A COMPARISON OF TIMBER AND FORAGE VALUES WITHIN LODGEPOLE PINE (*PINUS CONTORTA*) STANDS IN SOUTH-CENTRAL BRITISH COLUMBIA

by

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Abstract

This research compared the influence of pre-commercial thinning (PCT) and fertilization on forage and timber values in three managed lodgepole pine (*Pinus contorta* Dougl. Var. latifolia Engelm.) forests in the Interior of British Columbia (BC). Cattle (*Bos taurus*) were grazed in two of the forests. The respective values of treatments were compared using their land expectation value (LEV). Timber values were calculated using the Tree Interpolation Program for Stand Yields (TIPSY) growth and yield model. Cattle use was calculated by relating estimated grazing densities with TIPSY-derived canopy closure estimates for known periods, and establishing a relationship using a linear regression. The value of forage as upland cattle pasture was calculated using a pasture lease rate ($/animal unit month) derived from prior market research in BC, Alberta, and the United States of America.

In all study areas the unrelated control was the profit-maximizing silvicultural strategy. In the Summerland study area, no treatment was profitable. In the Kelowna study area, all the unfertilized treatments were profitable. In the Cariboo study area, all treatments were profitable. In all forests, the unfertilized 2000 stems/ha. treatment was the best alternative option, and under the right conditions could be a profit-maximizing investment. The inclusion of forage values in the comparison of investments did not change which treatment was profit-maximizing: treatments affected timber values much more than forage values. This research suggests that under conditions of high site productivity and an assumed social discount rate of 4%, PCT and intensive fertilization can be a profitable management option for interior lodgepole pine stands.

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AU: animal unit

AUM: animal unit month

BA: basal area

BC: British Columbia

BCMoFR: British Columbia Ministry of Forests and Range

BDU: bone dry units

BEC: biogeoclimatic ecosystem classification

BH: breast height

BSE: bovine spongiform encephalitis

CC(%): canopy closure

DBH: diameter breast height

DR: discount rate

FRPA: Forest and Range Practices Act

FSP: forest stewardship plan

MBF: 1000 board feet

NTFP: non-timber forest product

LEV: land expectation value

LFR: lumber recovery factor

LRMP: land and resource management plan

MAI: mean annual increment

PCT: pre-commercial thin

SDR: social discount rate

SI: site index

sph: stems per hectare

TASS: tree and stand simulator

TIPSY: table interpolation program for stand yields

Glossary

Animal unit: a standardized measurement for livestock quantities

Animal unit months: a standardized measurement of livestock pressure, the number of animal units multiplied by the number of months they are present

Breast height: the distance from the ground to the middle of the chest, standardized to 1.3m

Brushing: the clearing away of vegetation competing with crop trees early in the rotation

Diameter breast height: the diameter of a tree's trunk at 1.3m off the ground

Cost-benefit analysis: the process of comparing the costs and the profits (direct and indirect) associated with an investment

Discount rate: the rate or return an investment would have to beat in order to compensate for lost opportunity costs and risk, a measurement of an investors preference for present over future capital

Ecology: [Gk: *οίκος* ("household") - *λόγος* ("knowledge")] the understanding of organisms and how they relate to each other and their environment, the study of the nature of interactions between entities

Economics: [Gk: *οίκος* ("household") – νόμος ("law")] the study of the quantifiable aspects of the relationships between organisms and their environment; the study of supply and demand, resource flows, and markets in human society; the quantification of the flow of resources during interactions between entities

Fixed-effects model: a mathematical model that can be used to analyse panel data, it is constrained by the assumption that differences observed between individuals are the result of unequal starting conditions, not due to some temporary and specific influence

Forest stewardship plan: a public document outlining management strategies for forested lands that is to be submitted to the government of BC by a forestry company; details how a company plans to meet government objectives in a results-based system

Growth: the rate at which something (a tree's merchantable volume) increases per unit time (a year)

Land expectation value: a present value for an investment, if it is repeated *ad infinitum*

Land and resource management plan: a public document completed by communities stating their management objectives for surrounding public lands

Lost opportunity costs: the costs associated with having capital tied up in an investment; for example, if a great investment is passed up for what turns out to be a mediocre investment the lost opportunity costs are high because more money could have been made from the great investment

Market value: the value that all buyers and sellers agree to for a good

Merchantable volume: the volume of timber that can be milled for lumber per hectare; in this research this usually means that any timber with a diameter of less than 12.5cm were not counted

Mean annual increment: the rate at which a tree grows per year averaged over the tree's lifespan

Net present value: a single figure value that is the sum of all future costs and benefits discounted to a present day value

Non-timber forest product: any forest product that is not timber related, traditionally this refers to any forest-derived plant products that are not used for wood

Opportunity costs: see *Lost opportunity costs*

'Optimum Nutrition Fertilizer': fertilizer applications that have been tailored to provide trees with a multiple complementary nutrients in balance with desired levels of nitrogen, phosphorous and potassium

Panel data: the data set produced from sampling the same set of individuals from a population multiple times over regular time intervals; an econometric statistical method used to reduce error arising from natural variation from within a population

Pasture lease rate: a government defined equation used to determine rents on upland cattle pasture in BC

Perfectly competitive market: a theoretically perfect market, free from government intervention, with instant transactions, and many buyers and sellers with absolute knowledge on the product, its supply, and its demand

Perfectly managed forest: an even-aged stand of trees that has not suffered from repression

Point of diminishing returns: the point at which when each additional unit of input results in a smaller gain to production than the previous unit; the year in which there is less growth than the year before, MAI is decreasing

Pre-commercial thin: the selection and removal of non-dominant trees to a particular density early in the rotation, when the trees are about 3m in height; no merchantable timber is produced directly from this treatment

Profit maximizing investment: the investment that will generate the most capital (have the greatest LEV) among many alternative investment opportunities

Pruning: the removal of all branches lower than 2.5-3.0 m on a tree; a silvicultural technique used to reduce the number of knots in the trunk

Rate or return: the rate at which an initial investment generates income, a percentage determined by dividing the yearly returns (or losses) on an investment by the initial investment

Real price: an inflation free measurement of a good or service's value in relation to other goods; real price can be used to determine how the value of something has fluctuated in comparison to the rest of the market, usually a standardized 'household basket' of basic staples is used as a benchmark

Risk: the chance that certain expectations about the future are not correct, usually risky investments have to pay off better than low-risk investments to compensate for the chance that there will be no pay off

Rotation period: the number of years an investment (a stand) takes from start to finish; the time period over which capital is reinvested

Silvicultural Yields, Lumber Value, and Economic Return: a set of models used by TIPSY to generate economic information on silvicultural practices

Site index: a measure of a stand's productivity; the average height of the dominant trees (m) at a stand age of 50 years

Site value: TIPSY term for land expectation value

Social discount rate: the discount rate for social projects, public investments

Soil expectation value: an alternative term for land expectation value

Stand density: the number of trees per unit area (stems/ha)

Stock price: the average price ($/kg) for cattle sold in auction through the BC Livestock Producer's Cooperative Association

Stocking density: the number of animals per unit area

Table Interpolation Table for Stand Yield: a government created stand-based model designed to assist forest managers in simulating and understanding the effects of common silvicultural investments

Tree And Stand Simulator: a stand-based growth and yield model that uses empirically derived growth curves and ecological data to generate forecasted data tables

Yield: the total quantity of something (merchantable timber) that can be removed/harvested at a given point in time (harvest)

CHAPTER 1: AN OVERVIEW OF FORESTRY IN BRITISH COLUMBIA

1.1 INTRODUCTION

1.1.1 Introduction to forestry in British Columbia

The forests of British Columbia (BC) have always been valuable to their residents. Prior to the dominance of European-style management, the First Nations people valued the forests for a wide range of foods, firewood, game, furs, dyes, fibres, medicine, building materials, and its intrinsic existence. Much of the indigenous economy subsumed when the British government increasingly exerted its control over BC from the 1850s onward, claiming the vast majority of the province in the name of the Crown, and introducing a cadastral property management system. The colonial government of BC saw the enormous value that Coastal old growth had in European markets. Timber production has been a significant part of the BC economy for over a century. The logging of massive old growth has fuelled the Coastal timber industry since the 1840s; however, logging in the Interior did not become a comparable industry until the 1960s. In comparison, ranching has been a significant part of the Interior economy since the gold rushes in the 1860s. An important part of the BC Interior economy is the lease of upland pasture for summer grazing. By 1970, improved roads and rail, increasing foreign markets, government concessions, and a foreseeable end to Coastal old growth timber supply resulted in the expansion of the forest industry to the Interior. In 1987 new legislature was passed mandating multiple-use forestry (Haley 2005).

Forestry in BC is at a crux; environmental and socioeconomic factors are influencing how we value our forests. Climate change is a looming threat: the climatic conditions for healthy forest ecosystems that typify BC might disappear. The current mountain pine beetle (*Dendroctonus ponderosae*) epidemic is destroying large portions of Interior forests, rendering the ecological and economic forecasts of only a decade or two ago obsolete. Social values are changing, and the government is altering forestry management practices and laws to reflect the importance now placed on recreational, traditional, community, food, and aesthetic values that people derive from forests. We have control over only a few of the factors that have influence on the value of BC's forests, and one of those is management.

1.1.2 Land management systems in British Columbia

The majority of BC's forests (94%) are publicly owned (Haley 2005). Of the publicly owned forests, 22% of the provincial timber supply comes from tree farm licences, and 58% from forest licences (Haley 2005). To be involved with forestry in BC is to be involved with the people and government of BC.

In order to discuss potential forest management practices it is necessary to establish the objectives of a forest manager. Knowing forest management goals will provide initial guidelines by which to base assumptions to compare the outcomes of various silvicultural treatments. Specific government objectives for forest management are listed in the Forest and Range Practices Act (FRPA) as maintaining anything on publicly managed lands related to: soils, visual quality, timber, forage and associated plant communities, water, fish, wildlife, biodiversity, recreation resources, resource features, and cultural heritage resources (BCMoFR 2002). The government also outlines specific standards for the management of ungulate winter range, recreation, aquatic ecosystems, and cattle range (BCMoFR 2002). It can be assumed that a democratic government's forest management objectives would be to plan so that the overall value of a forest is maximized for all stakeholders; so that the forest is of greatest public value. Although the government is no longer directly involved in much ground-level forest planning, it has moved towards a results-based system that mandates that license holders implement a Forest Stewardship Plan (FSP) (Haley 2005). In order to be permitted to harvest timber, BC Timber Sales or the holder of: a major forest licence, a community forest agreement, a community salvage licence, or a pulpwood agreement; must complete an FSP (BCMoFR 2006). This FSP must be consistent with governmental objectives, such as Land and Resource Management Plans (LRMP) (BCMoFR 2002).

A results-based system grants forest managers the freedom to develop innovative ways to meet economic, ecological, and social objectives. One way of accomplishing these goals is the intensive management of particular stands in a forest to achieve desired harvest volumes from a smaller land base. Intensively managing certain stands in a forest to achieve timber harvest objectives, so that other stands may be conserved, is one way of accomplishing these goals (McCullough 1999; Sedjo 1999). McCullough (1999), Lindgren et al. (2006), and Sullivan et al. (2006a, 2006b) suggest that intensively managed, plantation-style forest stands can still contribute to the maintenance of biodiversity at a stand and a forest level. To meet the rising demand of an ever-growing human population for wood products it may be necessary to intensify wood production in certain areas in order to permit the conservation of other forests (Sedjo and Botkin 1997; Sutton 1999; Sedjo 1999, 2001).

In south-central BC, lodgepole pine (*Pinus contorta* Dougl. Var. latifolia Engelm.) are a merchantable tree species that responds well to intensive management

(Johnstone 1985; Lindgren et al. 2007). Ideally, intensively managed stands could also retain features that would contribute to meeting management objectives unrelated to merchantable timber yields. *Pre-commercial thinning* (PCT) and fertilization are two intensive silvicultural practices that have been shown to improve tree growth in lodgepole pine (Brockley 1989; Johnstone and Pollack 1990; Farnden and Herring 2002). Mixing intensive management of lodgepole pine as a plantation species and extensive management of the remainder of the forest would increase ecosystem diversity at a landscape level: a forest of mixed stand ages and structures will have more micro-habitats and habitats for a range of species, than a forest comprised entirely of high density, unthinned stands.

1.1.3 Identifying forest products of value

When it comes to forest management, profitability is an essential consideration. If we are to compare the value of different treatments using a numeric basis for comparison, it is necessary to create a list of forest features of value to human society and to establish a scale by which to compare them. Forests provide a wide range of goods and services to human society. Some examples include: carbon sequestration, recreational space, wild game, aesthetic appreciation, preservation of biodiversity, buffering of ground water flow, summer pasture, and timber. Ideally, we could assign all these goods and services a dollar value, tally their respective quantities in each treatment, and then derive an area-based value ($/ha) with which to compare stands. Unfortunately, the monetary value of some of these goods and services is difficult to calculate. Although it is easy to find agreement that these goods and services are valuable, nobody can agree on how valuable. Other forest products are easily regulated and marketed, and buyers are well-informed about the product and the market; therefore, a product's value is reflected well in their market price. To limit the scope of this research and to keep it pertinent to managers, only those products with well-defined market prices have been considered. In this case, two forest products – timber and forage – are readily identified as significant to Interior economies. Both have large markets and standardized products, resulting in consistent pricing. There are specific circumstances under which other southern Interior forest products might have market value, such as medicinal plants or mushrooms; however, these are smaller and underdeveloped markets, limiting their applicability to providing general guidelines for silvicultural practice.

1.1.4 Cattle and forest pasture

There is a long human history of upland cattle grazing. As summer arrives, forage in the warm valleys grows first, while the grasses at higher elevation remain dormant and buried under snow. As the summer progresses and the valleys grow hot, the grasses die back: meanwhile, at higher elevations the snow has only recently melted and the forage is lush and green. The cattle are herded up to mountain pasture during the summer months to relieve the pressure on valley pasture and to capitalize on this green upland forage. Cattle are a significant part of the Interior economy. Beef cattle (*Bos taurus* L.) account for about one-half of all farm production in the Cariboo, and approximately one-quarter of all farm production in the Thompson/Okanagan (Statistics Canada 2001).

Thinning and fertilization have been shown to affect both ungulate use and understory vegetation (Lindgren et al. 2006; Sullivan et al. 2006a, b). In the interior of BC forage and timber are two forest products of particular interest to this research. Sullivan et al. (2002, 2006a) have investigated the ecological impact of various silvicultural practices throughout BC. Sullivan et al. (2006a) reported increases in habitat use of both mule deer (*Odocoileus hemionus* Rafinesque) and moose (*Alces alces* L.) in the same thinned and fertilized sites used in this study. Similar unpublished source information for the same study areas exists for cattle, which will help establish any correlations of habitat use with PCT and fertilization. It is unclear how forage values contribute to the overall profitability of PCT and fertilization. This research will help forest managers further understand some of the influence of silvicultural treatments on forage and timber values.

1.2 OBJECTIVES

The objectives of this study was 1) to forecast timber and lumber volumes, and cattle usage in three established lodgepole pine research forests using a growth and yield model, and 2) to determine the influence of PCT and heavy fertilization on the value of timber and cattle forage in lodgepole pine forests in the southern interior of BC. The results will indicate the comparative profitability of the various PCT and fertilization treatments in each study area. To provide a real-world reference, the study was based on three established research forests. Sullivan et al. (2001, 2006a, b) and Lindgren et al. (2006, 2007) are currently using these forests to explore the ecological impacts of these same treatments. As an overall objective, this study is intended to provide a supplemental economic analysis to the ecological analyses of Sullivan et al. (2006a, b) and Lindgren et al. (2006, 2007). It is not an objective of this paper to attempt to derive values for non-timber forest products that do not have readily available market price information.

1.3 DESCRIPTION OF STUDY AREAS

All three forests were selected on the basis of relatively consistent stand structures, and were dominated by young lodgepole pine with similar ages, height, diameter, and initial density (Sullivan et al. 2006a, b). In silvicultural terms, these forests were intensively managed. The following descriptions are based on Sullivan et al. (2006a, b) and Lindgren et al. (2007).

The Summerland study area was located in the Bald Range at an elevation between 1450-1520 m, approximately 25 km west of Summerland (49°40′N; 119°53′W), within the Montane Spruce (MS_{dm}) biogeoclimatic zone (Meidinger and Pojar 1991). Pinegrass (*Calamagrostis rubescens* Buckl.) is the dominant forage species in the Summerland study area (Wikeem et al. 1993; Lindgren et al. 2006). The MS biogeoclimatic zone is a mid-latitude band of forest that typically has cool, continental climate with cold winters and short summers. The Summerland study area was noted as having "gently rolling topography and a sandy loam soil," mean annual temperature of 0.5-4.7 °C, and annual precipitation ranging from 380-900 mm. The Summerland study area was clearcut of lodgepole pine and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) in 1978 following a mountain pine beetle outbreak (*Dendroctonus ponderosae* Hopk.). The site regenerated naturally with lodgepole pine as the dominant tree species. Other tree species that regenerated as minor components include: Douglas-fir, interior hybrid spruce (*Picea glauca* (Moench)) Voss x *Picea engelmannii* Parry), subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), ponderosa pine (*Pinus ponderosa* Dougl. Ex. P. and C. Laws.), willows (*Salix* spp.), sitka alder (*Alnus sinuata* (Regel) Rydb.), and trembling aspen (*Populus tremuloides* Michx.). Prethinning densities in the Summerland study area ranged between 9980 to 1150 stems/ha.

At the start of the study (1993), mean (±SE) stem diameter at breast height (DBH) ranged from 2.2 ± 0.1 cm to 4.1 ± 0.1 cm, and mean (±SE) tree height ranged from 2.3 ± 0.1 m to 3.4 ± 0.1 m. Mean tree age was 12 – 14 years.

The Kelowna study area was located 37 km north of Kelowna, BC (50°04'N; 119°34'W). This study area was located within the Montane Spruce (MS_{dm}) biogeoclimatic zone (Meidinger and Pojar 1991); thus, the Kelowna study area was geographically and ecologically similar that in Summerland. The dominant forage and other understory species in this study were similar to those found in the Summerland study area. The topography of the study area was gently rolling, at approximately 1220-1240 m elevation. The soil was described as a sandy loam. The area regenerated naturally with predominantly lodgepole pine after being clearcut in 1980. Pre-thinning stem density was approximately 8686 stems/ha. The Kelowna study area was 84.8 ha, almost divided in two by a long riparian zone. This area was divided into eight treatments, with an additional stand of 12.6 ha 500 m away serving as the unthinned control.

In 1993, mean (±SE) DBH in the Kelowna study area ranged from 3.1 ± 0.1 cm to 4.7 ± 0.1 cm, and mean (±SE) tree height ranged from 3.0 ± 0.1 m to 4.1 ± 0.1 m. Mean tree age was 12 – 13 years.

