reference data set. The two multivariate targets use TPA and QMD for consistency with the use of BAPA by the Forests and Fish rules, since BAPA is directly proportional to TPA $\times$ QMD^2. By splitting BAPA into its constituent parts TPA and QMD it is possible to avoid size-density issues inherent in the use of BAPA, e.g., the fact that stands having different structural compositions and tree size distributions can have nearly identical BAPA values. Descriptions of each target and the naming conventions used in the remainder of the manuscript appear below.

Target 1: SI/BA

This target is based on the original, interim DFC targets for BAPA by Douglas-fir site class from the Forests and Fish Law. The BAPA lower bounds for this target are 285 ft^{2}ac^{-1}, 275 ft^{2}ac^{-1}, 258 ft^{2}ac^{-1}, 224 ft^{2}ac^{-1}, and 190 ft^{2}ac^{-1}, respectively, for Douglas-fir site classes I – V. Assessments using this target are made at an age of 140 years, and observations are accepted if the combined core and inner zone BAPA exceeds the threshold for the appropriate site class.

Target 2: OSFA/BA

This target is based on the current one-size-fits-all (OSFA) BAPA DFC target of 325 ft^{2}ac^{-1} from the Forests and Fish Law. The DFC target is the median BAPA value from the DFCVDS rounded up to the nearest whole number. Assessments using this target are made at an age of 140 years, and observations are accepted if the combined core and inner zone BAPA exceeds the threshold.

Target 3: FIAREF

This target uses the TPA and QMD attributes from the FIAREF reference condition data set and the nonparametric assessment procedure from Gehringer (2006) to specify quantitative targets using an acceptance percentage and approximate contours of the joint distribution for TPA and QMD. Assessments for this target are performed for each observation, regardless of age, allowing the computation of a percentage of time in target for stand trajectories.

Target 4: DFCVDS

This target uses the TPA and QMD attributes from the DFCVDS reference data set and the nonparametric assessment procedure from Gehringer (2006) to specify quantitative targets using an acceptance percentage and approximate contours of the joint distribution for TPA and QMD. Assessments for this target are performed for each observation, regardless of age, allowing the computation of a percentage of time in target for stand trajectories.

At this point it seems prudent to acknowledge up front that apples and oranges comparisons will be taking place, not least of which is the comparison of Douglas-fir dominated and mixed stands with conifer dominated and mixed stands. These comparisons, however, are a fundamental aspect of the Forests and Fish rules, and the uses of the DFCVDS data and the BAPA targets here are consistent with the manner in which they are being used by Washington State. That said, it is time to describe the target comparisons.

2.3 Target comparison part 1: Data

The data based target comparisons used the FIAREF and DFCVDS reference data sets as observations, assessing each reference data set relative to the four quantitative targets defined in Section 2.2. Acceptance percentages of 95%, 90%, 80%, and 50% were used for the multivariate assessments, to demonstrate the statistical consistency of the multivariate assessment approach when the target and observation data sets were the same and to identify differences in the acceptance regions when the target and observation data sets were different. Assessment results are computed as the percentage of the FIAREF or DFCVDS reference data sets accepted by the assessment criteria used for each target.

2.4 Target comparison part 2: Models

Five management options, five multi-zone management scenarios, and two forest growth models have been selected for the forest growth model comparison to highlight some of the issues involved in using quantitative forest structure targets derived from actual measurement data with output from forest growth models. Forest growth model trajectories from the five management scenarios were assessed relative to the four quantitative targets defined in Section 2.2. A 160 year time horizon was used when running the forest growth model projections for compatibility with the time horizon of the Forests and Fish Law. This time horizon was deemed sufficient for comparisons within the context of the law, while providing an indication of the initial post 140 year trajectories for the management scenarios.

The forest growth models used were SMC-ORGANON version 6.0 (O6.0) and SMC-ORGANON version 8.2 (O8.2), and represent different calibrations of the SMC-ORGANON forest growth model (Hann et al., 1997, Hanus et al., 1999, Hann et al., 2003, 2006) to the forest inventory database of the Stand Management Cooperative (Chappell et al., 1988). These two forest growth models were selected since SMC-ORGANON version 6.0 was the forest growth model used to create the DFC model and SMC-ORGANON version 8.2 included updates to the growth equations for Douglas-fir that significantly changed the growth trajectories produced by the model. The nature of these changes will be discussed later in Section 3.2, along with a comparison to historical reference data for Douglas-fir in the Pacific Northwest (Meyer, 1930, McArdle and Meyer, 1930, McArdle et al., 1949).

Tree lists for each of the management options described below were based on the SMC-ORGANON model projections with five year output intervals using an initial tree list representing an actual, 20 year old riparian stand, the base stand. The base stand is a 100% pure stand of Douglas-fir, that contained 471 standing, live Douglas-fir trees per acre, located in south-western Washington State. The base stand had a site index of 120 ft at 50 years and was a Douglas-fir site class II stand (King, 1966). The trees in the base stand had a mean DBH of 7.4 inches, with a standard deviation of 1.9 inches and a range from 4.0 inches to 13.0 inches, a mean height of 48.5 ft, with a standard deviation of 3.9 ft and a range from 43.0 ft to 67.0 ft. This stand structure was considered to be representative of the young, relatively dense riparian forest stands that dominate the managed riparian areas in western Washington, and was chosen as the base stand for the management option projections for this reason. All of the management options were assumed to represent a one acre riparian buffer area with Douglas-fir site class II and a 50 year site index of 120 ft (King, 1966).

The SMC-ORGANON model projections were performed using internal height and diameter growth calibrations that adjust the model to the account for the initial tree dimensions, site index, and age. No other model calibrations were performed.

The management option descriptions appear in the list below. In the management option descriptions a commercial thinning is denoted by CT and represents a thinning operation producing sufficient merchantable material to at least offset the cost of the thinning operation. Two types of thinning operations are used: thinning from below and proportional thinning. Thinning from below removes the smallest diameter trees first and proportional thinning removes trees equally from all diameter classes. For each management option the complete set of management operations over the 160 year time horizon are included.

NOACTION Plant 471 TPA and grow with no thinning.

UPLAND Plant 471 TPA. CT to 180 TPA from below at age 20. CT to 100 TPA from below at age 35. Clearcut at age 50, leaving 2 TPA at least 20 inches DBH and another 2 TPA at least 12 inches DBH. Plant 300 TPA. CT to 180 TPA from below at age 70. CT to 100 TPA from below at age 85. Clearcut at age 100, leaving the 4 largest TPA. Plant 300 TPA. CT to 180 TPA from below at age 120. CT to 100 TPA from below at age 135. Clearcut at age 150, leaving the four largest TPA. Plant 300 TPA.

UNDERPLANT Plant 471 TPA. Commercial thin to 180 TPA from below by DBH at age 20. Commercial thin to 100 TPA from below by DBH at age 35. Commercial thin to 60 TPA from below by DBH at age 50. Commercial thin to 48 TPA proportionally by DBH at age 60. Commercial thin to 41 TPA proportionally by DBH at age 70. Commercial thin to 25 TPA from below by DBH at age 70 and underplant with 150 TPA Douglas-fir and 150 TPA western red cedar (*Thuja plicata*). Commercial thin to 180 TPA from below by DBH at age 100. Commercial thin to 120 TPA from below by DBH at age 120. After age 120, no further thinning.

10LEAVE Plant 471 TPA. CT to 180 TPA from below at age 20. CT to 100 TPA from below at age 35. Clearcut at age 50, leaving 10 TPAat least 12 inches DBH. Plant 300 TPA. CT overstory to 8 TPA proportionally at age 60. CT overstory to 7 TPA proportionally at age 70. CT to 180 TPA from below at age 70. CT to 100 TPA from below at age 85. Clearcut at age 100, leaving 10 TPA at least 12 inches DBH. Plant 300 TPA. CT overstory to 8 TPA proportionally at age 110. CT overstory to 7 TPA proportionally at age 120. CT to 180 TPA from below at age 120. CT to 100 TPA from below at age 135. Clearcut at age 150, leaving 10 TPA at least 12 inches DBH. Plant 300 TPA. CT overstory to 8 TPA proportionally at age 160.

20LEAVE Plant 471 TPA. CT to 180 TPA from below at age 20. CT to 100 TPA from below at age 35. Clearcut at age 50, leaving 20 TPA at least 12 inches DBH. Plant 300 TPA. CT overstory to 16 TPA proportionally at age 60. CT overstory to 14 TPA proportionally at age 70. CT to 180 TPA from below at age 70. CT to 100 TPA from below at age 85. Clearcut at age 100, leaving 20 TPA at least 12 inches DBH. Plant 300 TPAĊT overstory to 16 TPA proportionally at age 110. CT overstory to 14 TPA proportionally at age 120. CT to 180 TPA from below at age 120. CT to 100 TPA from below at age 135. Clearcut at age 150, leaving 20 TPA at least 12 inches DBH. Plant 300 TPA. CT overstory to 16 TPA proportionally at age 160.

Descriptions of the five management scenarios, their respective management zones, and the assigned management options appear below. The management scenarios were generated using a multi-zone managed riparian buffer simulation system (Gehringer, 2008b) that uses bootstrap simulations (Efron, 1982, Efron and Tibshirani, 1998) to approximate distributions of stand attributes for each management scenario and output year using the management option tree lists generated by a forest growth model. The bootstrap simulations randomly selected and placed trees within a riparian management subzone proportionally using tree lists from the management option assigned to that subzone. All of the management scenarios were assumed to represent a one acre riparian buffer area having a width, measured perpendicular or upslope to a stream, of 170 ft, the total buffer width required by the the Forests and Fish Law for Douglas-fir site class II, and a reach along a stream of 256.2 ft. All management scenarios were assumed to represent stands with Douglas-fir site class II and a 50 year site index of 120 ft (King, 1966). A random, uniform, distribution of tree locations was assumed within each defined management zone, and only trees having diameter at breast height values of at least four inches were used.

Assessments under the Forests and Fish rules were performed assuming that streams were less than 10 ft in bankfull width for all management scenarios except the FF Option 2 $\geq$ 10 ft scenario, and a 90% acceptance region was assumed when using the multivariate assessment procedure. Assessment for the multivariate assessment procedure and the TPA–QMD targets used the entire simulated riparian acre to compute the TPA and QMD attributes for the assessments.

50 ft No Harvest This management scenario represents the baseline 50 foot no harvest zone required by the Forests and Fish rules and has two subzones. The first subzone is assigned the NOACTION management option and ranges from 0 ft to 50 ft from a stream. The second subzone is assigned the UPLAND management option and ranges from 50 ft to 170 ft from a stream.

Bio-pathway This management scenario represents a biological pathway (Carey et al., 1999) intended to produce a mixed species, Douglas-fir and western red cedar, forests with multiple canopy layers and has three subzones. The first subzone is assigned the NOACTION management option and ranges from 0 ft to 25 ft from a stream. The second subzone is assigned the UNDERPLANT management option and ranges from 25 ft to 80 ft from a stream. The third subzone is assigned the UPLAND management option and ranges from 80 ft to 170 ft from a stream.

FF Option 2 $\geq$ 10 ft This management scenario approximates the Forests and Fish rules for streams greater than ten feet wide under Option 2 and has three subzones. The first subzone is assigned the NOACTION management option and ranges from 0 ft to 100 ft from a stream. The second subzone is assigned the 20LEAVE management option and ranges from 100 ft to 120 ft from a stream. The third subzone is assigned the 10LEAVE management option and ranges from 120 ft to 170 ft from a stream.

FF Option 2 $<$ 10 ft This management scenario approximates the Forests and Fish rules for streams less than ten feet wide under Option 2 and has three subzones. The first subzone is assigned the NOACTION management option and ranges from 0 ft to 80 ft from a stream. The second subzone is assigned the 20LEAVE management option and ranges from 80 ft to 114 ft from a stream. The third subzone is assigned the 10LEAVE management option and ranges from 114 ft to 170 ft from a stream.

No Action This management scenario represents the no action baseline of an unmanaged forest and has a single zone, which is assigned the NOACTION management option from 0 ft to 170 ft.

The astute reader will at this point have noticed two minor discrepancies between the Forests and Fish management scenarios FF Option 2 $\geq$ 10 ft and FF Option 2 $<$ 10 ft, just described, and the previous description of the rules for the Forests and Fish management Option 2. First, the 20LEAVE and the 10LEAVE management options permit the harvesting of some of the leave trees, 6 of 20 TPA and 3 of 10 TPA, respectively. The decision to allow harvest of some of the leave trees in these scenarios was made for economic reasons, specifically, to help offset the cost of the commercial thinning operations. Second, the thinnings were from below, since the ORGANON forest growth model is not spatially explicit and cannot represent tree locations. Given the distances of these trees from a stream, at least 100 ft for FF Option 2 $\geq$ 10 ft and 80 ft for FF Option 2 $<$ 10 ft, the removal of the leave trees should have limited impact on the stream. The lack of tree locations for the thinnings has no impact on the required basal area computations. Aside from the harvest of the leave trees and the lack of tree locations, the FF Option 2 $\geq$ 10 ft and FF Option 2 $<$ 10 ft management scenarios are consistent with riparian forest management required under the Forests and Fish rules.

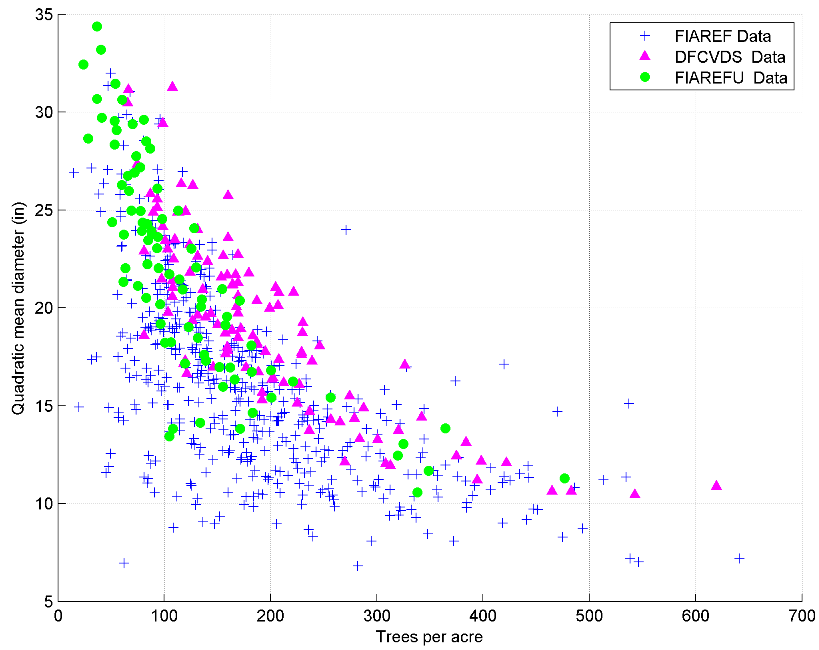

Figure 1: Quadratic mean diameter *vs.* trees per acre for the FIAREF and DFCVDS reference data sets and an unmanaged subset of the FIAREF reference data set.

Table 1: Assessment results for the FIAREF and DFCVDS data sets as observations.

Observation data	FIAREF				DFCVDS			
Acceptance region	95%	90%	80%	50%	95%	90%	80%	50%
SI/BA	47%	47%	47%	47%	88%	88%	88%	88%
OSFA/BA	13%	13%	13%	13%	50%	50%	50%	50%
FIAREF	95%	90%	80%	50%	94%	88%	83%	39%
DFCVDS	80%	61%	51%	20%	94%	88%	79%	49%

3 Results and discussion

3.1 Target comparison part 1: Data

Assessment results for the FIAREF and DFCVDS reference data sets used as observations relative to the four quantitative targets are given in Table 1. Values are the percentage of the data points from either observation data set considered acceptable relative to the assessment criteria for each of the four targets. The SI/BA and OSFA/BA targets use fixed minimum BAPA values and the acceptance percentages, therefore, do not vary, whereas acceptance percentages for the multivariate assessments using the FIAREF and DFCVDS targets varied with the targeted acceptance region. Assessment results are presented graphically in sequence by targeted acceptance region in Figure 2 through Figure 5 using the FIAREF reference data as the observations and in Figure 6 through Figure 9 using the DFCVDS reference data as the observations. The graphical assessment results are presented as TPA–QMD plots, with the accepted points shown in green and the rejected points in red. The SI/BA and OSFA/BA figures on the top row also indicate the BAPA isolines, or lines of equal BAPA for each of the relevant BAPA minimums in the respective targets. Points above the BAPA isoline are accepted and those below it are rejected. The SI/BA abd OSFA/BA figures are identical in each sequence of acceptance region figures, and were included to facilitate direct comparisons with the multivariate assessment method for each targeted acceptance percentage.