The Cariboo study area was located in the Alex Fraser Research Forest, University of BC, 75 km northeast of Williams Lake, BC (52°29′N; 121°45′W). This study area was located within the SBS_{dm} biogeoclimatic zone (Meidinger and Pojar, 1991). The dominant forage species include Richard's needlegrass (*Stipa richardsonii*

Link.) and sheep fescue (*Festuca ovina* L.). Other species that might contribute to forage include: rough fescue (*Festuca scabrella* Torr.), Idaho fescue (*Festuca idahoensis* Elmer), bluebunch wheatgrass (*Agropyron spicatum* (Pursch) Scribn. and Smith), Kentucky bluegrass (*Poa pratensis* L.), prairie Junegrass (*Koeleria cristata* Pers.), yarrow (*Achillea millefolium* L.), and arrowleaf balsamroot (*Balsamorhiza sagittata* (Pursch) Nutt.) (Wikeem et al 1993). Although the SBS zone is further north and has a wetter summer, the MS and SBS zones have similar winter conditions (Meidinger and Pojar 1991). The topography is rolling to flat and elevation ranges from 850 – 870 m. Nearby mature stands consist of a mix of interior hybrid spruce, subalpine fir, Douglas fir. In addition, a natural wildfire damaged areas of the pre-existing forest, resulting in a forest interspersed with extensive stands of naturally regenerated lodgepole pine. The 80 ha study area was clearcut harvested in 1976. There was some natural regeneration after the clearcut; however, the site was planted with lodgepole pine in 1983. The pre-thinning density of the Cariboo study area was 3333 stems/ha.

In 1993, mean (±SE) DBH ranged from 4.4 ± 0.2 cm to 7.2 ± 0.3 cm, and mean (±SE) tree height ranged from 3.4 ± 0.1 m to 5.4 ± 0.2 m. Mean tree age was 13 years.

Cattle were present in the Summerland and Cariboo study areas, but were not present in the Kelowna study area.

1.4 DESCRIPTION OF TREATMENTS

1.4.1 Silvicultural methods

This experiment was designed to compare treatments in intensively managed second-growth lodgepole pine stands. The two silvicultural treatments were fertilization and PCT. All treatments were thinned; some to exceptionally low densities by common silvicultural standards. One-half of the treatments were fertilized with an *optimum nutrition* fertilizer; a fertilizer mix based on the research of Tamm et al. (1999), Brockley (1992), and Kishchuk et al. (2002). It is important to note that the chemical composition of the fertilizer reflects the balanced nutrient needs of lodgepole pine: even though fertilization improves tree growth, an unbalanced application can impede growth (Kishchuk et al. 2002; Brockley 2003). This fertilization was repeated for 10 years at 2-year intervals, aiming to increase available nitrogen, with all other nutrients (such as phosphorous, boron and potassium) applied in a balanced ratio relative to nitrogen (Lindgren et al. 2007).

As *per* Sullivan (2006a, 2006b), stands were thinned in 1993: stand A1 was very low density, thinned to a target 250 stems/ha; stand B2 was thinned to 250 stems/ha and fertilized; stand C3 was low density, thinned to a target 500 stems/ha; stand D4 was thinned to 500 stems/ha and fertilized; stand E5 was medium density, thinned to a target 1000 stems/ha; stand F6 was 1000 stems/ha and fertilized; stand G7 was high density, target 2000 stems/ha; stand H8 was 2000 stems/ha and fertilized; stand I9 was unthinned > 3000 stems/ha. In 1998, trees in thinned stands (A1-F6, 2000 stem/ha treatments excluded) also had their lower limbs pruned off to a height of 3.0 m in 1998. At each density one of two stands was treated with an optimum fertilization in 1994, 1997, 1998, 2000, and 2003 (Sullivan et al. 2006a).

Table 1: *Designation of abbreviations for treatments and control*

Stem Density (trees/ha.)	**Unfertilized**	**Fertilized**
250	A1	B2
500	C3	D4
1000	E5	F6
2000	G7	H8
control	I9	

The treatments in each of the study areas were not random, as the logistics of helicopter fertilization dictated the distribution of fertilizer throughout plots. However, Sullivan et al. (2006b) consider this to be statistically random, as plot selection was dictated by an application bias, not an experimental bias. Overall, the experiment had a split-plot design, with stem density as the main plot, and fertilization as the split-plot (Lindgren et al. 2007).

1.4.2 Ecological differences between treatments

An increase in understory biomass, structural diversity, and species diversity, particularly herbs has been observed in response to a PCT treatment in young lodgepole pine stands (Sullivan et al. 2001; Lindgren et al. 2007). Sullivan et al. (2001) also showed an increase in tree species diversity, and small mammal species richness and diversity in thinned stands.

In an examination of the influence of repeated fertilization on tree growth, Lindgren et al. (2007) found that individual trees in fertilized sites had a higher diameter growth rate than trees in unfertilized stands; however, there was no significant difference in height. Although the crown volume of fertilized and thinned stands recovered from PCT and pruning in less than ten years and had a rate of DBH increase greater than the control, the total stand volume of unthinned stands was greater and increased faster than in thinned stands (Lindgren et al. 2007). At the stand level, PCT did not significantly affect total basal area (BA), despite thinned stands having a significantly fewer trees (Lindgren et al. 2007). Although thinning and fertilization increased timber production per individual tree, they seem to have decreased total timber production per unit area (Lindgren et al. 2007).

Investigations into the effects of fertilization and thinning on wildlife usage of these forests have been conducted by Sullivan et al. (2006a, b). Sullivan et al. (2006a) found that mule deer preferentially utilized the fertilized stands for summer range and moose preferred thinned and fertilized stands in both summer and winter (Sullivan et al. 2006a). This was likely due to the increase in herbaceous biomass as browse in those treatments, although there was a decrease in understory species diversity observed in association with fertilization (Lindgren et al. 2007). It was found that both PCT and fertilization had a positive effect on grazing by cattle (Lindgren et al., 2011).

In general, it seems that the treatments – particularly thinning – yield positive ecological results. Thinned sites have increased understory diversity and attract ungulates. Additionally, although there are fewer trees per unit area, trees in thinned sites grow thicker and faster, so PCT does not necessarily result in lower harvest volumes.

CHAPTER 2: FORECASTING GROWTH AND YIELD IN EXISTING STUDY AREAS

2.1 INTRODUCTION

2.1.1 Forecasting growth and yield data

One obstacle to effective forest management is the time lag between the implementation of a silvicultural treatment and the results of that treatment. Many treatments that have an effect on tree growth occur early in a rotation: however, results can be accurately determined only at the time of harvest. Due to this many decade delay in obtaining results, it is advantageous – from a human perspective – to use past experiences to forecast expected results (Clark et al. 2001). This feature of timber production has necessitated that foresters develop mathematical and conceptual models to assist in predicting a forest's *growth* and *yield*. Although inferential in nature, forecasting trends permit forest managers to proactively adapt timber management strategies in a much shorter time frame than by adapting strategies only on a reactive basis.

2.1.2 Growth and yield models used to forecast timber and lumber production in BC forest management

There are numerous complex computer models available in BC to forecast the growth and yield of forests (Stearns-Smith 1999). Of particular use in this research is the Tree and Stand Simulator (TASS), that estimates tree and stand growth and yield for a even-aged, managed stand under a range of typical conditions (diLucca 1999). Developed in the 1960s, TASS is a spatially explicit independent tree model: the model 'grows' individual trees and estimates stand information from the interactions between these individuals (diLucca 1999). The accuracy of the tree-based simulation has been refined using empirically-derived stand-level data. TASS forecasts various growth parameters, including: mean tree height, mean tree diameter, mean tree volume, stand volume, stand basal area, canopy closure, and mortality (diLucca 1999). The ability to forecast growth and yield using TASS facilitates a 'virtual' comparison of the influence of various management strategies on stand dynamics. TASS is currently not publicly available. However, the publicly available Table Interpolation Program for Stand Yield (TIPSY) model is based on previously generated TASS growth and yield outputs, providing information in a format designed for end-users.

2.1.3 The energetics of thinning: 'wasted' sunlight in unthinned forests

Thinning can improve the growth of crop trees by reducing competition. In naturally crowded lodgepole pine stands, dominant individuals suppress smaller trees as the stand matures (Kishchuck et al. 2002; Johnstone 1985). A PCT pre-empts this process by removing non-crop trees early in the rotation period. The increased availability of light, water, and nutrients results in an increased growth rate for the remaining crop trees (Johnstone 1985). Interestingly, because most of these suppressed trees would have been crowded out and died prior to harvest anyway, conventional wisdom suggests that timber yields (volume per unit area) remain relatively constant over a wide range of interim stand densities (Johnstone 1985). In a review of the literature, Johnstone (1985) developed the following guidelines for thinning lodgepole pine: young trees respond more than mature trees, individual trees responded the most to heavy thinning, and the greatest response to thinning was observed in highly productive sites; however, the greatest relative gains in volume in response to thinning were observed in unproductive sites. Thinning can increase the growth rate of crop trees and increase merchantable timber volumes in some instances (Johnstone 1985).

2.1.4 The role of fertilization and the cycling of nutrients in forest ecosystems

When a nutrient deficient forest is fertilized once, an increase in tree growth rate is usually observed for only a few years. All the plants in the ecosystem quickly sequester the available nutrients from fertilization to help alleviate internal deficiencies; however, the deficient environmental conditions prevail and within a decade it is difficult to tell that fertilization has been conducted (Kishchuk et al. 2002). In the case of repeated optimum fertilizations – like the treatments in this research – it is possible that an overall environmental nutrient deficiency might be alleviated, resulting in long-term improvements in site productivity; instead of chronically scarce nutrients being scavenged and locked up in timber. Once a limiting nutrient is no longer scarce it enters the nutrient cycle. The stands in this research have been subjected to repeated fertilizations, chemically balanced to try and alleviate any relative deficiencies in available soil nutrients. Repeated optimum fertilizations might increase site productivity over the long-term, rather than just result in a temporary boost in vegetation growth.

Additionally, fertilization can accelerate stand development by increasing the mortality of suppressed trees. The crown growth of dominant trees is stimulated, further decreasing light availability to suppressed individuals (Allen 1987). Dominant crop trees thus gain earlier access to resources that they would have had to previously share with suppressed trees. Eventually repressed individuals die: the same land area now supports fewer individuals. If repeated fertilization does not increase overall site productivity, it might enhance the value of crop trees.

2.2 OBJECTIVES

The overall objective of this chapter is to use the TIPSY model to establish future values for timber and lumber yields, and cattle use in each study area. The particular objectives of this chapter are to: 1) use TIPSY to generate growth and yield tables for each treatment and the controls, 2) calibrate TIPSY results using field data from the study areas, 3) use regression techniques to relate cattle usage levels to a TIPSY-derived stand value.

2.3 METHODS

Tree sampling plots were located at every 50 m interval on transects that systematically covered each stand area at each of the three study areas. In 1993, the 10 closest potential crop trees in a radius from each 50 m interval were then selected as sample trees and permanently tagged. In the unthinned stands the process of selecting 'potential crop trees' was somewhat subjective, as many trees were present in each plot and rarely were ten of these trees obviously larger than the remainder. In these plots the ten 'typical' trees were chosen, avoiding obviously stunted individuals. In 1993, 1998, and 2003, height, diameter at breast height (DBH), and volume were measured – in addition to other growth parameters – by Lindgren et al. (2007). Lindgren et al. (2007) used equations derived by Brockley and Simpson (2004) in nearby and similar study areas to calculate tree volume.

From 1999 to 2003, circular 5 m^2 plots were established to count cow pats. Arrays of five plots were systematically located at 50 m intervals throughout each treatment. The average number of plots per stand varied in each study area: Summerland, 55 to 145; Kelowna, 60 to 140; and Cariboo, 35 to 100 (Sullivan et al. 2006a). Measurements were taken twice yearly and were conducted in early May and early October. All faeces were cleared from each plot after sampling in order to eliminate the chance of recounting during future measurements (Sullivan et al. 2006a). Due to the spreading nature of cow faeces, the presence of cow faeces in a plot was measured on a binary, ‘true/false’ basis: any number of cow pats in a plot was counted as 1 pat/5m^2.

2.3.1 Calculating a forest’s productivity using tree height and estimated tree age

Site Index (SI) is a tree height to age ratio used by foresters to describe the productivity of a site (Marshall and LeMay 2005). SI was calculated using the Site Tools program (BCMoFR 2004), which used equations derived by Thrower (1994). In each plot in the control, the height of each sampled tree with the greatest DBH and unimpeded growth in 2003 was used for site index calculations. There were 110-290 sample trees per treatment. 2003 data for sample trees from the treatments were not used for the calculation of site index, as tree growth had been affected by the treatments. The average age per tree was based on the figures provided by Sullivan et al. (2006a); an estimated range of 12-14 years was simplified to 13 years for all three forests. SI was calculated based on the relationship between age and height in lodgepole pine determined by Thrower (1994). It was not possible to use the growth-intercept relationship derived by Nigh (1997) to estimate SI because the year at which the crop trees reached 1.3 m in height was not known.

2.3.2 Calibrating the timing of simulated TIPSY treatments

Despite an equivalent SI in lodgepole pine stands, there is considerable variation in the length of time it takes trees to clear competitive vegetation and become free to grow. Using absolute age to calculate SI in a young stand can be a significant source of error, as rapid or retarded growth in early years may significantly skew the age to height ratio used to estimate long-term site productivity. Calculating SI using age and height is more accurate in older stands when the temporal variation (standard deviation) in the number of years it takes for a stand to reach breast height (1.3 m) is comparatively small compared to the total age of the stand. To allow for this unknown variation in the age versus growth rate relationship, the TIPSY-defined age, at which the simulated TIPSY treatments were to occur, was adjusted so that the height of the TIPSY trees coincided with the mean height of the actual trees in the study area at the time of the initial treatment: 1993, age 13. The 1993 mean height of all trees in the study areas was calculated, and the start year (as defined by TIPSY) for each treatment was adjusted in TIPSY so the height of the virtual stand matched the 1993 mean height of the research stands. The difference between the actual stand age and the TIPSY age needed to have corresponding 1993 heights is equivalent to how many years, sooner or later than expected, the study area trees reached breast height. It was assumed that initial treatments occurred in 1993 (at an actual stand age of 13 years), and that TIPSY treatments occurred at the TIPSY age when TIPSY height corresponded with the actual mean height of the control. This comparison of TIPSY simulations at various SIs helped establish a reasonable range for the actual study area SI. TIPSY height was assumed to be the mean height of all trees, not the mean of height of crop trees only, as used for SI calculations.

2.3.3 TIPSY inputs

The TIPSY model required input data on a range of environmental parameters: biogeoclimatic zone, forest district and region (defined according to TIPSY's geographical divisions), dominant tree species, initial stem density, and SI. TIPSY also required information on silvicultural treatments: pruning, thinning, target stem density for thinning, fertilization, stand age at which fertilization occurred and efficacy of fertilization. TIPSY was not yet capable of handling compounded fertilization treatments, so two 100% effective fertilizations at 1993 and 2003 were substituted for the five applications that actually occurred during that decade. Also, TIPSY automatically sets the PCT to occur when the stand reaches a height of 3 m. None of the forests actually had mean heights of 3 m in 1993. However, all three study areas reached 3 m within 3 years of the initial treatment years, so although TIPSY's handling of the timing of the PCT is inaccurate, it is at least approximate. TIPSY was also not capable of modelling lodgepole pine growth at the very low stand density of 250 stems/ha. In return, TIPSY provided a range of biological, silvicultural and ecological information on all treatments at a range of site indices, including: mean height, diameter at breast height, tree volume, tree basal area, stand density, stand volume, stand basal area, canopy closure, and merchantable volumes. In addition to total volume, TIPSY also calculates *merchantable volume* (calculated to eliminate the economically meaningless inclusion of bark, stump, and crown in timber volumes).

2.3.4 The comparison of TIPSY results to actual data

TIPSY results were compared to actual data. Tree data from each year (1993, 1998, 2003) for each treatment was organised into *panel data* format. Borrowing econometric techniques, the data were analyzed using a *fixed-effects model*. All growth parameters were assumed to be in a simple linear relationship with age over a 10-year period. The relationship established by the fixed-effect model between age and various growth parameters was then compared to corresponding TIPSY growth curves.

2.3.5 Determination of cattle stocking densities

Cattle actively grazed during the summer months in both the Summerland and Cariboo areas. Stocking densities were calculated by converting fecal pellet counts into an estimate of how many *animal unit months* per hectare (AUM/ha) were supported per treatment. First, the number of plots with cow pats was divided by the total number of plots and the plot area ($5m^2$), giving a value for pats/m^2; converted to pats/ha by multiplying by a factor of 10^4. The number of pats/ha was then divided by the number of pats produced per cow per day – in this case a value of 12.6 pats/cow/day was used (Julander 1955) – yielding a value for cow-months/ha. A typical herd composition for interior cattle operations was determined using information from Statistics Canada (2007). Combined with average values for AUs per cow-calf, bull, steer, yearlings and heifers (Agriculture and Agri-Food Canada 2003), herd composition statistics facilitated the derivation of an average value for AU/cow in the interior of BC, in this case 0.70AU/cow. Multiplying the number of cow-months/ha by the value for AU/cow gave a value for AUM/ha/yr supported in each treatment in 1999, 2001, and 2003.

The *stocking density* (AUM/ha) of each treatment was correlated with the TIPSY estimate of canopy closure (CC) in that treatment for that same year. A regression was conducted to establish the correlation between AUM/ha of cattle supported and canopy closure. It was assumed that the relationship between AUM/ha and CC was linear: the data were too coarse to warrant a more biologically descriptive curve. An AUM/ha to CC relationship was determined per forest, combining data from every treatment. Based on preliminary observations, fertilization was considered to influence cattle usage (Lindgren and Sullivan 2011). An analysis of covariance (ANCOVA) was performed to establish the degree to which fertilization affected cattle use in the Summerland and Cariboo study areas. P-values less than 0.10 were considered to be significant. If forecasts using a linear relationship between CC and AUM/ha returned negative values, then treatments were recorded as supporting a value of 0 AUM/ha.

2.4 RESULTS

Site Tools returned the site indices (Table 2) using a stand age of 23 and the mean 2003 height of crop trees in the control:

Table 2: *The 2003 mean top height, standard deviation, and the associated SI for the untreated controls in all study areas.*

Forest	Top height (m)	St. Dev.	Site Index (SI)	SI + St.Dev.	SI - St.Dev.
Summerland	6.15	0.72	15.5	16.2	13.6
Kelowna	8.73	1.40	19.7	21.4	17.0
Cariboo	12.46	1.27	25.5	27.5	23.3

The site index calculations indicated that the Cariboo study area was the most productive forest, and the Summerland study area was the least productive forest. At current growth rates, Site Tools predicts that at an age of 50 years the average height of crop trees will be: 15.5 m in the Summerland study area, 19.7 m in the Kelowna study area, and 25.5 m in the Cariboo study area.

2.4.1 Comparison of TIPSY forecasts to statistics from field data

The following graphs (Figures 1-9) compare actual values (+/- standard deviation) (error bars), mean growth rate (+/- standard deviation) (solid blue line; dashed red lines), and TIPSY-defined growth curves for the control (solid black lines). For volumes, actual values were compared with the total volume of both all trees and of only the crop trees.

***Figure 1**: A comparison of the mean height and growth rate (±2 standard deviations) of all sampled trees in the Summerland study area control to TIPSY height at various site indices*

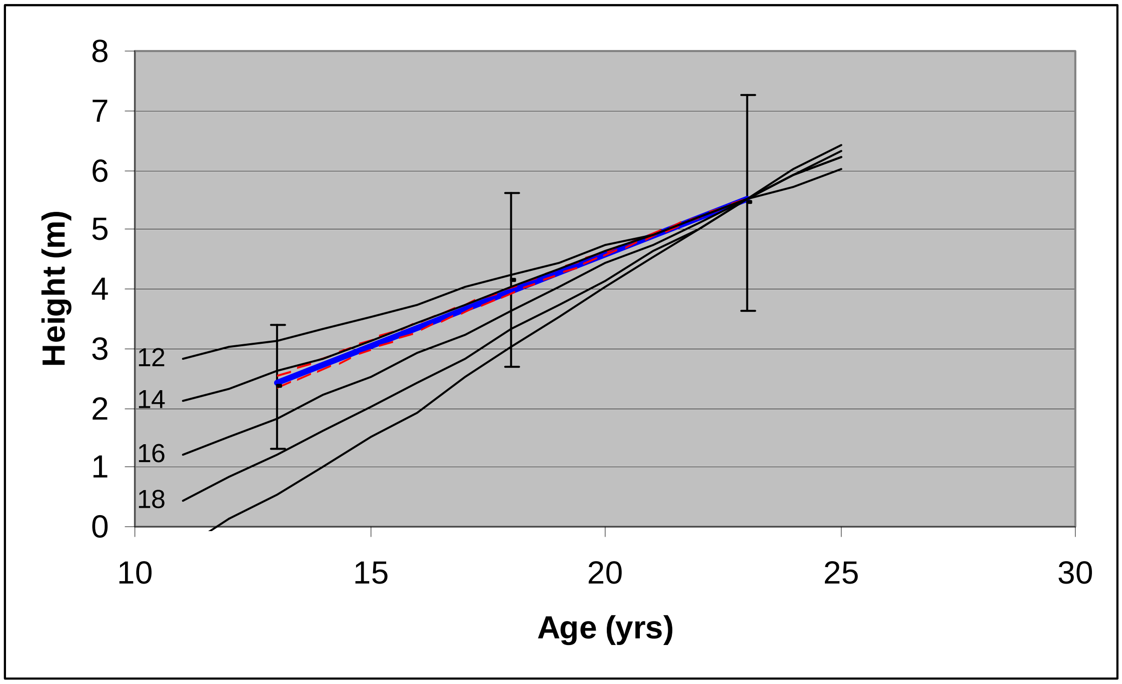


Figure 2: *A comparison of the mean height and growth rate (±2 standard deviations) of prime sampled trees in the Summerland study area control to TIPSY height at various site indices*

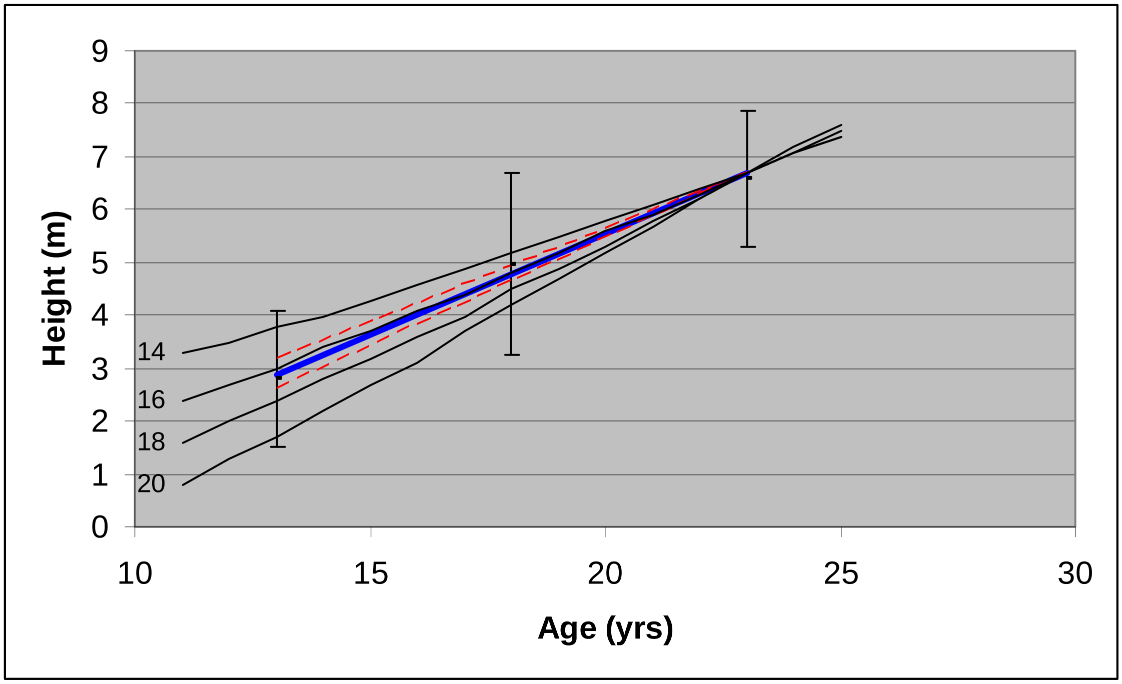


Figure 3: *A comparison of the mean DBH and growth rate (±2 standard deviations) of prime sampled trees in the Summerland study area control to TIPSY DBH at various site indices*

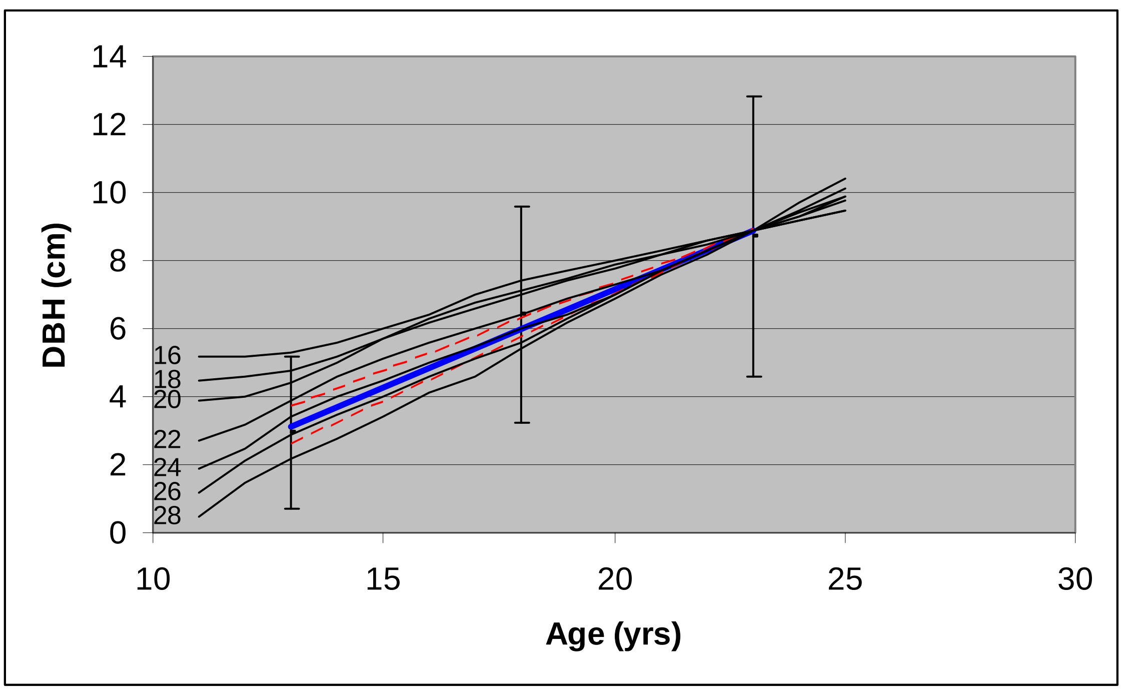


Figure 4*: A comparison of the mean height and growth rate (±2 standard deviations) of all sampled trees in the Kelowna study area control to TIPSY height at various site indices*

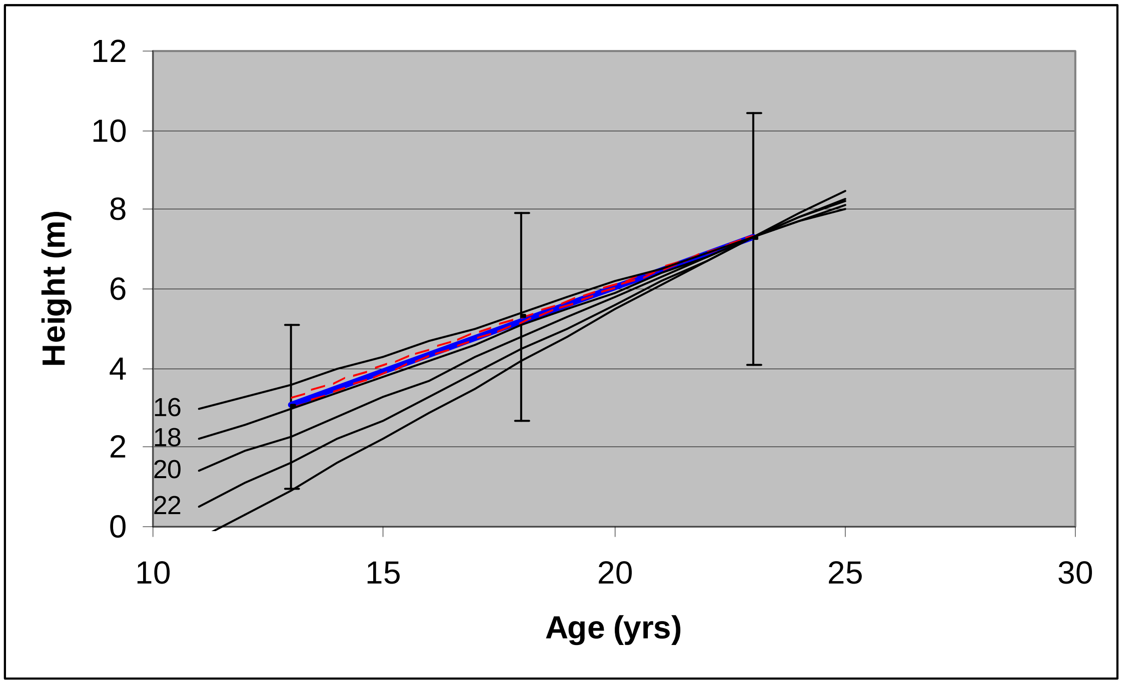


Figure 5: *A comparison of the mean height and growth rate (±2 standard deviations) of prime sampled trees in the Kelowna study area control to TIPSY height at various site indices*

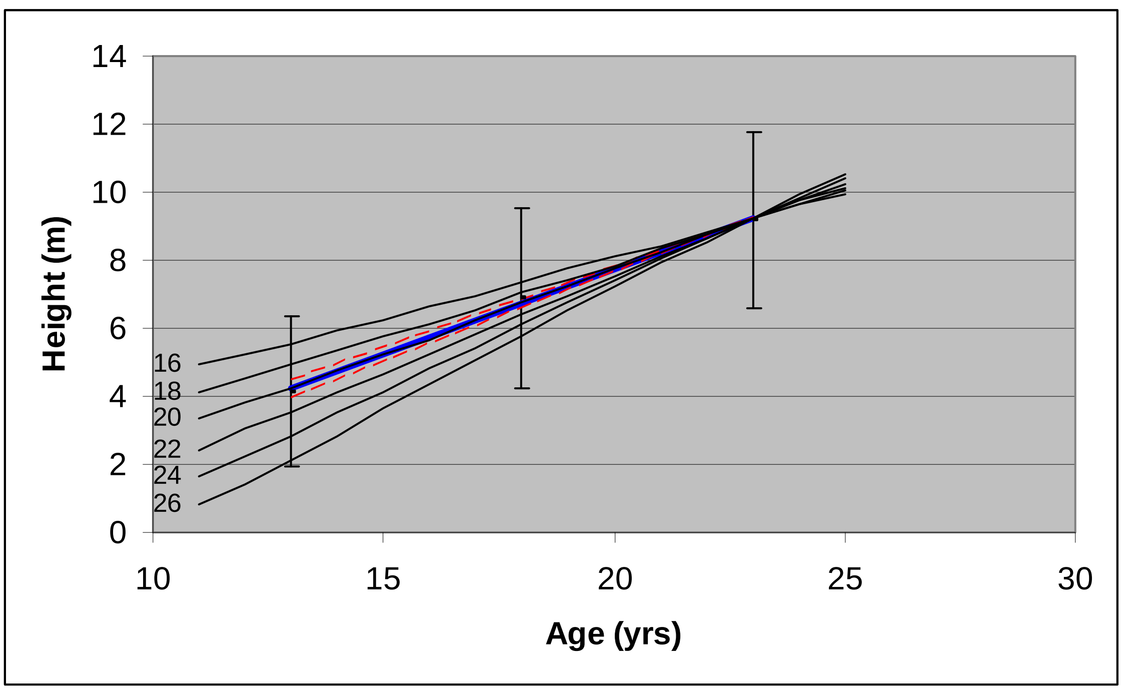


Figure 6: *A comparison of the mean DBH and growth rate (±2 standard deviations) of prime sampled trees in the Kelowna study area control to TIPSY DBH at various site indices*

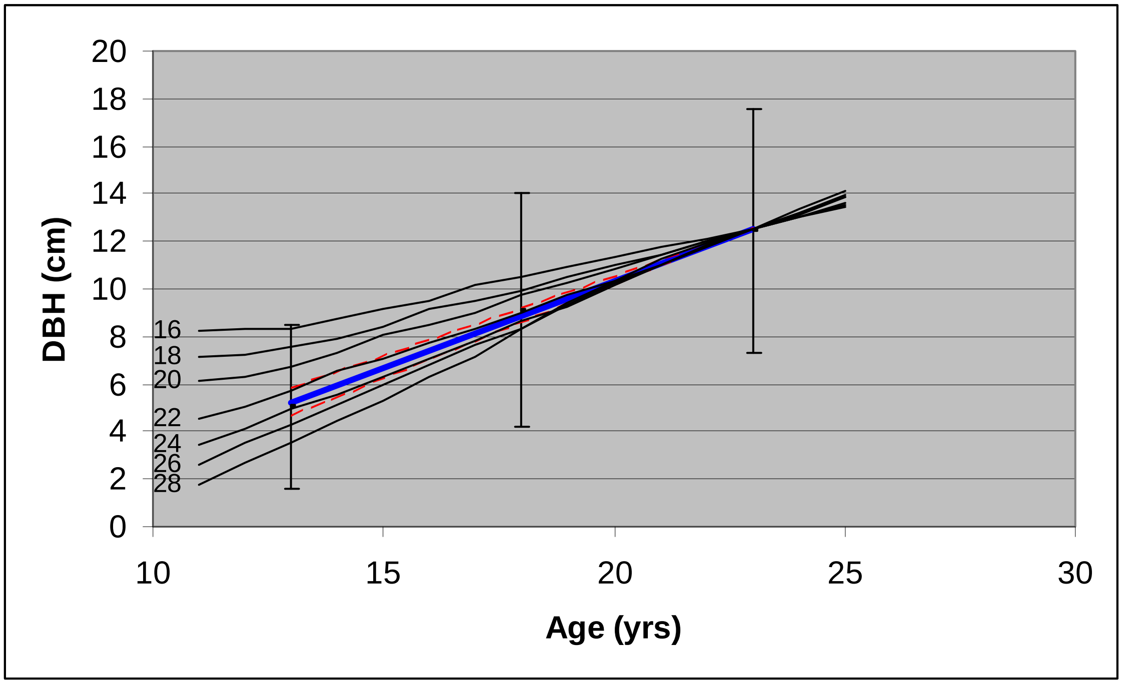


Figure 7: *A comparison of the mean height and growth rate (±2 standard deviations) of all sampled trees in the Cariboo study area control to TIPSY height at various site indices*

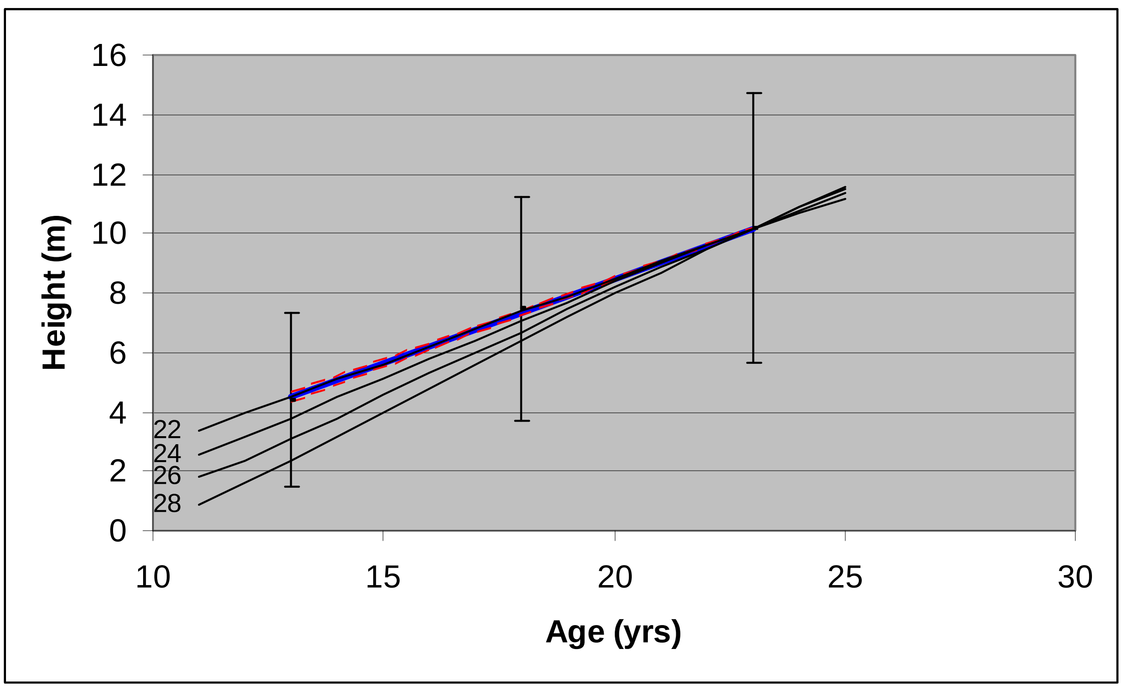


Figure 8*: A comparison of the mean height and growth rate (±2 standard deviations) of prime sampled trees in the Cariboo study area control to TIPSY height at various site indices*