The assessment results from Table 1 and the accompanying figures indicate a dichotomy between the results for the FIAREF observations and the DFCVDS observations. This is more clearly seen for the SI/BA and OSFA/BA targets, but can be found in the FIAREF and DFCVDS targets as well for the 50% acceptance region. First, if the FIAREF reference data set is representative of forests in the region, then the BAPA levels in the SI/BA target are likely too high, accepting only 47% of the observations, but if the DFCVDS reference data are representative of conifer forests in the region, then the SI/BA BAPA targets work well, accepting 88% of the observations overall. The OSFA/BA target essentially rejects the FIAREF reference data by accepting only 13% of the observations, while accepting 50% percent of the DFCVDS observations, by design since the OSFA/BA BAPA target is the median of the DFCVDS reference data.

The FIAREF target is in good agreement with the observed acceptance percentages for both the FIAREF reference data and DFCVDS reference data when used as observations. Agreement between the targeted FIAREF acceptance regions and the observed acceptance percentages for the FIAREF observations was expected, and demonstrates the statistical consistency of the multivariate targeting approach. The agreement between the targeted

FIAREF acceptance regions and those observed for the DFCVDS observations demonstrates that there is a significant overlap between the FIAREF and DFCVDS data sets, with the exception of the most restrictive case, the 50% FIAREF target percentage which produced an observed DFCVDS acceptance percentage of 39%, where the accepted DFCVDS observations appear to the lower left of the data, see the lower left plot in Figure 9.

The DFCVDS target does not have as strong an agreement between the target acceptance regions and the observed acceptance percentages for the FIAREF and DFCVDS observations. In all cases, the observed DFCVDS acceptance percentages are within two units of their respective targeted values, but the acceptance percentages for the FIAREF observations are all much lower than expected, 80%, 61%, 51%, and 20%, respectively, for the targeted 95%, 90%, 80%, and 50% acceptance regions, with increasing deviations as the targeted acceptance region becomes more restrictive, see the lower right plots in Figure 2 through Figure 5. The deviations from the targeted acceptance regions for the DFCVDS observations can be explained by the relatively small sample sample size of 113 points and truncation in the multivariate assessment procedure (Gehringer, 2006) to produce conservative outcomes, that is, outcomes more likely to reject near an approximate probability contour for a target acceptance region.

The deviations from the targeted acceptance regions for the FIAREF observations and the DFCVDS target can be partly explained by examining the TPA–QMD distributions of the FIAREF and DFCVDS reference data. The DFCVDS data distribution has lower variability than the FIAREF data distribution, with generally narrower ranges for the TPA and QMD values, and it is also shifted up and to the right relative to the distribution of the FIAREF data. All three of these factors influence the multivariate assessment procedure, making the targeted acceptance regions narrower, due to the lower variability and narrower data ranges, and further away from the mode of the FIAREF data, due to the shift up and to the right. The apparent overlap between the FIAREF and DFCVDS data sets is reduced, thereby reducing the observed acceptance percentages for the FIAREF observations relative to the DFCVDS target.

The acceptance regions for each reference data set and the multivariate targets based on it clearly shrink toward the mode of their respective TPA–QMD distributions as the targeted acceptance regions decline, as seen in the plots for the matching target and observation data sets, the lower left plot for the FIAREF data in Figure 2 to Figure 5 and the lower right plot for the DFCVDS data in Figure 6 to Figure 9. The BAPA isolines, however, restrict the acceptable observations to a crescent shape below and following the apparent self-thinning relationship, rather than emphasizing the most likely region in the TPA–QMD distribution. This may be an indication that the SI/BA and OSFA/BA targets do not identify the most relevant region, from a multivariate statistical perspective, with regard to the desired or desirable forest structures and they may not be compatible with the ecological intent of the Forests and Fish Law.

Both the FIAREF and DFCVDS reference data sets attempt to characterize the distribution of forest or riparian forest structures for mature, 100 to 180 year old, conifer dominated forests in western Washington State, for the primary purpose of creating a quantitative management target specifying desired or desirable forest structures. The dichotomy between the FIAREF and DFCVDS reference data sets demonstrated via the assessment results raises the issue of a potential selection bias for one or both of the reference data sets.

To address this issue a comparison to an historical reference condition for Douglas-fir will be made. The historical reference condition is derived from the normal yield tables for Douglas-fir contained in Technical Bulletin 201 (B201) published by the United States Department of Agriculture (McArdle and Meyer, 1930, McArdle et al., 1949) and a related manuscript (Meyer, 1930) that derived relationships between the normal yield tables and actual, or typical, on the ground, yields for Douglas-fir. Before proceeding with the comparison, some terminology must be defined and the context for its use made explicit.

Bulletin 201 uses the idea of *stocking* rather than the more quantitative idea of trees per unit area, e.g., TPA, to "describe the degree to which an area is covered by Douglas fir trees. The ideal or most effective number and distribution of trees is called *normal*, or *full*, stocking (emphasis added). Normal stocking ... is not theoretical maximum stocking but represents the condition of a large number of selected acres in natural stands where no accidents have interfered with growth. Normal stocking ... can be found on single acres ... and in many forests uniformly over an area of 10 or 20 acres." Actual stands may "sometimes be overstocked in reference to the standard tables," however large "areas may appear fully and uniformly forest clad, but close inspection nearly always discloses 'holes' or blank spaces that aggregate enough to bring" yields below those of the normal-yield tables. Actual stands, therefore, are generally understocked relative to normal or fully stocked stands due to the presence of small gaps or breaks in the canopy. Meyer (1930) found that the average BAPA values for Douglas-fir forests were approximately 81% of the normal value from Bulletin 201, with a standard deviation of 19.4% of the normal value and a range from 25% to 145% of the normal value.

Within the context of defining a quantitative forest structure target for a mature, 100 to 180 year old, unmanaged condition, a representative sample must fall into the category of sampling the range of *actual* stands, not the selected normal or fully stocked stands. The reference condition used for comparison is BAPA over time, for site class II Douglas-fir, with a 100 year site index of 170 ft from Bulletin 201 along with an average (actual) value computed as 81% of the normal value and minimum and maximum values computed using the percentage adjustments from Meyer (1930). These four BAPA curves provide a straightforward means to investigate the potential for BAPA selection bias in the FIAREF and DFCVDS reference data sets, relative to the historical average (actual) condition.

Figure 10 presents a plot with the four historical reference curves from bulletin 201 and scatter plots of the BAPA data for the FIAREF and DFCVDS reference data sets and the FIAREFU unmanaged subset for all site classes. Ages have been jittered using $U(-2.5, 2.5)$ random variables in the figure to better resolve the BAPA distributions for each data set over time. The majority of points from the FIAREF and DFCVDS reference data sets fall between the estimated minimum and maximum values, and there is, again, significant overlap between the distributions of points. The DFCVDS reference data, however, appear to have a greater proportion of their values, approximately half, above the normal BAPA curve, relative to the FIAREF reference data and the FIAREFU subset. Figure 11 plots the mean BAPA plus or minus one standard deviation (SD) and mean age, computed using the jittered values, for the FIAREF and DFCVDS reference datasets and the FIAREFU subset, providing approximate, real world 67% confidence intervals for the mean BAPA values. The mean BAPA for the FIAREF data is below the average (actual) BAPA curve, but the curve is well inside one standard deviation, the mean BAPA for the DFCVDS data

Table 2: Management scenario assessment results for each model, basal area per acre target at age 140, and the TPA-QMD target data sets for a 90% acceptance region.