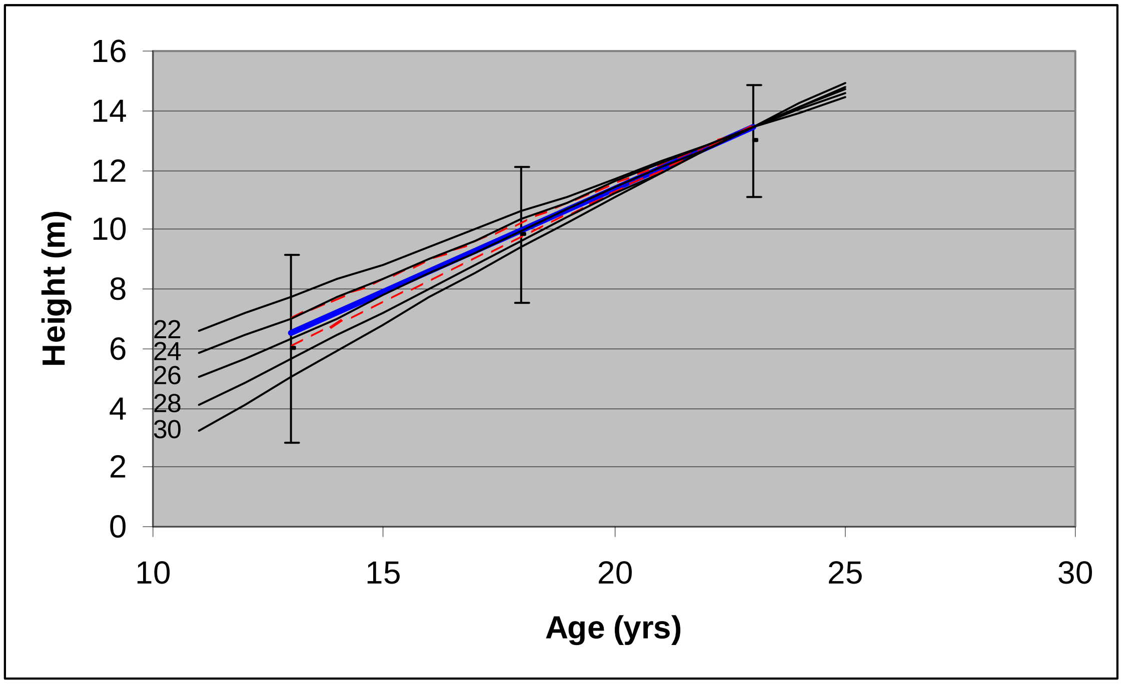
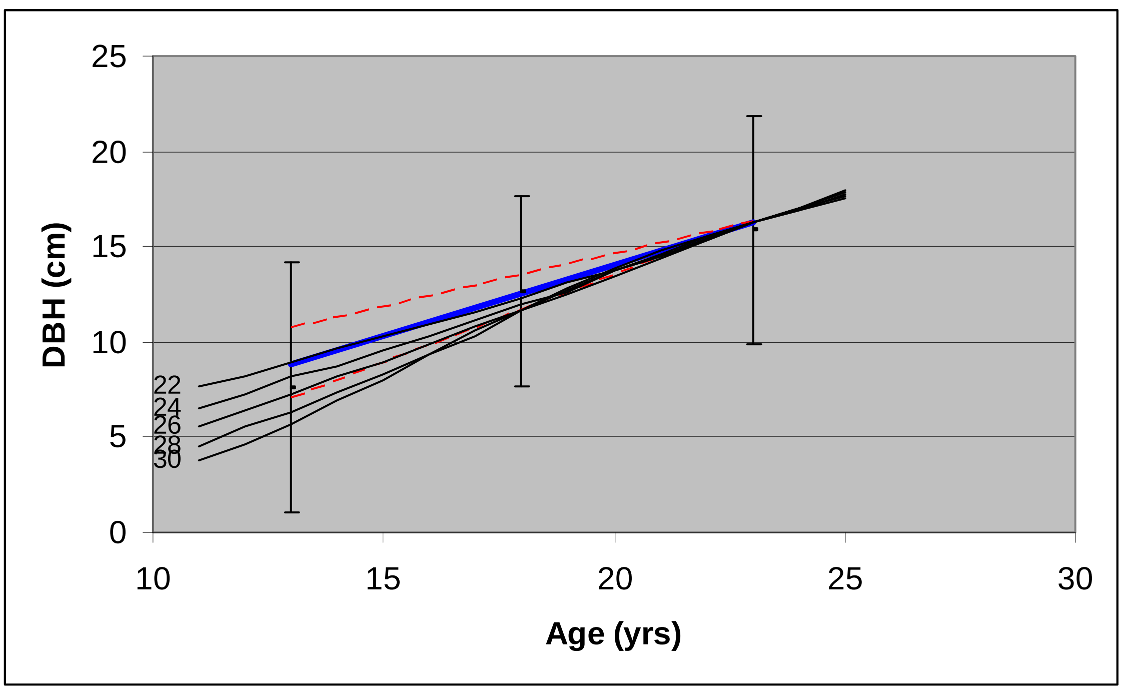


Figure 9*: A comparison of the mean DBH and growth rate (±2 standard deviations) of prime sampled trees in the Cariboo study area control to TIPSY DBH at various site indices*



The TIPSY projections for growth corresponded well with actual observations. Growth rates for all parameters fell within expected margins of error, confirming the site indices derived using the age-height curves developed by Thrower (1994). Although probably the parameter most relevant to timber profits, TIPSY predictions for crop tree volume (+12.5 cm) and stand volume (+17.5 cm) were nearly useless, as in many cases TIPSY did not return meaningful values for these parameters until a stand age of approximately 20 years.

2.4.2 Forecasted cattle use

A relationship between canopy closure (CC) and AUM/ha was established for the Summerland and Cariboo study areas. As can be seen in Figures 10 and 11, cattle use in fertilized stands was greater than in unfertilized stands at equivalent degrees of CC. The ANCOVA for the Summerland and Cariboo study areas (Tables 5 and 8, respectively) confirmed that cattle usage as a function of CC, and the difference in cattle usage between fertilized and unfertilized stands were both statistically significant. Tables 3, 4, 6, and 7 show the linear relationship between CC and cattle usage established by the regression analysis (AUM/ha = (“X Variable 1”)(CC) + (“Intercept”), also plotted as the best-fit line in Figures 10 and 11. The r^2 values for unfertilized and fertilized stands were 0.64 and 0.68 in the Summerland study area and 0.71 and 0.61 in the Cariboo study area. Figures 12 and 13 show future cattle use in each stand as predicted by the derived relationship between AUM/ha and the TIPSY-derived CC.

Figure 10: *The relationship between cattle usage and canopy closure in Summerland study area*

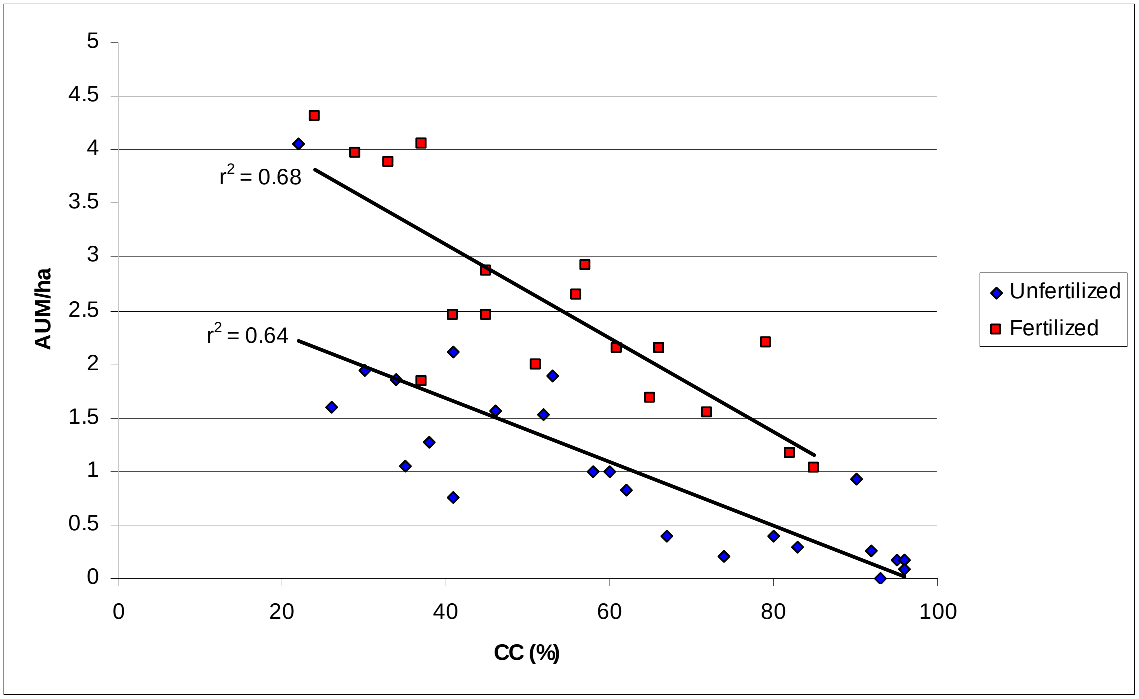


Figure 11: *The relationship between cattle usage and canopy closure in the Cariboo study area*

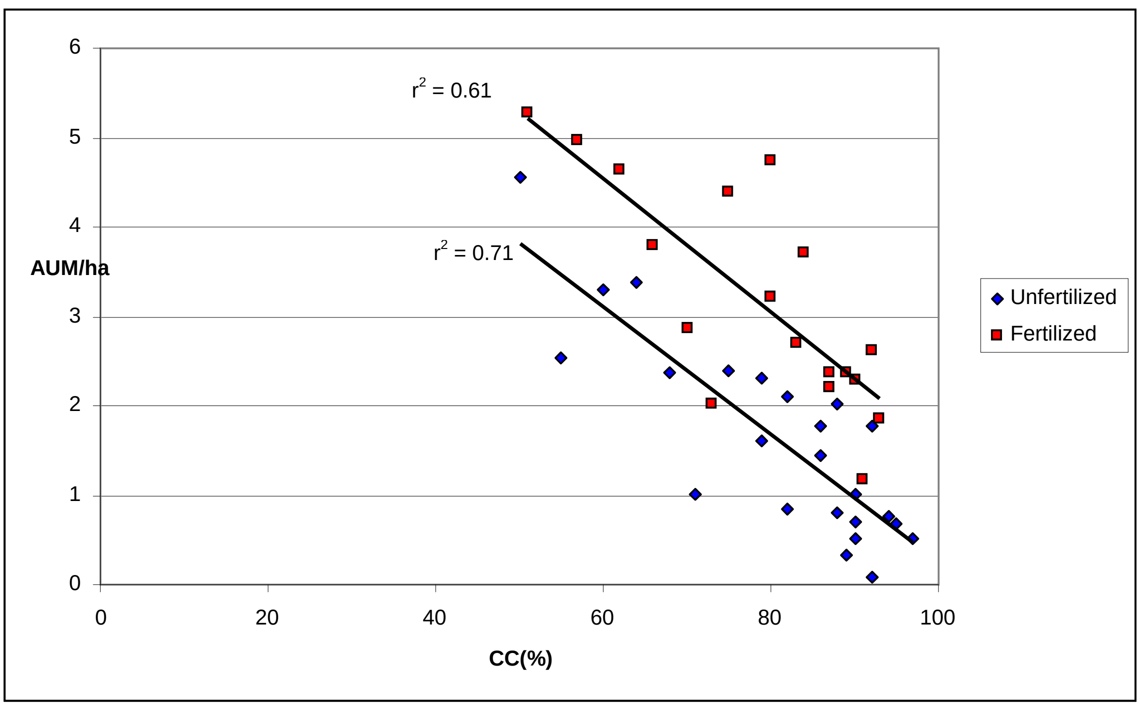


Table 3: *Regression summary for cattle usage in unfertilized stands in the Summerland study area*

Regression Statistics	
Multiple R	0.806
R Square	0.64
Adjusted R Square	0.62
Standard Error	0.57
Observations	24

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	12.68	12.68	39.68	2.44 e-06
Residual	22	7.03	0.32		
Total	23	19.70			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	2.87	0.31	9.25	4.9 e-09
X Variable 1	-0.030	0.005	-6.300	2.44 e-06

Table 4: *Regression summary for cattle usage in fertilized stands in the Summerland study area*

Regression Statistics	
Multiple R	0.82
R Square	0.68
Adjusted R Square	0.66
Standard Error	0.58
Observations	18

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	11.24	11.24	33.40	2.82E-05
Residual	16	5.38	0.34		
Total	17	16.62			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	4.86	0.43	11.37	4.45E-09
X Variable 1	-0.0436	0.0076	-5.78	2.82E-05

Table 5*: Summary of ANCOVA for difference between fertilized and unfertilized stands in the Summerland study area*

	Dependent Variable		
	Unfert.	Fert.	Total
Count	(4 stands)(6 yrs)	(3 stands)(6 yrs)	42
Means	1.0561	2.52	1.6835
Adjusted Means	1.1632	2.3772	1.6835
Aggregate Correlation within Samples:			
r			-0.8
r^2			0.64

ANCOVA

	df	*SS*	*MS*	*F*	*P*
Adjusted Means	1	14.75	14.75	43.53	2.82E-05
Adjuster Error	39	13.21	0.34		
Adjusted Total	40	27.96			

Test for homogeneity of regressions:

Source	*df*	*SS*	*MS*	*F*	*P*
Between regressions	1	0.8	0.8	2.46	0.125069
Remainder	38	12.41	0.33		
Adjusted error	39	13.21			

Table 6*: Regression summary for cattle usage in unfertilized stands in the Cariboo study area*

Regression Statistics	
Multiple R	0.84
R Square	0.71
Adjusted R Square	0.70
Standard Error	0.61
Observations	24

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	20.23	20.23	53.87	2.39E-07
Residual	22	8.26	0.38		
Total	23	28.49			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	7.374	0.794	9.29	4.56E-09
X Variable 1	-0.071	0.0097	-7.34	2.39E-07

Table 7*: Regression summary for cattle usage in fertilized stands in the Cariboo study area*

Regression Statistics	
Multiple R	0.78
R Square	0.61
Adjusted R Square	0.59
Standard Error	0.78
Observations	18

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	15.42	15.42	25.27	0.000124
Residual	16	9.76	0.61		
Total	17	25.18			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	9.04	1.18	7.65	9.74E-07
X Variable 1	-0.075	0.015	-5.03	0.000124

Table 8: *Summary of ANCOVA for difference between fertilized and unfertilized stands in the Cariboo study area*

	Dependent Variable		
	Unfert.	Fert.	Total
Count	24	18	42
Means	1.62	3.18	2.29
Adjusted Means	1.70	3.07	2.29
Aggregate Correlation within Samples:			
r			-0.81
r^2			0.66

ANCOVA

	df	*SS*	*MS*	*F*	*P*
Adjusted Means	1	19.16	19.16	41.41	<.0001
Adjuster Error	39	18.05	0.46		
Adjusted Total	40	37.21			

Test for homogeneity of regressions:

Source	*df*	*SS*	*MS*	*F*	*P*
Between regressions	1	0.02	0.02	0.05	0.824
Remainder	38	18.03	0.47		
Adjusted error	39	18.05			

Figure 12: *A comparison of cattle use between stands in the Summerland study area*

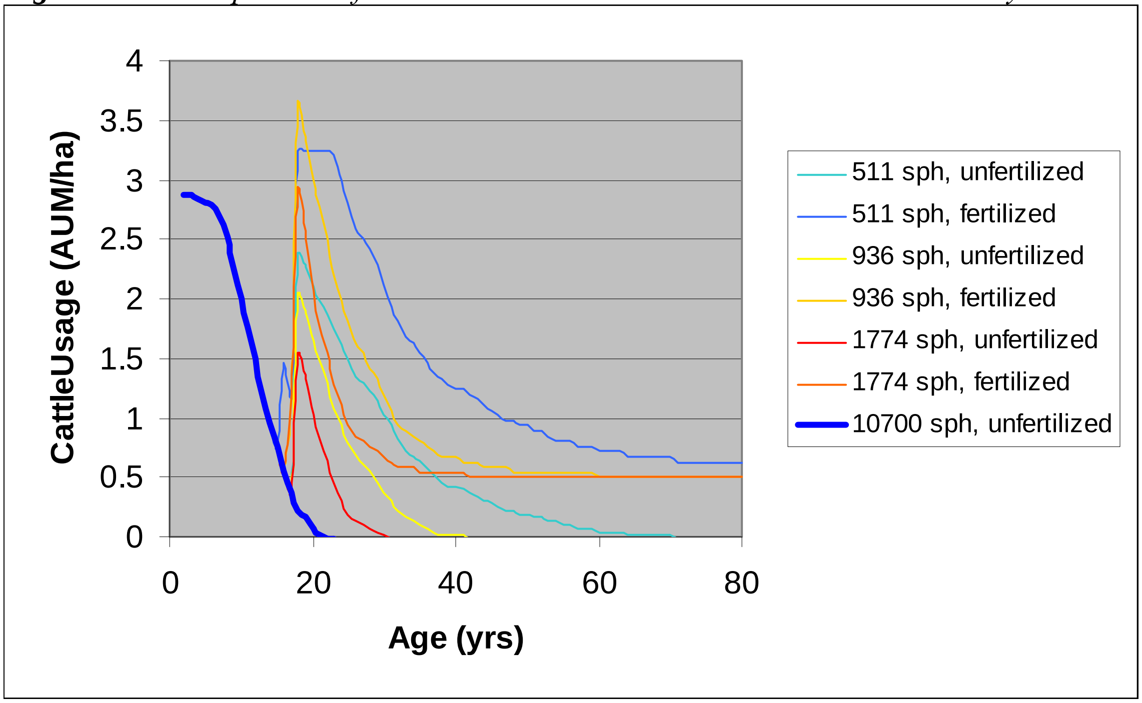
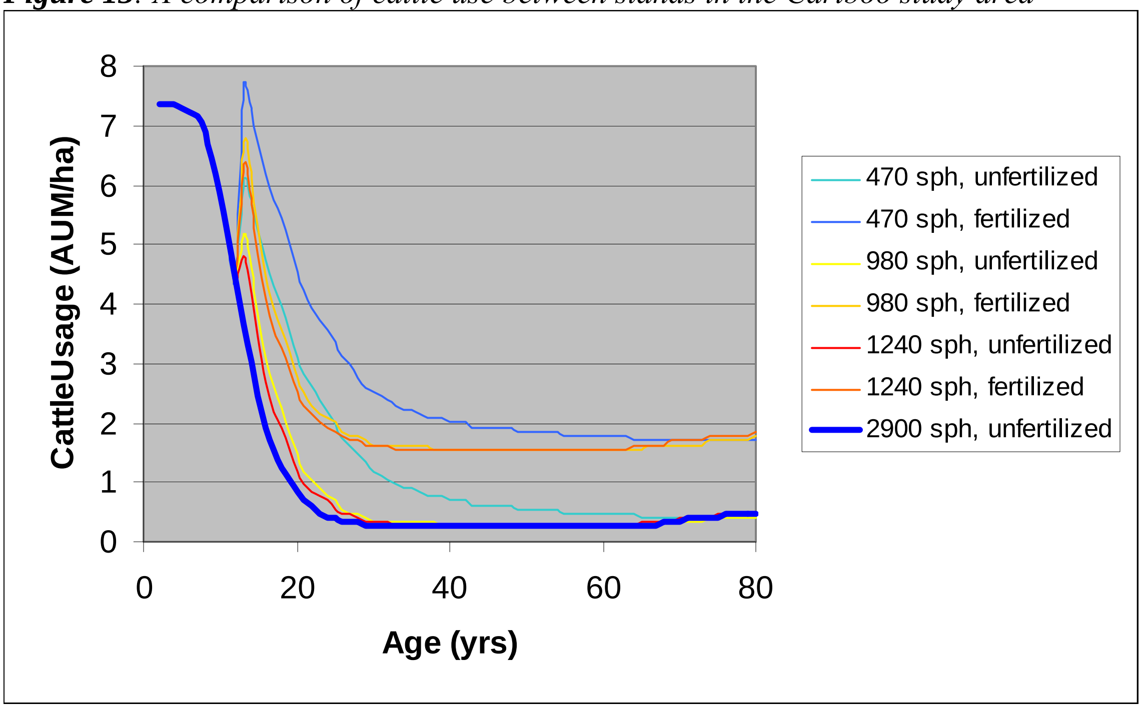


Figure 13*: A comparison of cattle use between stands in the Cariboo study area*



2.5 DISCUSSION

2.5.1 TIPSY growth and yield forecasts for each stand

A comparison of the TIPSY growth curves to actual observations indicated that the TIPSY estimates for each study area and treatment are reasonable. Although the rate of increase of stand volume is comparable between TIPSY and actual values, the actual volume calculated is consistently greater than that estimated by TIPSY. This underestimation of volume by TIPSY could be due to a measurement error, a calculation error, study areas that are not statistically normal populations, or TIPSY needs to be recalibrated. In Kelowna and – to a greater extent – Summerland, actual DBH was also greater than the TIPSY derived DBH. As Lindgren et al. (2007) calculated volume using DBH as a parameter, this correlation could indicate that a measurement bias causing actual DBH to be over-estimated is being compounded through to otherwise accurate volume calculations. Secondly, as the discrepancy in DBH between sample values and TIPSY is not obviously from human measurement error, the volume equations used by Lindgren et al. (2007) might be the source of discrepancies between TIPSY and observed values. Finally, it is possible that all three study areas have volumes larger than statistically normal for their height and DBH. For example, the trees might be less tapered than expected by TIPSY due to some external environmental influence. Alternatively, it may be that TIPSY was calibrated using trees with volumes lower than the statistically normal volume for lodgepole pines of equivalent height and DBH.