Target	SI/BA		OSFA/BA		FIAREF		DFCVDS	
Model version	O6.0	O8.2	O6.0	O8.2	O6.0	O8.2	O6.0	O8.2
50 ft no harvest	Yes	No	No	No	100%	100%	38%	34%
Bio-pathway	Yes	No	No	No	100%	100%	34%	21%
FF Option 2 $\geq$ 10	Yes	Yes	Yes	No	100%	100%	79%	72%
FF Option 2 $<$ 10	Yes	Yes	Yes	No	100%	100%	69%	55%
No action	Yes	Yes	Yes	Yes	83%	83%	83%	83%

is located slightly below the normal BAPA curve, but is almost exactly centered within the real world confidence interval, and the FIAREFU mean BAPA value is slightly below the average (actual) BAPA curve, but the curve is near the center of the real world confidence interval.

Figure 12 and Figure 13 provide a similar comparison, but specialized to site class II plots from the FIAREF and DFCVDS reference data and the FIAREFU subset. The overall relationships are similar to those using all of the data, with a few differences. First, the FIAREF mean BAPA value is now almost exactly centered on the average (actual) BAPA curve. Second, the DFCVDS mean BAPA value is now above the normal BAPA curve, and its real world confidence interval just reaches the average (actual) BAPA curve. Finally, the FIAREFU mean BAPA value is slightly above the average (actual) BAPA curve, but the curve is well within the real world confidence interval.

While not exhaustive, this straightforward analysis indicates that the DFCVDS reference data is subject to bias, possibly selection bias from excessive filtering of candidate plots, and that the bias produces a BAPA distribution centered on the normal curve rather than the average (actual) curve. This conclusion was also obtained independently (Iles, 2003). The FIAREF reference data, on the other hand, reproduces the average (actual) mean BAPA value, the observed variability, and the observed range, relative to the historical reference condition used in the comparison, making this data set a good candidate for a quantitative target representing the distribution of forest or riparian forest structures for mature, 100 to 180 year old, conifer dominated forests in western Washington State.

3.2 Target comparison part 2: Models

Results for the assessments of the five management scenarios relative to the four quantitative targets are presented in Table 2. As for the data assessments, there are a number of interesting features in the results, and each of the targets will be considered in turn. Assessments using the SI/BA target accepted all five of the management scenarios for SMC-ORGANON 6.0, but rejected the 50 ft No Harvest and Bio-pathway management scenarios while accepting the FF Option 2 $<$ 10 ft, FF Option 2 $\geq$ 10 ft, and No Action scenarios for SMC-ORGANON 8.2. The assessment criteria did not change, so there must have been a change in the SMC-ORGANON growth model that favors scenarios having lower overall harvest for the SI/BA assessments.

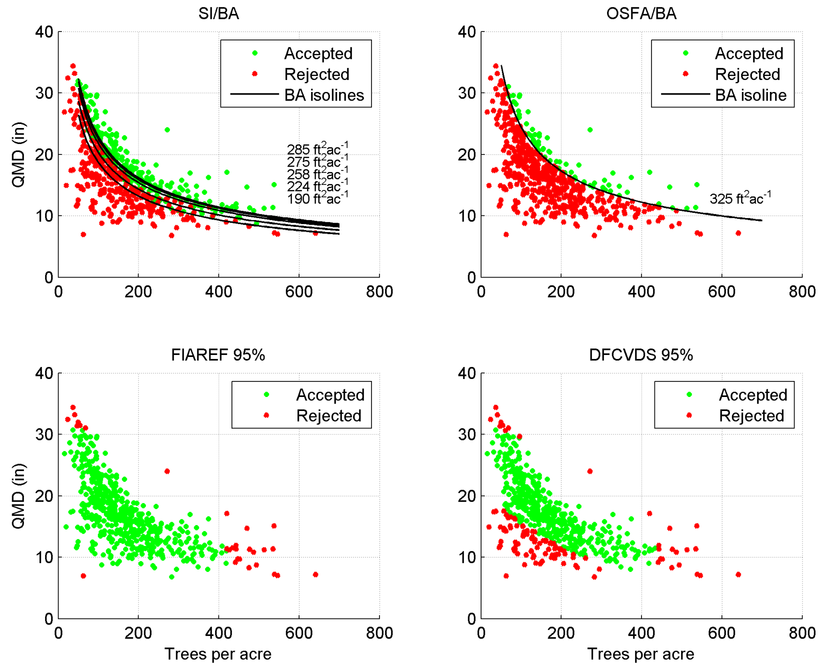

Figure 2: Assessment results for the FIAREF reference data set and a 95% acceptance region.

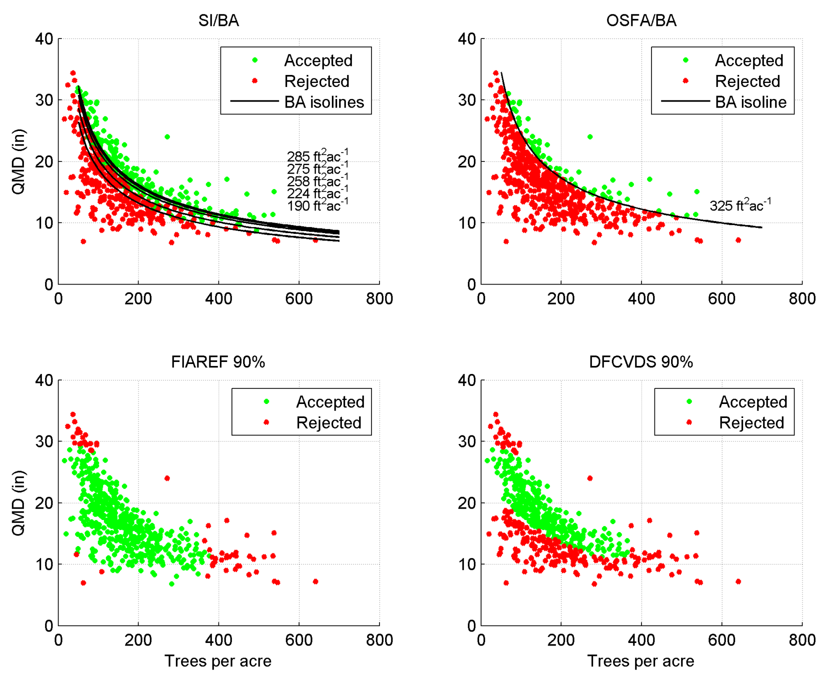

Figure 3: Assessment results for the FIAREF reference data set and a 90% acceptance region.

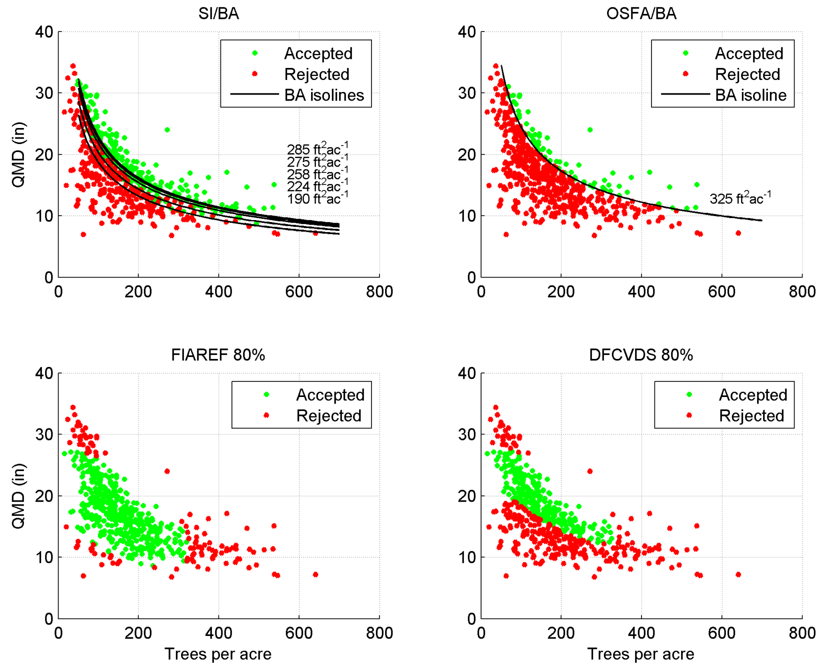

Figure 4: Assessment results for the FIAREF reference data set and a 80% acceptance region.