A comparison of growth rates suggests that TIPSY was reasonable in predicting the response of the trees to the repeated fertilizations while using a proxy input: TIPSY was unable to model compound fertilizations. However, it is unlikely that a permanent change in site productivity (by alleviating a chronic, site-specific nutrient deficiency) from compounded fertilizations would be evident until growth rates 10 or more years from the time of the final treatment can be measured. Using currently available data, TIPSY is an acceptable model for predicting future values for growth parameters in each treatment. However, input data are limited and future investigation might reveal specific and significant discrepancies between forecasted and observed growth. See Appendix A for detailed comparisons between TIPSY and each treatment.

In addition to discrepancies between measured and modelled volumes, TIPSY did not incorporate the influence of pruning on tree growth. Researchers with the Ministry of Forests and Range have observed significant gains from pruning treatments only in Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) forests with a site index greater than 30; corresponding research has not been conducted on pruning lodgepole pines. Thus, the TIPSY model does not reflect any biological differences this treatment might give rise to (di Lucca 2007.). Consequently, TIPSY did not account for any differences in tree growth between pruned and unpruned (G7, H8 and I9 (control)) treatments.

2.5.2 Forecasted cattle usage as a function of TIPSY-derived canopy closure information

The regression analysis returned a negative relationship between CC and AUM/ha that was reasonable for both the Summerland and the Cariboo study areas. Cattle usage may be underestimated due to sampling methodologies or sub-capacity stocking rates, but will provide a solid benchmark when it comes to comparing cattle values to timber values. The SI of the TIPSY simulation did not have a large effect on the regression statistics. This was probably because the variation in cattle usage due to unknown factors was large in comparison to the variation due to differences in canopy closure between treatments at various site indices. Also, the fertilization treatment had a significant positive effect on cattle use. Potential sources of error for the estimation of the cattle use of the treatments is discussed further in the following section.

2.6 ASSUMPTIONS

2.6.1 A statistically 'normal' forest and climate

A primary assumption is that the study areas have forests typical of their ecological classification. This assumption has significant ramifications because the accuracy and relevance of the TASS-derived growth curves to this research, and this research itself is dependant on accurate ecological classification. However, any miscalculations made by TASS as a result of inaccurate ecological classification would be partially ameliorated by the use of site index as a measure of site productivity: site index is based on empirical observation, gauging productivity independent of any classification scheme.

It was also assumed that environmental parameters remain consistent over the rotation period. The research of Hamann and Wang (2006) suggests that climate change will reduce the geographic range of several economically important conifers. The growth of lodgepole pine could be significantly affected by an ecosystem shift.

2.6.2 The use of proxy values in determining cattle use

Estimates of forage usage were conducted in a roundabout fashion, as the study areas were not designed to control for cattle. Sampling methods, data conversion, and statistical assumptions all influenced the calculation of forage use. Firstly, because cow pats spread, any number of cow pats in one sample plot were counted as only one pat. It is possible that there were some areas that supported a relatively high density of cattle and that this information was not accurately reflected due to sampling methods.

To convert cow pats per plot to AUM/ha required a lengthy conversion calculation. The conversion equation itself contained the assumption on the rate at which cattle produce cow pats (Julander 1955), and the mean animal units (AUs) per cow in an Interior herd. It was not known whether the cattle population grazing the study areas was equivalent to the 'average' population distribution derived from Statistics Canada (2007) data.

Several factors were not accounted for in the cattle regression: total herd size was unknown, a linear relationship between CC and AUM/ha was assumed, and all other variables (other than CC and fertilization) were considered irrelevant to cattle usage. Due to recently depressed beef prices, cattle ranchers are not necessarily grazing their range at capacity. Certain years showed a significantly decreased total number of cows in the study area. If leased range is being grazed significantly below capacity, then the relationship between CC and AUM/ha will be biased, underestimating the stands carrying capacity (AUM/ha) per CC. Also, it was assumed that CC and AUM/ha were linearly related; that range carrying capacity would increase with more sun exposure. However, total cattle usage was actually greatest not in the ~250 stems/ha treatments (as would be predicted using a simple linear relationship between CC and AUM/ha), but the ~500 stems/ha treatments (Lindgren and Sullivan, 2011). This is possibly due to an understory ecosystem shift that occurs when enough sun hits the forest floor, making forage species in the lowest density treatments less palatable. Interestingly, in the Summerland and

Cariboo study areas the use of rangeland by cattle seems to reach a maxima ~500 stems/ha, with a canopy closure of maybe 20-35%. Finally, no other environmental factors were considered to have an influence on the use of each treatment by cattle. In reality, other factors likely affected range use in these study areas by cattle, including distance to the nearest water source, and distance to salt licks. Fortunately, all treatments in all study areas had comparable access to water. Salt lick placement varied year to year and was treated as random.

2.6.3 Effects of silvicultural treatments on lumber quality

It was assumed that the treatments did not have an influence on wood quality. Although it has been shown that fertilization and PCT affect tree growth rates (particularly DBH), it is unknown whether or not this increase in growth comes at the expense of wood quality. Ballard and Long (1988) found that thinning significantly influenced only the average diameter of the lowest branches; trees in thinned stands had thicker lower branches. Larger lower branches could mean knottier wood. Pruning, in turn, might ameliorate the effects of the tendency for growth stimulated by fertilization to go toward the production of large lower limbs.

2.6.4 The accuracy of empirically-derived growth and yield models

The final major assumption was that the TASS growth curves were accurate. This experiment tested silvicultural extremes, and TASS does not have ample sample data for growth rates under these conditions (Mitchell et al. 2000). TIPSY could not handle the most extremely thinned treatments in any of the study areas, as a stand density of ~250 stems/ha is below the accepted input range for TIPSY. It was also assumed that the growth curve derived for the fertilized TIPSY simulations (at ages 13 and 23) was equivalent to the five actual fertilizations over the same ten year period. Over the long-term this might not be the case, particularly if fertilization alleviates some chronic environmental nutrient deficiency. In this case, stand growth would be more accurately modelled using a growth curve corresponding to a higher site index, rather than the temporary increase in growth modelled by TIPSY.

2.7 CONCLUSION

TIPSY provided an adequate model for the estimation of future growth parameters in the Summerland, Kelowna, and Cariboo study areas: there was an acceptable match between the observed data and the values derived by TIPSY. There were some discrepancies between volumes calculated by Lindgren et al. (2007) and the volumes given by TIPSY, particularly in the Summerland study area; however, some TIPSY growth curves (including volume) are almost meaningless at such a young age and low stand density. A revisit to this research with data from another 10 or 20 years would help determine the source of discrepancies between TIPSY and Lindgren et al. (2007) stand volumes. Cattle were found to preferentially graze thinned and fertilized treatments.

2.8 MANAGEMENT IMPLICATIONS

This research is useful for calibrating TIPSY, which is a tool designed by the government for forest managers (di Lucca 1999). The comparison of TIPSY forecasts to the dataset used in this research has served as a check on TIPSY's accuracy. A comparison of TIPSY growth curves from a simulated first 25 years to the observed growth indicated that TIPSY is corroborating reasonably well with ecological reality. Future comparisons between TIPSY and the study areas will help further reveal any inaccuracies inherent to TIPSY, or the possibility that the study areas are not statistically normal to begin with. A limitation of TIPSY is its inability to forecast the effects of multiple fertilizations. It is possible that compounded and optimized fertilizations will result in a greater tree growth response than predicted by the isolated and standardized fertilizations incorporated into the TIPSY model.

In general, thinning resulted in greater cattle usage and increased biodiversity, while still yielding comparable timber volumes per hectare. Fertilization did not affect tree height, but did increase the BA and crown volume of dominant trees, and resulted in the accelerated mortality of suppressed trees. In the Summerland and Cariboo study areas fertilization increased the carrying capacity of the stand for cattle grazing.

2.9 FUTURE RESEARCH

2.9.1 The further refinement of the TIPSY model

The understanding of working ecological models can always be refined through persistent research. These study areas offer the opportunity to compare TIPSY growth curves over a long period. This research could be further improved through future comparisons of actual data from these study areas to TIPSY estimates. More years of data will give a greater basis for comparison, and some trends – like an increase in overall site productivity due to compound optimum fertilizations – will likely only manifest over a longer time-line than analyzed in this paper. Any silvicultural effects from pruning will also be evident only over the long-term. Destructive sampling would be useful to assess the impact of treatments on wood quality. Also, TIPSY includes more advanced features that can be used to customize its built-in growth curves. If the goal is to accurately model the study areas, TIPSY inputs could be further refined to decrease uncertainty.

These particular study areas could be quite useful for calibrating the TIPSY model. All study areas cover relatively large areas, and provide measurements for lodgepole pine stands under a range of silvicultural extremes. In particular, TIPSY has not been calibrated for stem densities as low as is seen in this experiment (the lowest density treatments in each study area are ~250 stems/ha), nor has it been calibrated to forecast the result of overlapping fertilizations. If optimum fertilizations turn out to have an unexpectedly large growth response it might be worthwhile calibrating TIPSY to handle compound, tailored fertilizations. Incorporating the effect of multiple, optimum fertilizations would be particularly worthwhile if repeated fertilizations are shown to increase overall site productivity, rather than just result in a temporary boost in growth rate. It may even be possible to create a model to calculate the quantity of various nutrients needed to result in a long-term increase in site productivity.

2.9.2 Empirical research on silvopasture in BC

Further research into the improvement of Interior forest pasture could provide some useful guidelines to improving summer forage. If adaptive management strategies in forestry are to incorporate forage values it would be prudent to develop a model for estimating a forest's capacity to support ungulates. Likely this would involve relating a forest's carrying capacity to ecological parameters, such as: canopy closure, precipitation, biogeoclimatic zone, or SI. In particular, cattle stocking densities were not controlled, nor were criteria for sustainable management set forth, making it difficult to determine whether the estimated stocking densities are sustainable.

CHAPTER 3: ECONOMIC COMPARISON OF THE PROFITABILITY OF EACH TREATMENT IN EACH STUDY AREA

3.1 INTRODUCTION

3.1.1 The common ground between 'economics' and 'ecology'

The terms *economics* and *ecology* have a common root: *oikos*, the Greek word for 'household'. In the ancient Greek household many decisions were made pertaining to resource management, probably ground-level decisions, like whether or not to purchase a new horse and try to harvest an extra field before the fall rains, or trying to determine the optimum balance of olives and raisins with which to fill the stores at harvest. Economics and ecology are both mathematical, logical disciplines that study the relationships between individuals in systems. In keeping with their common etymological root, it behoves us to use ecology and economics in tandem. Economics provides us with a human scale by which to compare resources, ecology provides us with a way to understand those resources, and how that scale does – or does not – relate to those resources in the greater ecological context. To modify an old quote: economics without ecology is blind, ecology without economics is lame.

3.1.2 Determination of an optimum rotation period for timber harvest

The optimum rotation period for a managed stand is dependent on management priorities. The rotation periods for maximizing volume at harvest, average annual production of timber volume per unit area, and average annual profits from timber per unit area are all different.

It is possible to wait until a forest is approaching a decadent, old-growth stage to harvest a massive volume of large timber. This management option would involve calculating when the overall stand volume had reached a maximum and harvesting before it started to decline (when mortality exceeds recruitment). This is what is known as the *point of diminishing returns*. TIPSY estimates that the maximum harvestable volume per hectare (when the forest reaches the senescent or decadent stage) is achieved sometime after 150 years of growth. (However, a 150 year old lodgepole pine stand is a scenario that seems to reflect TIPSY's inability to model the current mountain pine beetle (*Dendroctonus ponderosae,* Hopkins) epidemic in BC.) This harvest would produce the most timber volume per hectare. However, because a forest's growth rate slows as it approaches an old-growth state, this option would not produce the greatest volume of timber if total harvested volume was averaged over the rotation period.

To maximize timber production on a given land base we are not concerned so much with the total volume per hectare at the time of harvest, as with maximizing the volume produced per unit area per year. The rate at which a stand increases in volume per year is referred to as the *mean annual increment* (MAI). Initially, the forest's MAI is increasing, but there comes a point where the total volume added to the stand per year begins to decline: what economists would refer to as the *point of diminishing marginal returns*. For all study areas in this project, TIPSY estimated the point of diminishing marginal returns to occur sometime between a stand age of 50-70 years. At this point, the total stand volume averaged over the lifespan of the stand begins to decrease. A rotation scheme that harvested trees when the MAI was at a maximum would maximize the timber harvest from that stand per unit area per year. Theoretically, a rotation period based on the stand's maximum MAI would produce the most timber per hectare biologically possible, without intensifying silvicultural treatments. Quality of lumber, other values, and time preference aside, harvesting when the MAI is at a maximum also generates the most profits: overall, this rotation sends the greatest volume of timber to market per year.

3.1.3 Today's value of tomorrow's costs and benefits

Although selecting a rotation period based on maximizing the MAI and average annual profits seems like the obvious answer, there is an economic problem with this reasoning: a dollar today is not equivalent to yesterday's or tomorrow's dollar. The influence of time on value is referred to as the *discount rate*. There are two reasons why capital is worth more today than tomorrow: *lost opportunities*, and uncertainty about the future. *Lost opportunity costs* reflect the costs associated with the inability to invest the capital tied up in a venture elsewhere. For example, given the choice between $100 now and $100 in ten years it would be preferential to take that $100 now and potentially make a low-risk investment in something like government bonds at an interest rate of perhaps 4%. The $100 taken today would be worth $148 in ten years: in other words, $100 in ten years is equivalent to only $68 dollars at the present. Uncertainty about the future – or the *risk* involved in an investment – also affects the discount rate. This is evident in the stock market, where low-risk blue-chip stocks promise a much lower *rate of return* than high-risk stocks: investors expect large returns in return for loaning capital to a risky venture. The rate of return that an investment has to beat in order for an entity to consider it worth the risk and lost opportunity costs is referred to as the *discount rate* (DR).

3.1.4 Definition of the social discount rate

When the Canadian government makes silvicultural investments the inherent risk is low, unlike private businesses – which have tenuous rights over forest land and whose existence is subject to the vagaries of the market – the Canadian government has much more confidence that the profits of timber harvest will be realized by Canadians. Thus, for government investment in social programs the discount rate is equivalent to a low-risk investment in the private sector. The discount rate used by governments for evaluating future costs and benefits for government spending on social projects is called the *social discount rate* (SDR). There are some discrepancies as to value that should be used as the SDR; however, Heaps and Pratt (1989) suggested that a DR in the 3-7% range would be appropriate.

3.1.5 How to compare future values in the present

Although the existence of a time preference means that costs and benefits occurring at different times cannot be directly compared, it is possible to discount future costs and profits to an equivalent current value: an investment's *net present value* (NPV). If all costs and benefits associated with a timber rotation are discounted to a present value, then they can be summed to provide a single value for that investment. If the NPV is negative, the investment is not profitable; it would be better to invest the capital in something else. Note that an investment that initially appears profitable with a *cost-benefit analysis* might not yield a positive NPV. Future profits might be discounted to the point where they are exceeded by future costs, particularly if costs are incurred early in the investment and profits are not realized until the end of the investment. If the NPV is positive the investment is profitable. If given a choice, a rational investor would choose the option that had the greatest NPV: the *profit-maximizing investment*.

NPV provides a good basis for comparison for one-time investments, but it does not work for comparing repeated investments with different time periods. Unfortunately, silvicultural investments affect both harvest value and rotation period. If the silvicultural investments were a one-time investment, then this would not be a problem; however, the government has – and likely will – continue to oversee successive timber rotations. Thus, it is necessary to derive an alternate basis for comparing future costs and benefits that can incorporate discrepancies in rotation periods between investments. This is done by calculating discounted future profits and losses for an infinite number of rotations, yielding the *land expectation value* (LEV), a variation on Faustmann's soil-rent formula (Bentley and Teeguarden 1964) (Mitchell et al. 2000). Although assuming infinite rotations might not be realistic, the contribution of each successive rotation to the overall value decreases exponentially. The LEV is an appropriate value for comparing silvicultural investments as it seems likely that most BC forests will experience more than one rotation in timber production.

3.1.6 Calculating timber values

The determination of the costs and benefits associated with timber production was simplified in this research by a component of the TIPSY model. To develop a value for the harvested timber, TIPSY starts with information on individual trees provided by TASS (DiLucca 2000). First, the tree information from TASS is passed to the BUCK model, which translates individual tree information to individual log information (DiLucca 2000). The BUCK model then passes the virtual logs to the SAWSIM model, which mills the logs into an optimum quantity of lumber, with an emphasis on the production of structural lumber (*i.e.* 2x4s) (DiLucca 2000). The information on the quantity of dimensional lumber from all the logs produced in a stand is then passed onto the GRADE model, which estimates the quality of lumber produced (DiLucca 2000).

With TIPSY providing estimates on the quantity of dimensional lumber produced, the valuation of the timber becomes possible. Lumber prices are fairly accurate because the product is uniform, the lumber market is relatively competitive, and lumber producers are price-takers (Mitchell et al., 2000).

3.1.7 Calculating forage value

Unfortunately, determining the value of forage is not simple. The problem is that there is a dearth of data on the market value of upland forage because there is a limited supply of private, upland forage in BC (most upland forest/grasslands are public and managed by the government). The government of BC does charge a *pasture lease rate*, but as an artificially determined figure it does not serve as an accurate representation of the value of forage to BC. However, it provides a good lower limit for pasture prices, as it is unlikely that government would deliberately overprice forage and force ranchers to overpay for their forage. Given a lack of alternative markets for summer pasture in the Interior of BC this would be seriously detrimental to the cattle industry. Given the lack of accurate information on the value of upland pasture in BC, prices from other markets in similar regions of North America provide some indication of the value of pasture.