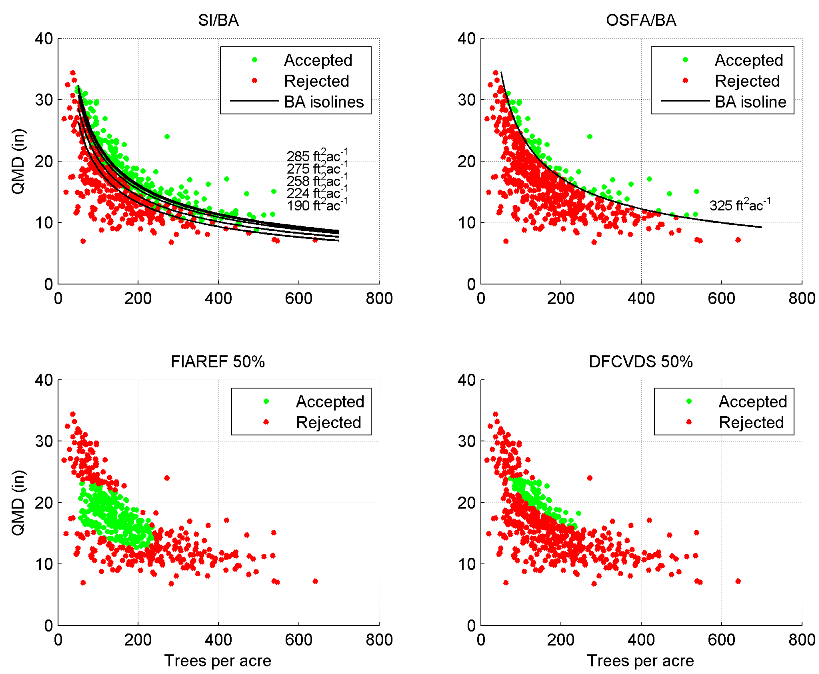

Figure 5: Assessment results for the FIAREF reference data set and a 50% acceptance region.

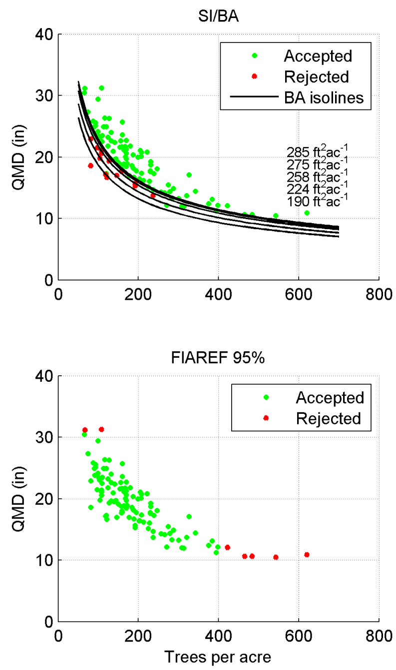

Figure 6: Assessment results for the DFCVDS reference data set and a 95% acceptance region.

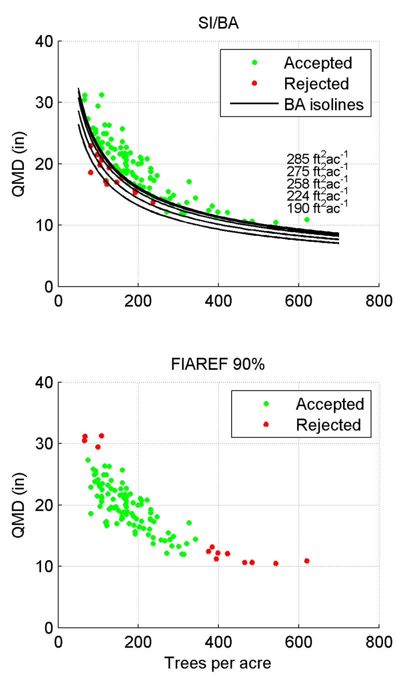

Figure 7: Assessment results for the DFCVDS reference data set and a 90% acceptance region.

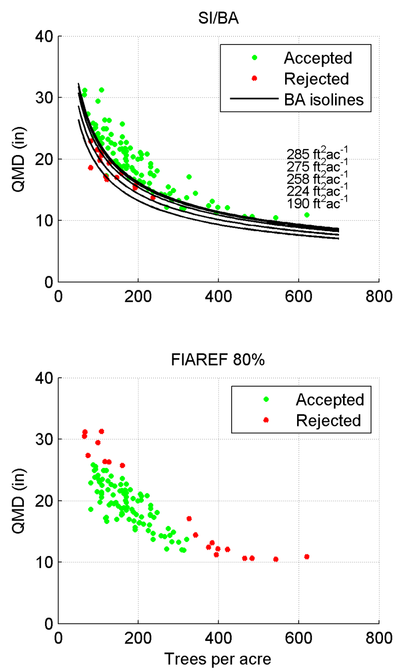

Figure 8: Assessment results for the DFCVDS reference data set and a 80% acceptance region.

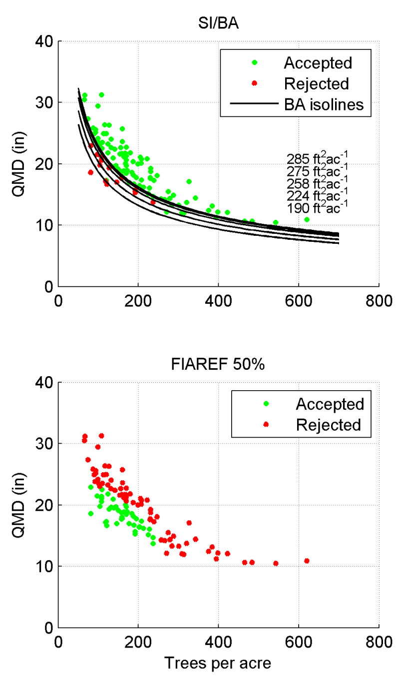

Figure 9: Assessment results for the DFCVDS reference data set and a 50% acceptance region.

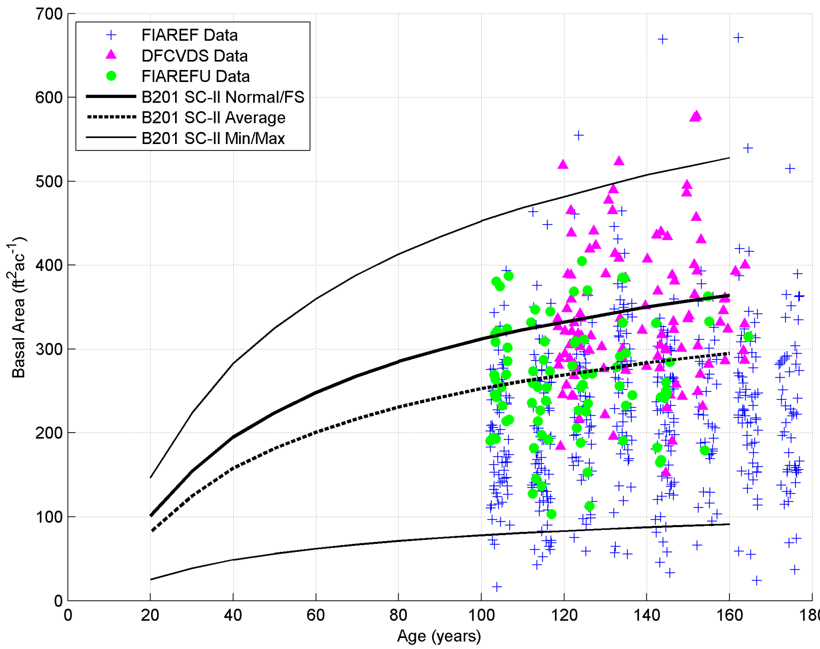

Figure 10: BAPA*vs.* age for the FIAREF and DFCVDS reference data sets and an unmanaged subset of the FIAREF reference data set. Ages have been jittered to better resolve the BAPA distributions.