3.2 OBJECTIVES

The objectives of this chapter are to: 1) establish market prices for inputs and outputs (*i.e.*, labour, management, equipment, timber prices, and pasture lease rates) 2) generate annual cash flow statements for each treatment, 3) establish an appropriate discount rate, 4) establish the profit-maximising rotation period for each treatment based on maximum LEV, 5) compare treatments on an economic basis.

3.3 METHODS

3.3.1 Cost-benefit analysis

Most costs and benefits associated with timber harvest were calculated using the default market averages used by TIPSY. These included: 1) site preparation, 2) pruning, 3) fertilizing, 4) PCT, 5) road development, 6) tree-to-truck costs, 7) haul costs, 8) road maintenance, 9) overheads, 10) milling costs, and 11) lumber revenue. A rate of inflation of 1.94% was derived using consumer price index data for the last 15 years (Bank of Canada, 2011).

Site preparation costs in all forest areas were $22/ha (Mitchell et al, 2000).

Costs associated with pruning were calculated using the following equation, also used by TIPSY.

Pruning ($/ha) = (# of trees / ha)(wage ($/hr)) / (# of trees / hr) (Stone 1992)

The TIPSY default number of trees that can be pruned in an hour on the first lift to 3 m is estimated at 19 trees/hr. Wages were set at $20/hr.

Fertilization costs were set to an average of $367/ha, according to the average used by TIPSY (Mitchell et al. 2000) for Interior forests. Fertilized treatments were counted as having five applications, one every two years, starting at stand age 15 years and ending at stand age 25 years.

The cost associated with PCT was calculated using the following equation, used by TIPSY and derived by Stone (1992):

PCT ($/ha) = 272.07 – 2.79 (treated area (ha)) + 11.54 (slope (%)) + 0.0365 (trees removed) + 26.46 (average height prior to treatment (m)) (Mitchell et al. 2000).

The treated area was assumed to be 80 ha, with an average slope of 2%. The average 1993 height from the control was used as the average height prior to treatment.

Road development costs for harvest were $1943/ha in the Summerland and Kelowna study areas, and $999/ha in the Cariboo study area (Mitchell et al, 2000).

Tree-to-truck costs were calculated for ground skidding using rates derived from the following formula:

$\$/m^3 = 16.09 + 9.42(\text{slope}/100) – 4.79(\text{harvest volume } (m^3))/1000$ (Mitchell et al. 2000).

Haul costs were calculated using TIPSY defaults to be $12.79/$m^3$ (Mitchell et al. 2000).

Road maintenance costs for harvest were $2.02/$m^3$ in the Summerland and Kelowna study areas, and $0.94/$m^3$ in the Cariboo study area (Mitchell et al. 2000).

Overheads incurred during harvest were calculated using the following equation:

$\$/m^3 = 9.52 + 0.0025(\text{slope}) – 0.015(\text{harvest volume } (m^3/ha))$ (Mitchell et al. 2000).

Milling costs were calculated using the following equation:

$\$/MBF = 2234.31(LRF^{)-0.5199}$ (Mitchell et al. 2000).

Lumber revenues were calculated using TIPSY derived volumes of lumber and the following lumber prices: chips, $567/BDU; 2x4, $516/MBF; 2x6, $505/MBF; 2x8, $512/MBF; 2x10, $612/MBF (Mitchell et al, 2000).

Revenues from pasture leases were calculated using the government defined *pasture lease rate*:

Forage Fee ($/ha) = (Stock Price ($/kg)) x 93% x (AUM/ha) (LWBC 2004)

The *stock price* is the weighted three year average price ($/kg) of live cattle sold through the BC Livestock Producer's Cooperative Association (LWBC, 2004). The 2005/2006 stock price was $2.01/kg (LWBC, 2004). This yielded a forage value of $1.87/AUM. This price was considered too low, and a 1977 value derived by Barichello (2011) was inflated to the 2011 value of $15.40 - $19.20/AUM. A value of $17.23/AUM was used.

The social discount rate was established at 6%, with a sensitivity analysis being conducted for discount rates of 3%, and 9% in an effort to represent the potential variation in social discount rate identified by Heaps and Pratt (1989). The NPV and the LEV associated with harvest at any given year were calculated using the following equations:

$$NPV = \Sigma^{A}_{i=0} R_i (1+r)^{-i} - \Sigma^{A}_{i=0} C_i (1+r)^{-i}$$

$$LEV = \Sigma^{A}_{i=0} R_i (1+r)^{A-i} - \Sigma^{A}_{i=0} C_i (1+r)^{A-i} / ((1+r)^{A} - 1)$$

Where A is the rotation period for the specific treatment, i is the specific year in that rotation, R_i is any revenues associated with year i, C_i is any costs associated with year i, and r is the social discount rate. Rotation period was determined by selecting the earliest year at which potential LEV was maximum.

3.4 RESULTS

As can be seen in Table 9, in all three study areas the untreated control was the profit-maximising treatment. The unfertilized, ~2000 stems/ha treatment was consistently the second most profitable treatment. In all three study areas the fertilized treatments were less profitable than the corresponding unfertilized treatments, with the fertilized treatments at densities ~500 stems/ha and ~1000 stems/ha consistently being the worst and second worst investment options, respectively. However, in the Cariboo study area the discrepancy between the LEV of fertilized and unfertilized stands was not as pronounced. In the Summerland study area, the ~500 and ~1000 stems/ha unfertilized stands and the control were profitable. In the Kelowna study area, only the ~2000 stems/ha unfertilized treatments and the control were profitable, all other treatments were not profitable. In the Cariboo study area, all treatments were profitable. In the Summerland study area, forage increased the LEV of all treatments by ~400-500 $/ha. In the Cariboo study area, forage increased the LEV of all treatments by ~1150-1500 $/ha. Pasture and timber LEVs were of a similar order.

Table 9: *Comparison of discounted values between treatments at mean site index (bold – profitable treatment, italics – profit maximising treatment)*

Study Area	**Site Index**	**Stand**	**LEV** Timber	Forage	Total	**Rotation Period**
Summerland	16	511 sph, unfert.	-466	483	17	65
		511 sph, fert.	-1050	602	-448	63
		936 sph, unfert.	-575	435	-140	63
		936 sph, fert.	-1087	537	-550	62
		1774 sph, unfert.	-171	399	228	62
		1774 sph, fert.	-644	482	-162	60
		10700 sph, control	141	365	505	65
Kelowna	20	619 sph, unfert.	-130	0	-130	55
		619 sph, fert.	-660	0	-660	55
		1004 sph, unfert.	-189	0	-189	55
		1004 sph, fert.	-614	0	-614	53
		1739 sph, unfert.	329	0	329	55
		1739 sph, fert.	-61	0	-61	52
		3928 sph, control	537	0	537	55
Cariboo	26	470 sph, unfert.	865	1321	2186	45
		470 sph, fert.	375	1510	1886	44
		980 sph, unfert.	1180	1173	2352	44
		980 sph, fert.	803	1355	2158	42
		1240 sph, unfert.	1786	1153	2939	42
		1240 sph, fert.	1444	1331	2775	42
		2900 sph, control	2081	1101	3182	42

Figure 14: *A comparison of timber and harvest LEV in the Cariboo study area (980 stems/ha, fertilized).*

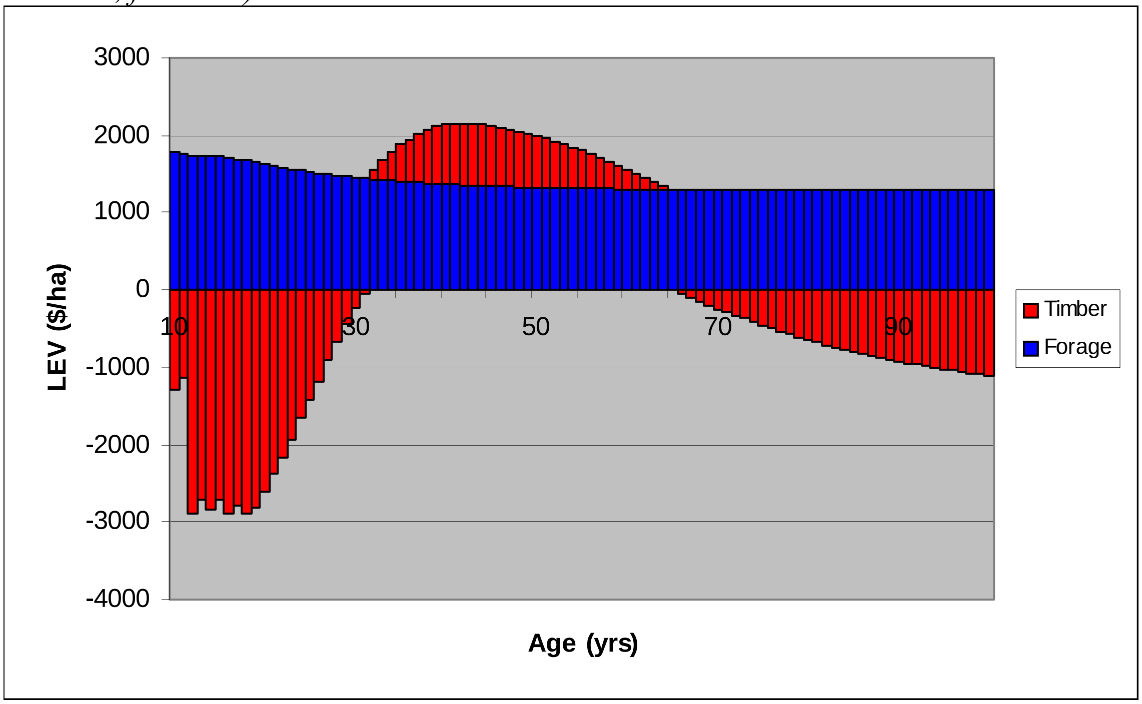


Figure 14 shows the typical relationship between forage and timber LEV associated with harvest in any given year. The LEV of forage accumulates a positive value early in the rotation and maintains most of that value indefinitely. On the other hand, timber LEV is drastically affected by the costs of treatment and the unprofitability of harvesting while the stand contains little merchantable timber. It is not until about 30 years into the rotation that timber harvest becomes a profitable option, with the most profitable time to harvest somewhere around 40 – 45 years. After about 65 years timber LEV once again becomes negative, and to harvest after this age is to lose money on the silvicultural investment. See Appendix C for similar figures for all stands in the Summerland and Cariboo study areas.

The sensitivity analysis revealed that silvicultural costs, harvest profits, forage profits, and discount rate all had an influence on the LEV, but did not ultimately affect the timber management decision: the untreated control remained the profit-maximizing investment opportunity. Although moderate alterations to the underlying economic assumptions affected the profits associated with each treatment, they did not result in any other treatment replacing the untreated control as the best investment option. See Appendix B for the data returned by the sensitivity analysis.

3.5 DISCUSSION

The trends observed in this research indicate that PCT and fertilizing lodgepole pine forests in the Interior do not increase LEV, in terms of timber and forage values. Fertilization appeared to be a particularly poor investment choice, unable to pay itself off under any of the investigated conditions. However, it should be noted that the fertilization regime used in this research was as extreme, constituting five applications in a ten-year time period. These fertilizations were tailored to try and ameliorate forest soils over the long-term, rather than just provide a temporary increase in tree growth rate. The long-term efficacy of fertilization will not be measurable until some time in the future.

Despite the negative results of this research it would not be prudent to assert that lodgepole pine forests in the interior of BC should not be fertilized or pre-commercial thinned, in light of some of the assumptions made and the scale of this research. In fact, some of the treatments (particularly the unfertilized ~2000 stems/ha treatment) had an LEV comparable to the control’s value. Given the limitations of this research, there are some conditions under which fertilizing and thinning might still be viewed as a most valuable investment opportunity.

3.6 ASSUMPTIONS

Predictably, comparing the long-term value of silvicultural treatments before the subject stands have reached 30 years old entailed making some assumptions. Most of these assumptions were derived directly from the employment of the economic concept of *et ceteris parabis*; all other things remain equal. As there is no controlled economic 'laboratory' environment, in order to analyze the influence of one parameter over the system as a whole, it is necessary to assume that all other economic factors remain constant. Foremost amongst these unaccounted for market factors is price.

3.6.1 Changes in real price

The equations used to derive NPV and LEV are independent of inflation; however, implicit to this derivation process is the assumption that the prices for input and outputs remain constant relative to each other. For example, if the price of labour increases 10% over 10 years, the price of timber also increases 10% over ten years. In conjunction with this assumption of consistent relative value is the assumption that prices are non-stochastic. Of course both of these assumptions are not particularly valid in the timber or forage industries, particularly over the long-term. In fact, the *real price* of lodgepole pine fluctuated significantly since 1966 and has decreased at an average rate of 0.11% (Feltham and Messmer 1996). In the case of pasture lease, the rates used in this research were before Canadian beef prices were relatively depressed due to *bovine spongiform encephalitis* (BSE) outbreaks (Statistics Canada 2008). With only one rotation taking more than 50 years there are plenty of opportunities for the real prices of the goods involved (labour, fertilizer, machines, timber) to fluctuate with changing market conditions, new cultural attitudes / governmental policies (labour prices increase due to improved safety standards), or new technology (production costs are diminished by using improved tools). It is possible that a global change in supply (countries with a developing forestry sector with low production costs flooding the market with cheap timber) or demand (a depressed United States housing market that no longer requires a net influx of structural lumber) will affect predicted harvest profits and losses. A significant decrease in the value of labour or machines in BC might make some of the investigated treatments the profit-maximising investment opportunity.

3.6.2 Price uncertainty

There were also assumptions made in the calculation of price itself, particularly involving the calculation of forage values. In contrast to the information on forestry cost-benefits, little is known about the value of forage in BC. Private pasture leases in Alberta range from $20-$30/AUM, $16-$18 in Saskatchewan, and $14.50 in the western United States (Agriculture and Rural Development 2007) (Saskatchewan Agriculture and Food 2006) (USDA 2008). These values from nearby regions suggest that Barichello's (2011) revised 1977 values for forage in BC are closer to the real price of forage than the governments $2.11 – $1.86/AUM pasture lease rate (LWBC 2004)

3.6.3 A 'perfect' forest

The LEV equation also assumes a *perfectly managed forest*, a simplistic model for stand management. One of the criteria of a perfectly managed forest is that it is comprised of only one tree species which is completely harvested at the end of the rotation; the next rotation starts with seedlings on bare land. For a dense lodgepole pine stand, this might be a valid assumption, as they are often so crowded that no other trees are growing besides the current, uniformly-aged cohort. However, significant ingress by other trees was observed on thinned sites (Lindgren et al. 2006). These volunteer tree species are not accounted for in the LEV calculations for this research, as pre-existing stock at the beginning of the rotation was not valued. This is erroneous because it is possible that a carefully managed, low-density lodgepole pine stand could function as a nursery for other valuable trees, reducing the rotation period of the subsequent stand.

3.7 CONCLUSION

This research indicates that PCT and fertilization do not increase the present market value per hectare of a lodgepole pine stand in the Interior of BC. However, not all goods and services with monetary values were accounted for, nor are all values monetary. Ingress was not accounted for, improved game habitat was not valued, the TIPSY model was not calibrated to respond to compound fertilizations, nor was any change in wood quality adjusted for. It is possible that in some situations it might be more valuable to thin or fertilize a lodgepole pine stand. Interspersed low-density lodgepole pine stands could result in an overall increase in forest diversity, particularly at a landscape level. Although this research indicates that the untreated control is the profit-maximizing silvicultural option, a PCT to ~1000-2000 stems/ha (no fertilization) produces an LEV comparable to the control (see Table 9). It is possible that the control only appears to be the profit-maximizing option, due to inaccurate ecological forecasting and/or missing economic information.

3.8 MANAGEMENT IMPLICATIONS

In general this research indicates that under normal circumstances that PCT and fertilization of lodgepole pine stands is unprofitable. However, the unfertilized ~2000 stems/ha (G7) and to a lesser extent the ~1000 stems/ha (E5) have comparable value per hectare. Under certain conditions forest managers might find it worthwhile to thin lodgepole pine stands: for example, to provide access to improved pasture for cattle, to increase ecosystem diversity at a landscape level, to start the next rotation early, to improve wild game habitat, or to serve as a fire break. Although not necessarily the most profitable option, PCT and fertilizing are still profitable in highly productive sites: a productive site will not lose money, even at an extremely low PCT stem density.

3.9 FUTURE RESEARCH

3.9.1 Forage valuation

More research is needed to improve the valuation of forage. The government-defined *pasture lease rate* is likely underpriced and not representative of the market price. Forage values might be better calculated by surveying ranchers on the rate at which they lease private upland pasture and deriving an average value, or with willingness to pay and willingness to accept surveys. Additionally, British Columbians also benefit from improved forage through an increased abundance in game species, in this case mule deer, elk and moose. Loomis et al. (1989) calculated the marginal product for various game species through surveying a range of guide outfitters. A similar exercise in BC could translate increases in forage available to game into the market value of that game to the hunting and guiding industries. However, the browsing of young, fertilized tree plantations by ungulates has been well-documented in northern Europe (Edenius 1993; Ball et al 2000). Damage to crop trees from grazing ungulates might outweigh the economic benefits of attracting these same ungulates. Also, beef prices have been depressed in Canada for the last few years, largely due to fluctuations in foreign markets as a result of BSE scares. The economics of silvopasture in BC has not received much attention.

3.9.2 Effects of silvicultural treatments on timber values

More research is also needed to detail the compounded effects of pruning, PCT and repeat fertilization on timber values. At a tree scale repeat fertilization and PCT combined with pruning might result in significant changes in wood quality. At the end of the current rotation samples of timber from each treatment should be compared and valued to determine the influence of these treatments on wood quality, especially as TIPSY and TASS do not regard pruning as having a significant effect on lodgepole pine (Mitchell 2000). Then it should be determined whether any observed differences in timber quality translates to differences in sawn lumber quality and value.

3.9.3 Effects of ingress on LEV

At a stand level it would be worthwhile studying the appreciable ingress by trees that occurs in the thinned treatments. It is possible that the recruitment that occurs in thinned stands will give a subsequent rotation a head start with regeneration, perhaps even making it unnecessary to prepare and replant the soil for a second rotation. This kind of relay cropping could potentially make the ~1000 stems/ha and ~2000 stems/ha more profitable than the control.

3.9.4 Value of low-density stands as fire breaks

Low-density managed forests may be useful in wildfire management. With less standing wood, low-density lodgepole pine plantations might serve as an effective wildfire buffer (Dombeck et al. 2004). This application of low-density plantings might be of considerable value to land managers if it could be shown that the benefits of limiting fire risks were greater than the cost of a PCT. In particular, many communities are located in valleys where soils are generally alluvial and rich. It is likely that the forest lands in these fertile areas would have higher site indices; a situation in which thinning to 2000 stems/ha (without considering the benefits accrued from diminished fire risk) may already be a profit maximizing investment alternative.

3.9.5 Possible resistance of low-density stands to mountain pine beetle

Low density plantings might also become profit-maximizing alternatives if they prove to be more resistant to mountain pine beetle (*Dendroctonus ponderosae*) attacks than unthinned stands (Waring and Pitman 1985). It might be a worthwhile investment to thin productive sites (high SI), if it meant that they had an increased chance of surviving an infestation over an unthinned control. However, there is a risk that a thinned stand would still be devalued by the mountain pine beetle anyway and the investor would have no way to reclaim the capital invested in the thinning. An unthinned stand requires no direct investment of capital in silviculture, consequently there is less risk incurred through treatment costs.

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Appendices

APPENDIX A: COMPARISON OF TIPSY GROWTH CURVES TO ACTUAL GROWTH RATE

Figure A.1*: Comparison of TIPSY results to observed height of all trees in the Summerland study area (PCT: 511 stems/ha, unfertilized)*

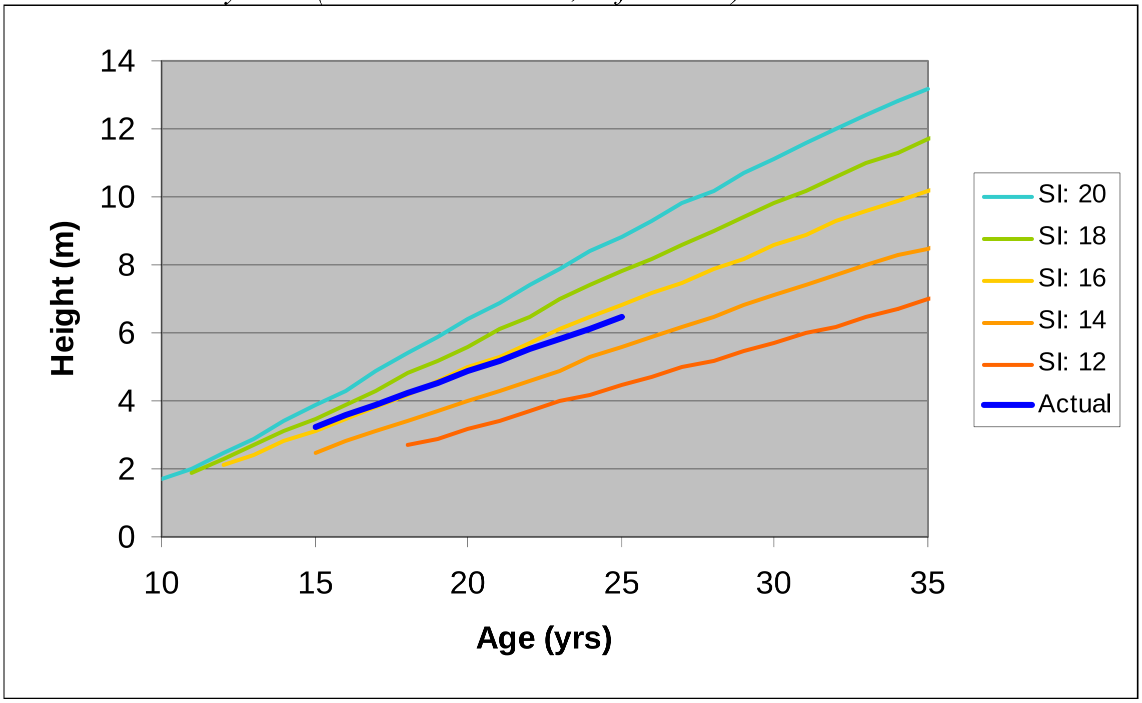


Figure A.2: *Comparison of TIPSY results to observed height of all trees in the Summerland study area (PCT: 511 stems/ha, fertilized)*

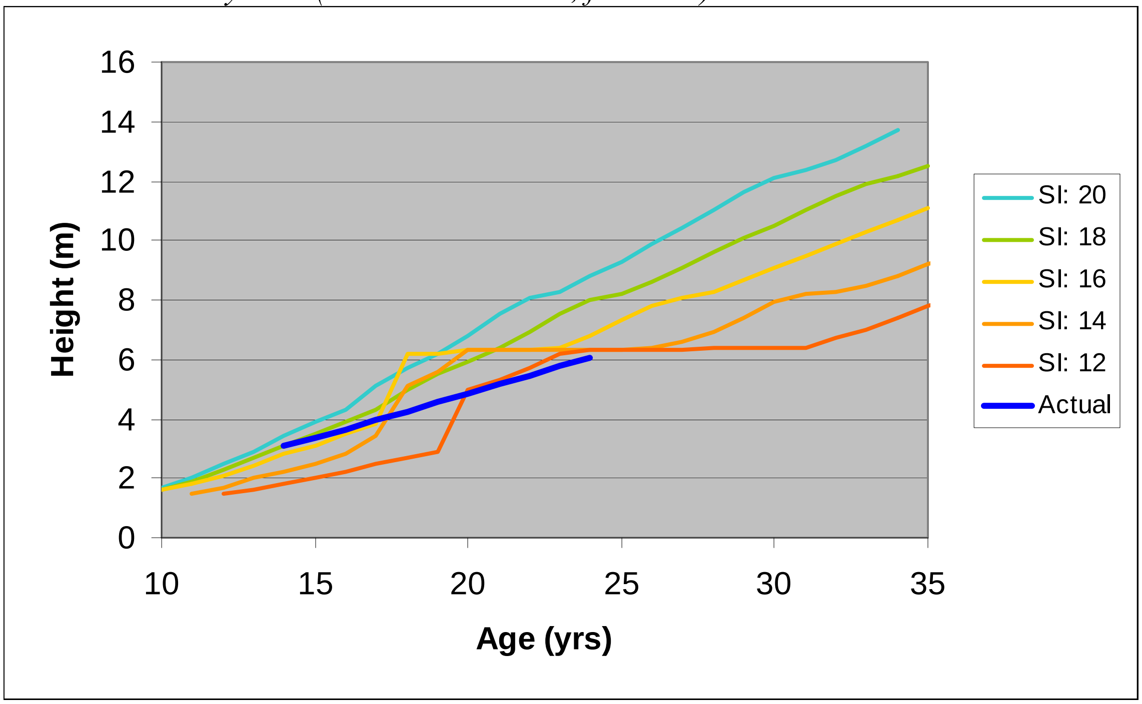


Figure A.3: *Comparison of TIPSY results to observed height of all trees in the Summerland study area (PCT: 936 stems/ha, unfertilized)*

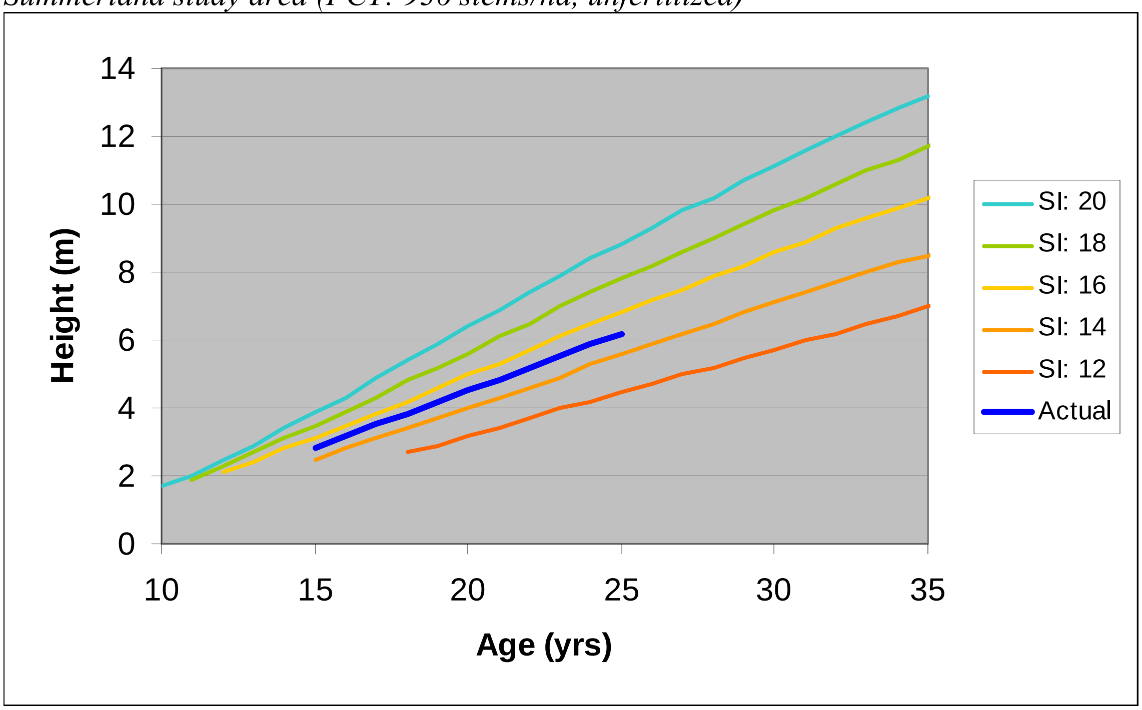


Figure A.4: *Comparison of TIPSY results to observed height of all trees in the Summerland study area (PCT: 936 stems/ha, fertilized)*

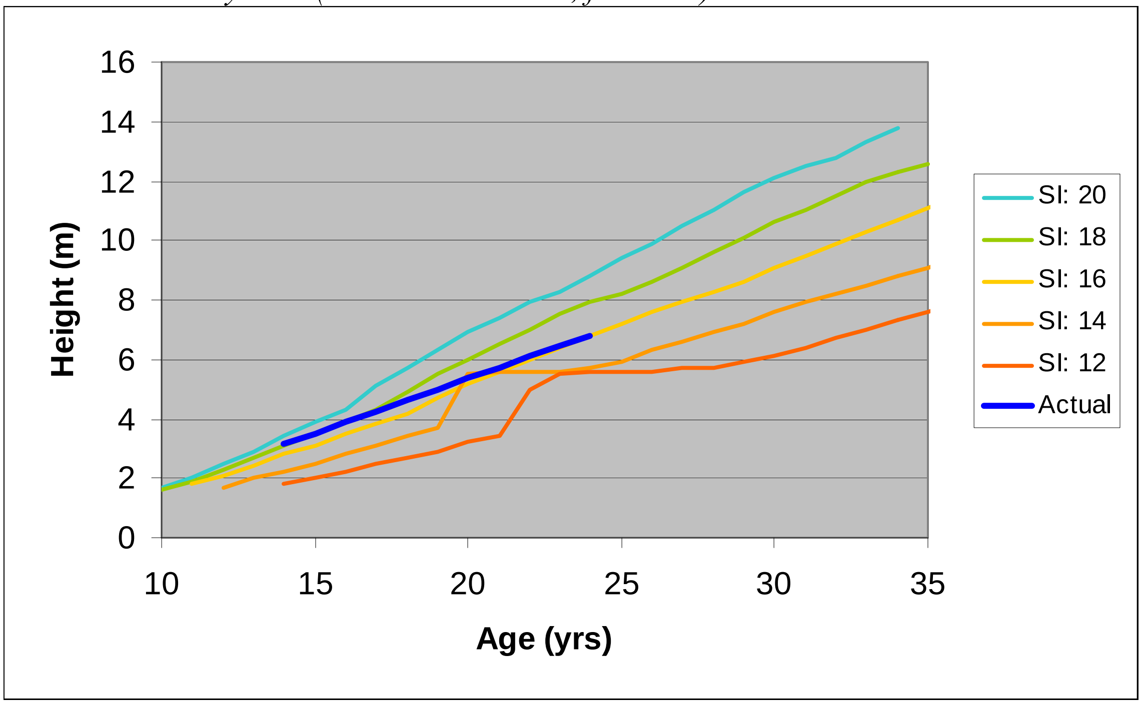


Figure A.5*: Comparison of TIPSY results to observed height of all trees in the Summerland study area (PCT: 1774 stems/ha, unfertilized)*

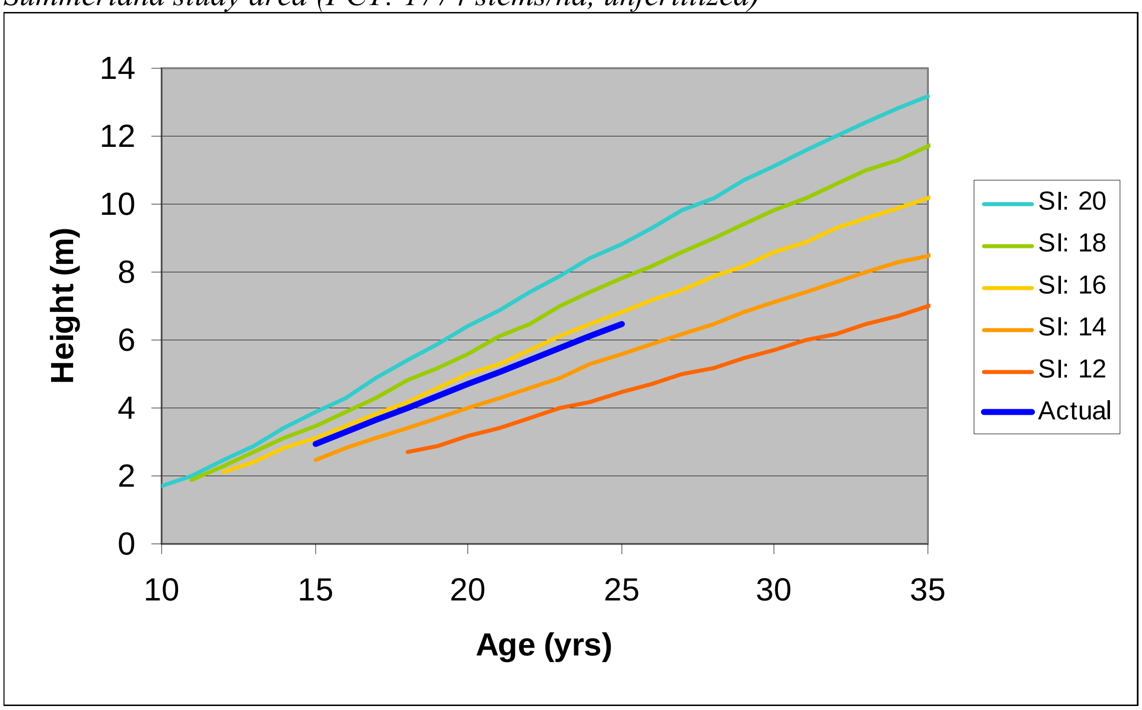


Figure A.6: *Comparison of TIPSY results to observed height of all trees in the Summerland study area (PCT: 1774 stems/ha, fertilized)*

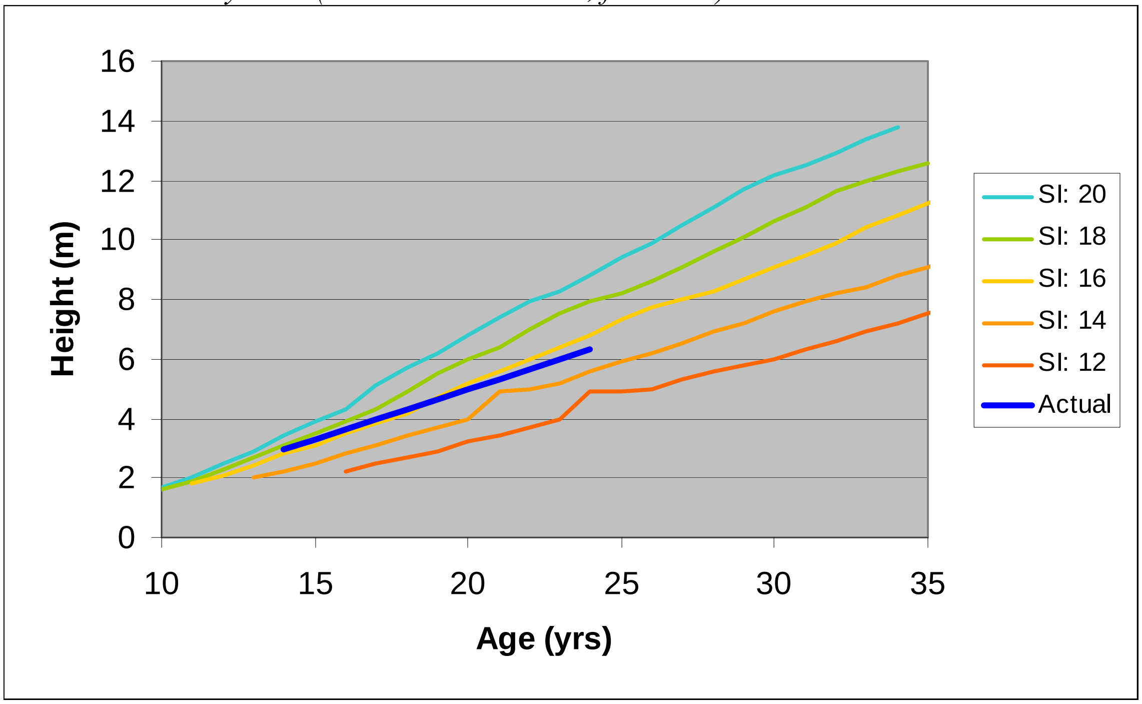


Figure A.7: *Comparison of TIPSY results to observed height of all trees in the Summerland study area (PCT: control)*

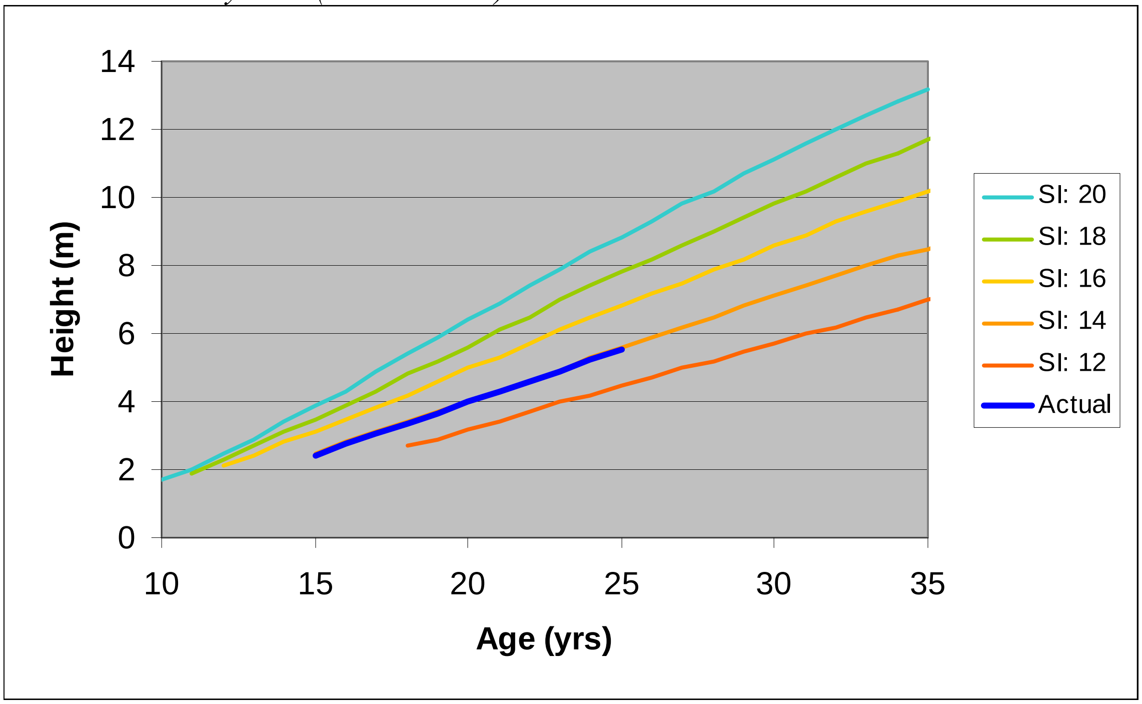


***Figure A.8**: Comparison of TIPSY results to observed height of all trees in the Kelowna study area (PCT: 619 stems/ha, unfertilized)*