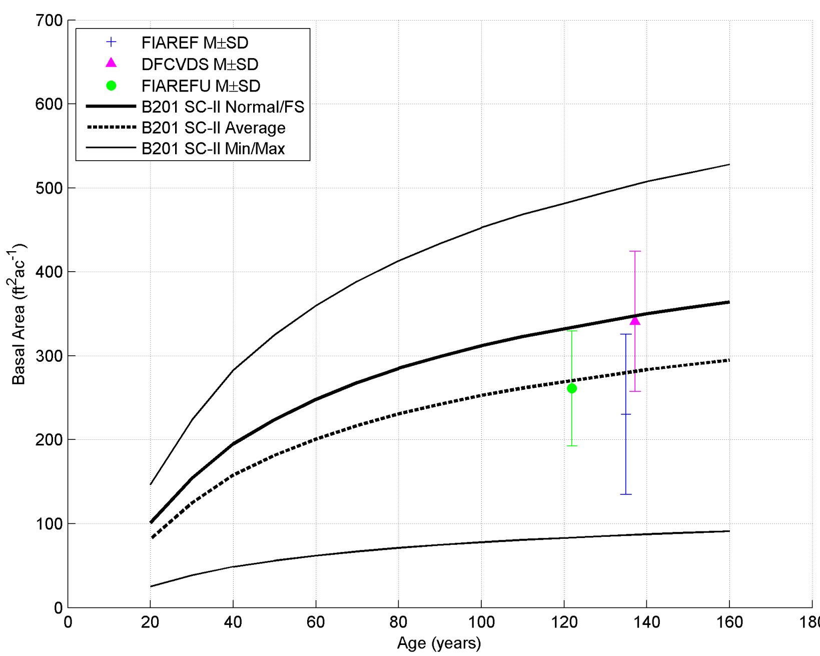

Figure 11: Mean BAPA ± 1 SD *vs.* age for the FIAREF, DFCVDS, and FIAREFU subset. Mean age was computed from the jittered ages.

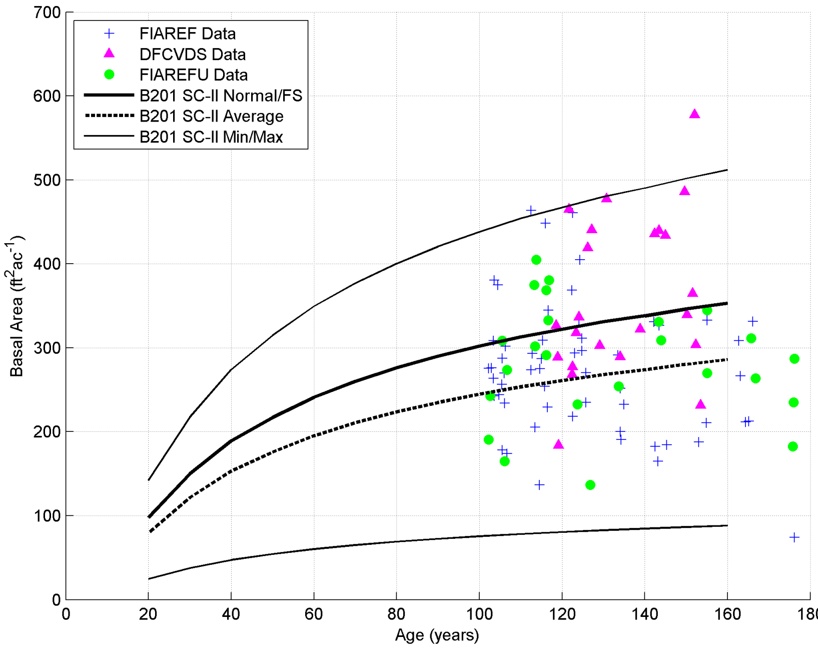

Figure 12: BAPA*vs.* age for the FIAREF and DFCVDS reference data sets and an unmanaged subset of the FIAREF reference data set and Douglas-fir site class II. Ages have been jittered to better resolve the BAPA distributions.

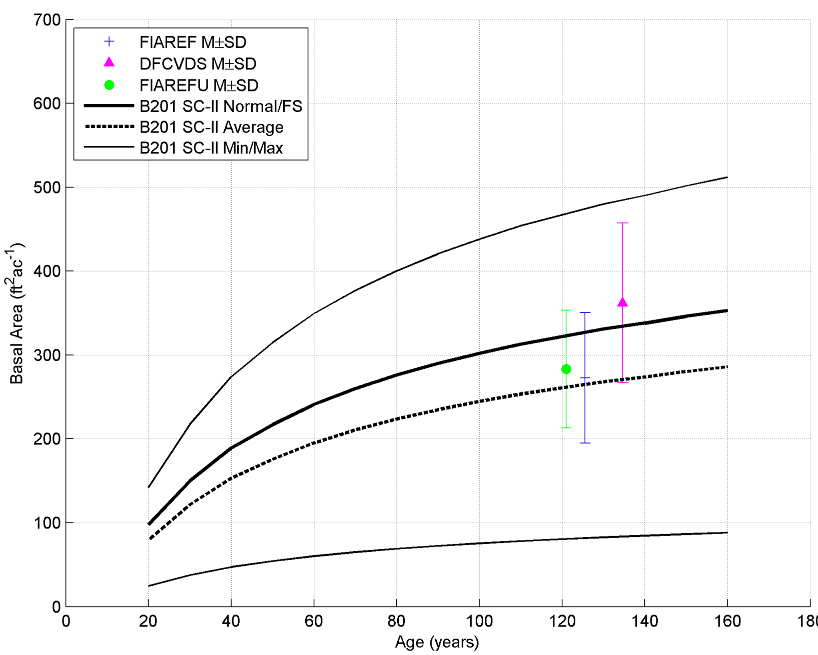

Figure 13: Mean BAPA $\pm$ 1 SD *vs.* age for the FIAREF, DFCVDS, and FIAREFU subset for Douglas-fir site class II. Mean age was computed from the jittered ages.

Assessments using the OSFA/BA target rejected the 50 ft No Harvest and Bio-pathway management scenarios while accepting the FF Option 2 < 10 ft, FF Option 2 ≥ 10 ft, and No Action scenarios for SMC-ORGANON 6.0, but rejected all of the scenarios except the No Action scenario for SMC-ORGANON 8.2. Again, the assessment criteria did not change, so the differences in results are directly related to the differences between SMC-ORGANON versions 6.0 and 8.2. A potential spanner in the works with respect to the OSFA/BA target has also been identified, since this target rejects both of the Forests and Fish management scenarios. Further examination of this issue indicated that a no harvest zone of approximately 110 ft was necessary to achieve the 325 ft^2ac^{-1} of basal area required by the Forests and Fish rules. This has the effect of reducing the partial harvest areas in the inner subzone to the outermost four feet or 10 feet, respectively, for streams less than 10 feet or greater than or equal to 10 feet in bankfull width, making the inner szone essentially superfluous for the OSFA/BA target.

Assessments using the multivariate TPA–QMD FIAREF target produced identical results for both model versions, accepting 100% of the modeled trajectories for the 50 ft No Harvest, Bio-pathway, FF Option 2 < 10 ft, and FF Option 2 ≥ 10 ft, management scenarios, while accepting only 83% of the trajectory for the No Action scenario. At first these results seem somewhat puzzling, but upon further reflection it is what should be expected given the TPA–QMD distribution of the target. The multivariate assessment procedure rejects the tails of the TPA–QMD crescent before rejecting the lower left region of the distribution, and there is no upper right to the distribution due to the self-thinning size-density relationship. The management scenarios having greater harvest, 50 ft No Harvest and Bio-pathway, will produce "spiral" trajectories in the central and lower left regions of the TPA–QMD distribution. The trajectory for Bio-pathway scenario will eventually leave these regions of the TPA–QMD distribution, moving up and to the left as the understory fully develops, but the 50 ft No Harvest scenario will remain, more or less, in this region. The two Forests and Fish scenarios, FF Option 2 < 10 ft and FF Option 2 ≥ 10 ft both produce trajectories that move from the lower right to the upper left through the central portion of the TPA–QMD distribution due to their large no harvest areas. The initial thinning events for these two scenarios create trajectories that start within the TPA–QMD distribution by reducing the number trees and increasing average tree diameter. Finally, the No Action management scenario has only 83% acceptance since its first five points are in the lower right tail of the TPA–QMD distribution that was removed from the target by using a 90% acceptance region, with the remaining trajectory points being kept in the acceptance region due to the self-thinning size-density relationship.

Assessments using the multivariate TPA–QMD DFCVDS target produced results that varied by SMC-ORGANON version and management scenario. There were, however, trends in the results, related to the degree of total harvest over the time horizon and the growth model version. The Bio-pathway scenario had the narrowest initial no harvest buffer at 25 ft and the greatest total harvest over the 140 year time frame, and the lowest acceptance percentages, 34% and 21%, respectively for SMC-ORGANON versions 6.0 and 8.2. After age 120, however, this scenario has an 80 ft no harvest zone, which over a longer time horizon would shift the "spiral" trajectory toward the central and upper left regions of the TPA–QMD distribution. The performance of this management scenario was impacted by the early, aggressive transformation to a multistory canopy and a time horizon that limited the did not permit the potential benefit to be observed. Next is the 50 ft No Harvest scenario with acceptance percentages of 38% and 34%, respectively for SMC-ORGANON versions 6.0 and 8.2. These acceptance percentages are higher than those for the Bio-pathway scenario due to the wider no harvest zone, 50 ft *vs.* 25 ft. Next are the two Forests and Fish scenarios, with the FF Option 2 < 10 ft having acceptance percentages of 69% and 55%, respectively for SMC-ORGANON versions 6.0 and 8.2, and the FF Option 2 ≥ 10 ft having corresponding acceptance percentages of 79% and 72%. The acceptance percentages for the No Action scenario were 83% for both versions SMC-ORGANON.

Of the minimum basal area targets based on the Forests and Fish rules, the SI/BA target accepted more of the management scenarios at age 140 than the OSFA/BA target, and SMC-ORGANON version 6.0 produced more acceptable scenarios than SMC-ORGANON version 8.2 for each of the two targets. The FIAREF multivariate TPA–QMD target had greater acceptance percentages than the DFCVDS target for all of the management scenarios, and SMC-ORGANON version 6.0 produced identical acceptance percentages to SMC-ORGANON version 8.2 for the FIAREF target and larger acceptance percentages for the DFCVDS target, except for the No Action scenario where the acceptance percentages were equal.

Differences in the assessment results at age 140 for each of the Forests and Fish targets, SI/BA and OSFA/BA, and a particular SMC-ORGANON model version were solely determined by the minimum BAPA values, with the lower BAPA target accepting more of the management scenarios. Differences in the acceptance percentages for the multivariate TPA–QMD assessments for a particular SMC-ORGANON model version are fully explained by the TPA–QMD distributions for each target and their relative positions within the state-space. Differences in the assessment results between SMC-ORGANON model version for a particular target, however, suggests the possibility of model bias since version 6.0 performs as well as or better than version 8.2 across all targets and scenarios.

To investigate the issue of possible model bias, mean BAPA trajectories and 95% bootstrap confidence intervals for the No Action management scenario were computed using tree lists from SMC-ORGANON versions 6.0 and 8.2 and the multi-zone managed riparian buffer simulation system (Gehringer, 2008b) and were compared to the the BAPA curves from Bulletin 201 in Figure 14. Several features are readily apparent. First, the BAPA trajectory for SMC-ORGANON version 6.0 is clearly above the trajectory for SMC-ORGANON version 8.2 and the normal or fully stocked BAPA curve from Bulletin 201. Second, the BAPA trajectory for SMC-ORGANON version 8.2 approaches and becomes indistinguishable from the normal or fully stocked BAPA curve from Bulletin 201. This is the behavior that is expected, since the majority of forest growth models, including SMC-ORGANON, grow idealized forest stands, and, due to self-thinning and size-density relationships, the trajectory should approach the normal or fully stocked BAPA curve from Bulletin 201. Third, the initial BAPA values for the No Action management scenario and both SMC-ORGANON versions are greater than the initial BAPA value for the Bulletin 201 normal and average (actual) curves. This is explained by the fact that the No Action management scenario represents a relatively densely planted stand, and, therefore, contains more trees than were present, on average, for the naturally seeded stands sampled for Bulletin 201. Finally, the 95% confidence intervals for SMC-ORGANON version 6.0 do not contain the mean values for version 8.2, and vice-versa, indicating that the differences are statistically significant, and thus SMC-ORGANON version 6.0 is biased high for BAPA.

Assessment results relative to a 275 ft^2ac^{-1} isoline for the SI/BA target, a 325 ft^2ac^{-1} isoline for the OSFA/BA target, and the 90% acceptance regions for the FIAREF and DFCVDS targets for the No Action management scenario are presented graphically in Figure 15 for SMC-ORGANON version 6.0 and 8.2. From the figure it is clear that SMC-ORGANON version 8.2 has slightly greater early mortality and slower average diameter growth than version 6.0, a result consistent with the BAPA trajectories discussed previously. The differences in the assessment results with respect to the SI/BA and OSFA/BA isolines for the two SMC-ORGANON model versions is quite significant. For the SI/BA isoline, the SMC-ORGANON version 8.2 trajectory crosses the isoline approximately 30 years after the version 6.0 trajectory, and for the OSFA/BA isoline, the SMC-ORGANON 8.2 trajectory crosses the isoline approximately 60 years after the trajectory for version 6.0. Under the Forests and Fish assessment rules, this shift in when the isoline was crossed had a significant impact, causing the 50 ft No Harvest and Bio-pathway scenarios to be rejected for the SI/BA target and SMC-ORGANON version 8.2 when they were accepted for model version 6.0, and possibly more importantly, causing the FF Option 2 $\geq$ 10 ft and FF Option 2 $<$ 10 ft scenarios to be rejected for SMC-ORGANON version 8.2 when they were accepted for version 6.0. This type of behavior has significant ramifications for both regulators and forest landowners.

The assessments using the two multivariate TPA–QMD targets, FIAREF and DFCVDS gave identical results, regardless of the SMC-ORGANON model version being used. The underlying TPA–QMD distributions for these target data sets overlapped both trajectories. In addition, when using the multivariate TPA–QMD targets for assessment, there were no management scenarios that were completely rejected when considering SMC-ORGANON version 8.2 *vs.* version 6.0, but acceptance percentages, however, did decline for the DFCVDS target. The multivariate assessment procedure, then, appears to be more robust than the targeted age dependent minimum BAPA values used in the SI/BA and OSFA/BA targets from the Forests and Fish rules. It may, therefore, make sense to consider multivariate targets like those used here, even though they may be more complex to use, than simpler targets that may be made less effective due to future changes in data sets or growth models.

3.3 Relevant attributes: Large Woody Debris

Much of the previous discussion of BAPA or TPA and QMD as components of a target designed to assess riparian forest function begs the question of their direct adequacy in this role, when individual tree sizes and locations relative to a stream are the most relevant attributes for riparian function. A better approach might be to choose one or more attributes representing the riparian functions provided to streams by their adjacent forests, e.g., large woody debris (LWD) or shade. The attributes representing the riparian functions could, then, be used directly to derive a quantitative target, or they could be used in a two stage procedure with more typical forest structure attributes (Zobrist et al., 2004, 2005). As an example of such a target, estimates or potentially available LWD (Gehringer, 2008a) pieces and volume per 328.1 ft of stream reach are given in Figure 16. The LWD values were generated using the sample plots from the FIAREF reference data set. Also shown in the figure are approximate probability contours for the LWD piece count and volume estimates, an approximate value for the mode of the distribution, and simple box-constraint lower

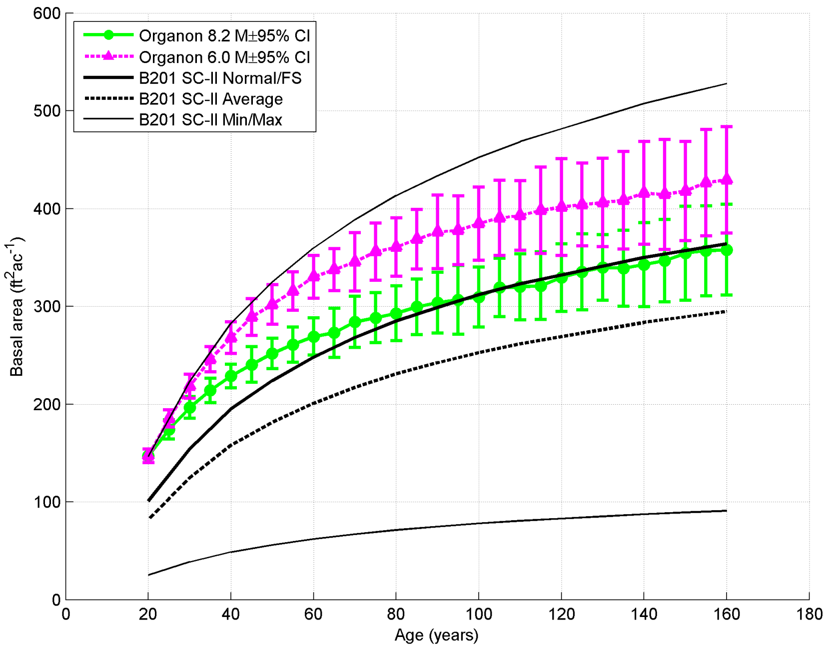

Figure 14: BAPA *vs.* age for the SMC-ORGANON versions 6.0 (O6.0) and 8.2 (O8.2).

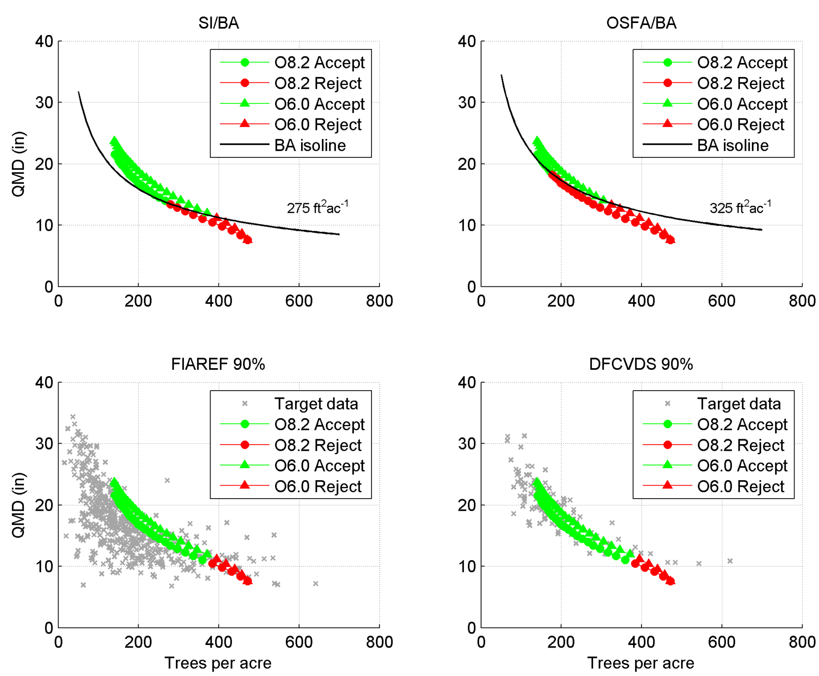

Figure 15: Assessment results for the No Action scenario and SMC-ORGANON versions 6.0 and 8.2.

bounds obtained using the median values from the marginal distributions for piece count and volume. Notice that the median based lower bounds exclude the mode of the distribution, and are therefore unlikely to provide an effective target for management. While the simple lower bounds could be adjusted to include the mode, the strong mode and contours suggest that a distribution oriented approach (Gehringer, 2006) may prove to be more effective.

4 Conclusions

A variety of issues have been raised regarding the use of quantitative forest structure targets, including the selection and use of target defining reference data sets, the use of models and subsequent comparisons to actual data, and the use of weakly related surrogates for attributes directly relating to a regulatory or management oriented assessment problem. The use of quantitative forest structure targets is going to increase, it benefits both regulators and landowners by clearly defining measurable objectives and assessment criteria within the context of complex problems in the sustainable management of forest ecosystems, whether natural or managed. A few opinions on the development and effective use of quantitative targets are now presented as good, bad, and ugly lists, a somewhat arbitrary breakdown of some of the issues at hand, followed by a few simple guidelines for defining and using quantitative forest structure targets.

4.1 The good

- Actually using quantitative targets is very good. Having clearly defined objectives and having an open and transparent procedure to measure the progress toward those objectives benefits both regulators and landowners.

- Using multiple forest structure attributes and their joint distribution when developing a target should create a quantitative target that is more likely to be achieved.

- Using statistically and biologically consistent assessment methods to specify the target and assessment criteria. Statistical and biological consistency increase the likelihood that the target is correct (or at least reasonable), relevant, and achievable.

- Using attributes that are directly related to the problem of interest, if available, rather than correlated surrogates also improves the likelihood that the target is reasonable and relevant.

4.2 The bad

- Using biased or unpedigreed data sets to specify a quantitative target.

- Using biased or unpedigreed models to specify a quantitative target or compare scenarios.

- Single value lower bounds for a single attribute. These are generally useless, and there is a tendency to try to use this approach for multiple attributes.

- Inappropriate bounds, for example mean values or median values used as upper or lower bounds.

- The use of time or age as a fundamental component of a forest structure target. Desired forest structures occur in natural forests at different times for different growing conditions or site classes, for example, but it is the structure that is desired, not the time at which the structure occurs. When selecting reference data to define a quantitative target, time or age may be useful during the data selection or filtering processes, but it should play little, if any, role in the assessment criteria. The state-space for the desired forest structure attributes should provide a more than adequate target from which to derive assessment criteria.

4.3 The ugly

- Leaving the mode of a distribution out of an acceptance region. If a relevant target has been specified, the mode, being the most likely point, should be at the *center* of an acceptance region.

- Simple marginal distribution based box constraints. It is too easy to misuse this type of constraint, which can rapidly restrict an acceptance region to an unlikely or low probability region of an attribute distribution. Effective use of this type of constraint requires careful consideration of the underlying distribution of the attribute(s), so why not use the attribute distribution directly instead.

- Assessment tools that are difficult to develop, maintain, or use. For example, given the issue with the two SMC-ORGANON model versions, what should be done with the DFC model that is based on SMC-ORGANON version 6.0?

- Complex forest management rules with little, if any, direct scientific justification for the complexity.

To effectively use quantitative management targets, five basic guidelines need to be followed. First, be sure that the data used actually represent the desired target. Second, be sure that the output from any model used is close enough to reality to be useful. Third, be sure to select relevant attributes when specifying the target and assessment procedures. Four, be sure to use statistically and biologically relevant assessment methods. Five, do not oversimplify: retain enough relevant complexity to address the assessment problem.

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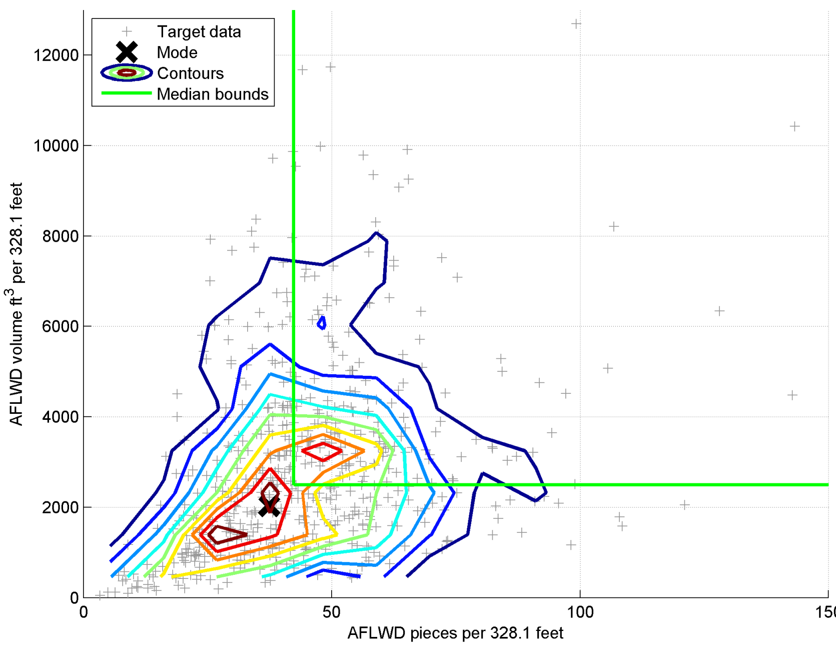

Figure 16: Estimates of LWD piece count and volume per 328.1 ft of stream reach with median based lower bounds.