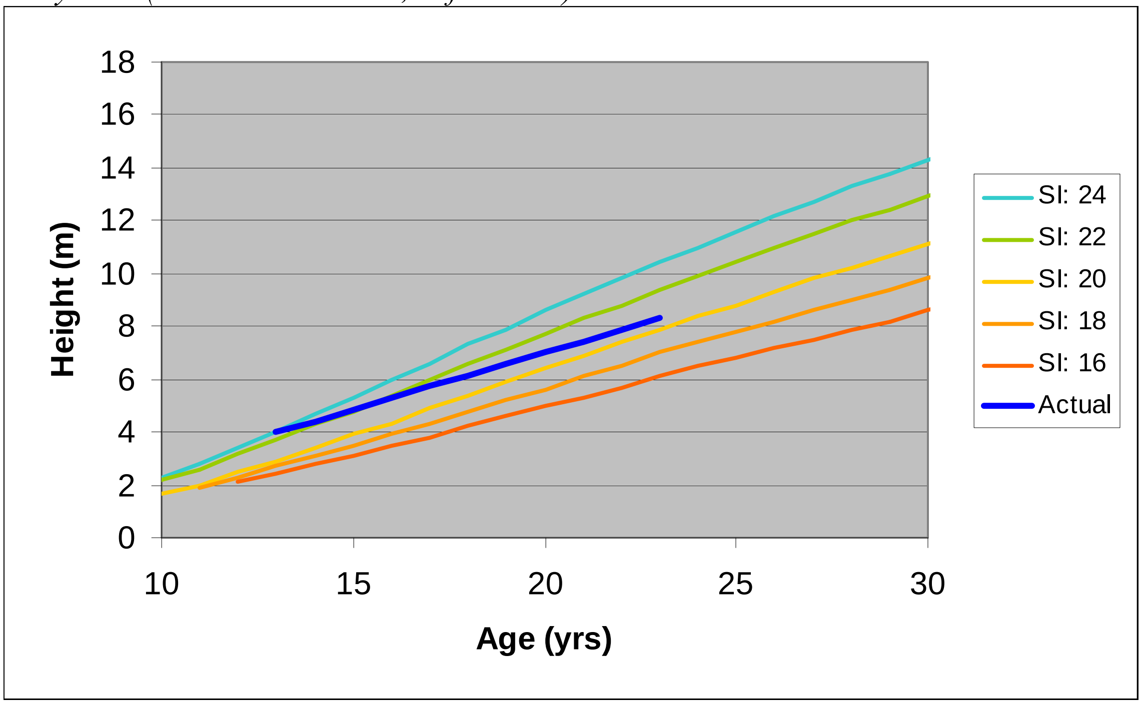


***Figure A.9:** Comparison of TIPSY results to observed height of all trees in the Kelowna study area (PCT: 619 stems/ha, fertilized)*

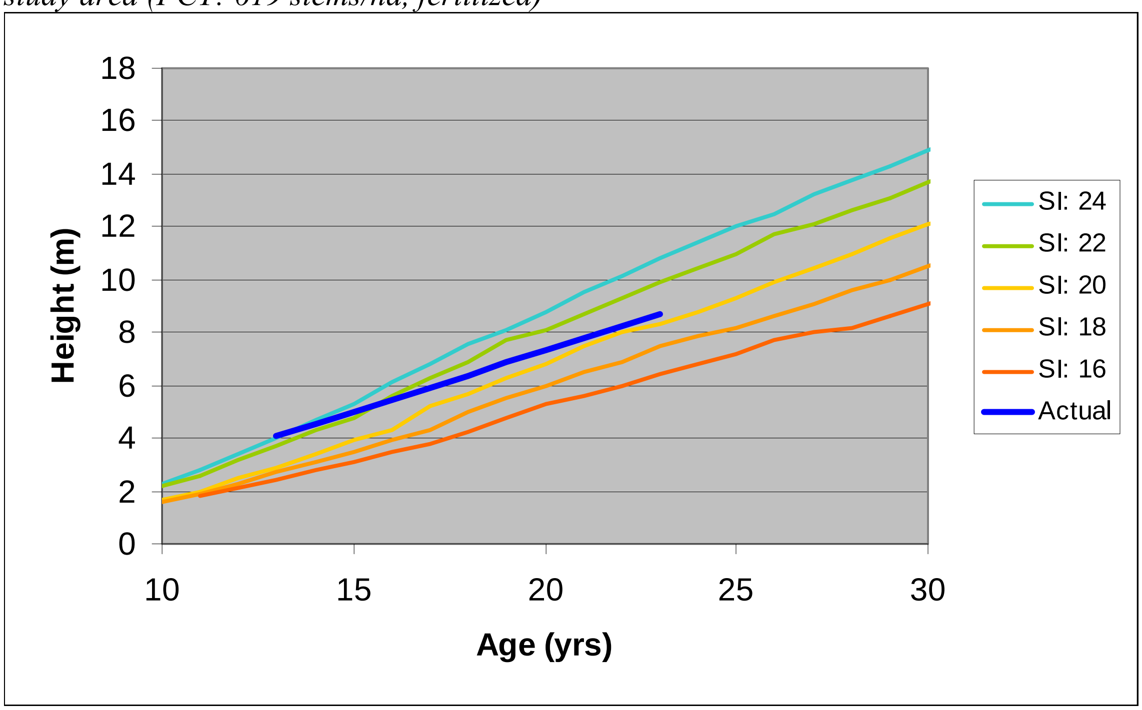


Figure A.10: *Comparison of TIPSY results to observed height of all trees in the Kelowna study area (PCT: 1004 stems/ha, unfertilized)*

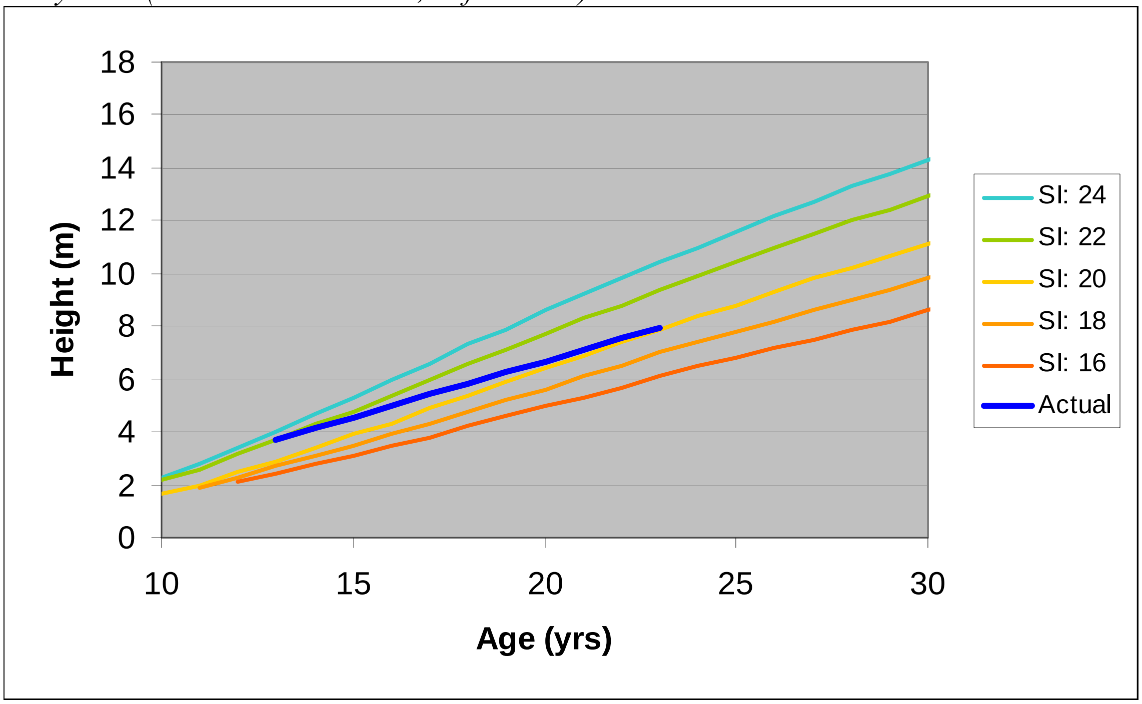


Figure A.11: *Comparison of TIPSY results to observed height of all trees in the Kelowna study area (PCT: 1004 stems/ha, fertilized)*

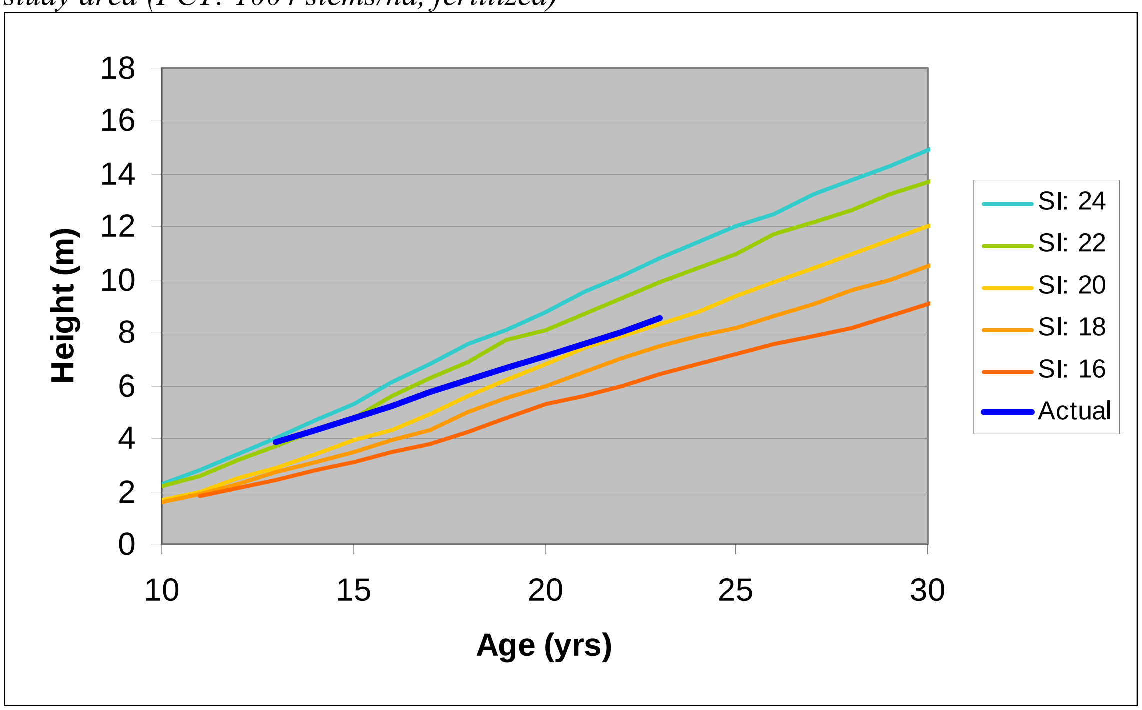


Figure A.12: *Comparison of TIPSY results to observed height of all trees in the Kelowna study area (PCT: 1739 stems/ha, unfertilized)*

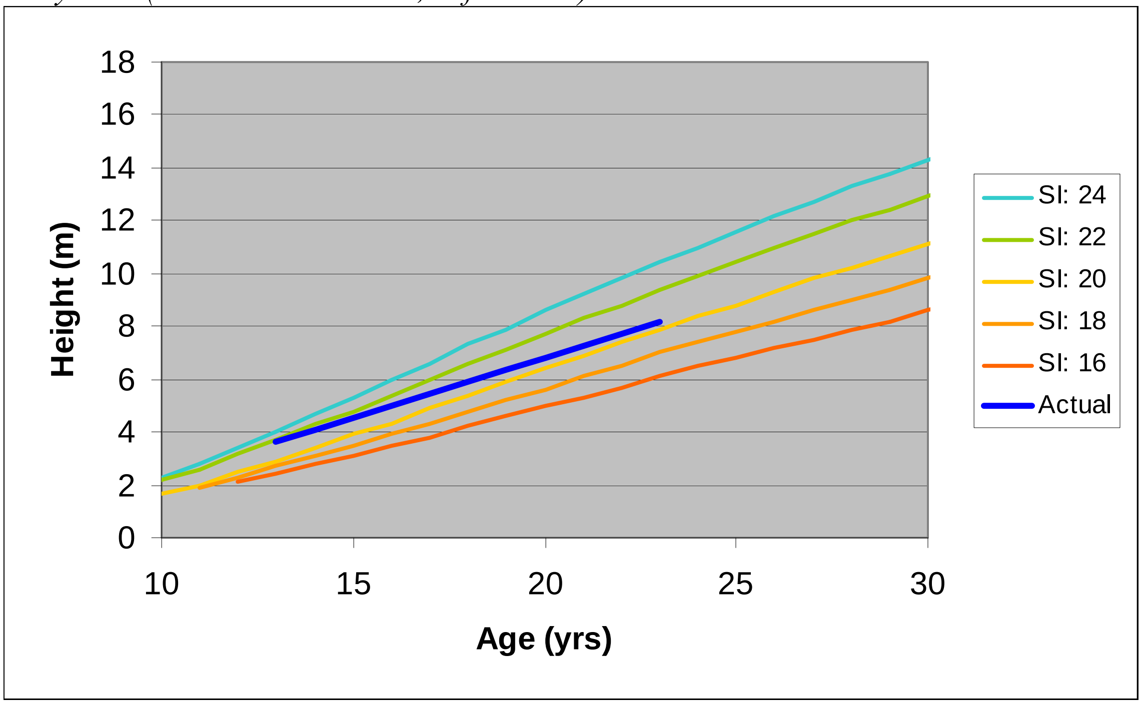


Figure A.13*: Comparison of TIPSY results to observed height of all trees in the Kelowna study area (PCT: 1739 stems/ha, fertilized)*

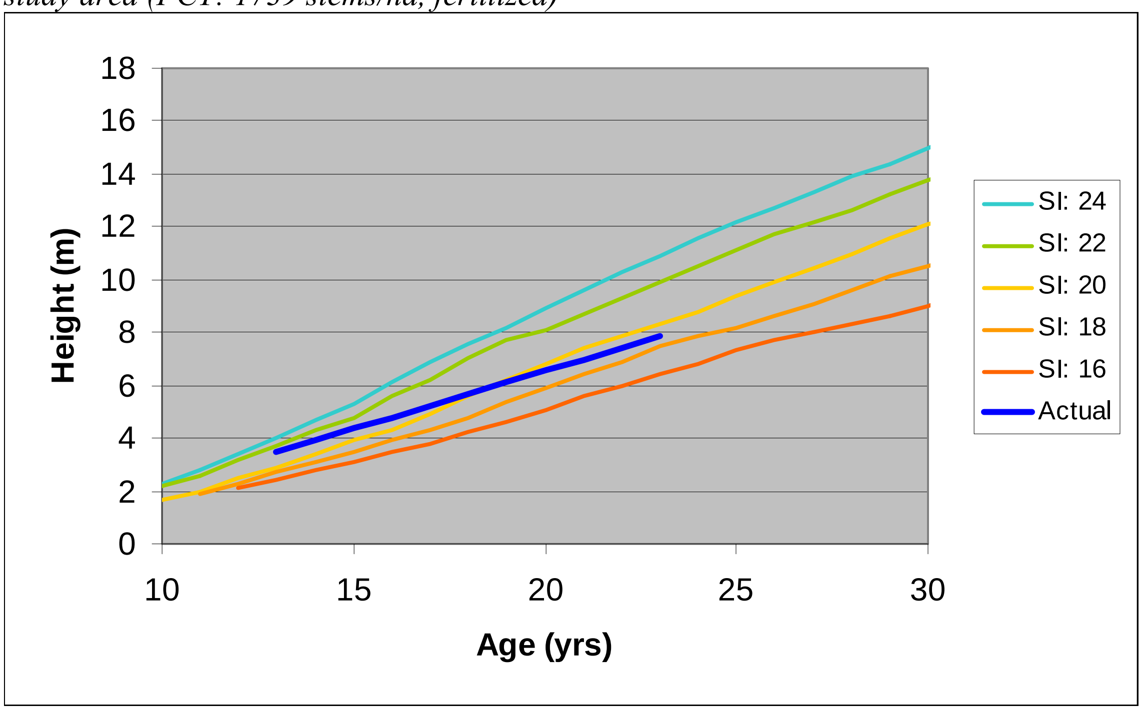


Figure A.14: *Comparison of TIPSY results to observed height of all trees in the Kelowna study area (PCT: control)*

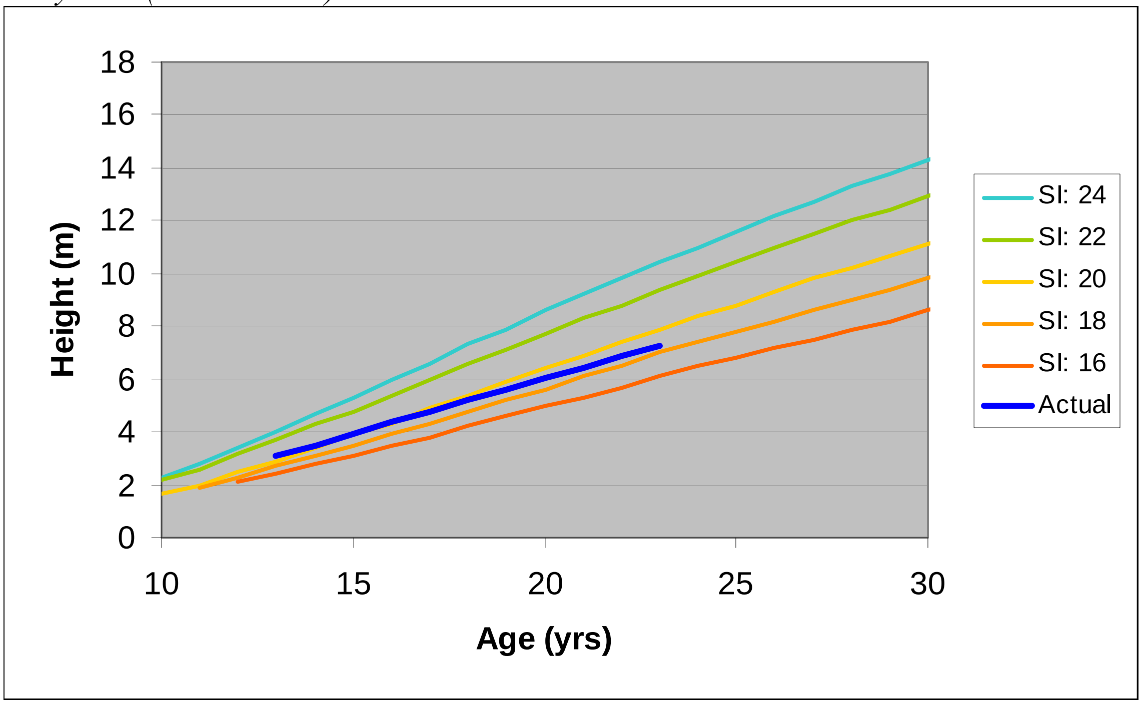


Figure A.15: *Comparison of TIPSY results to observed height of all trees in the Cariboo study area (PCT: 470 stems/ha, unfertilized)*

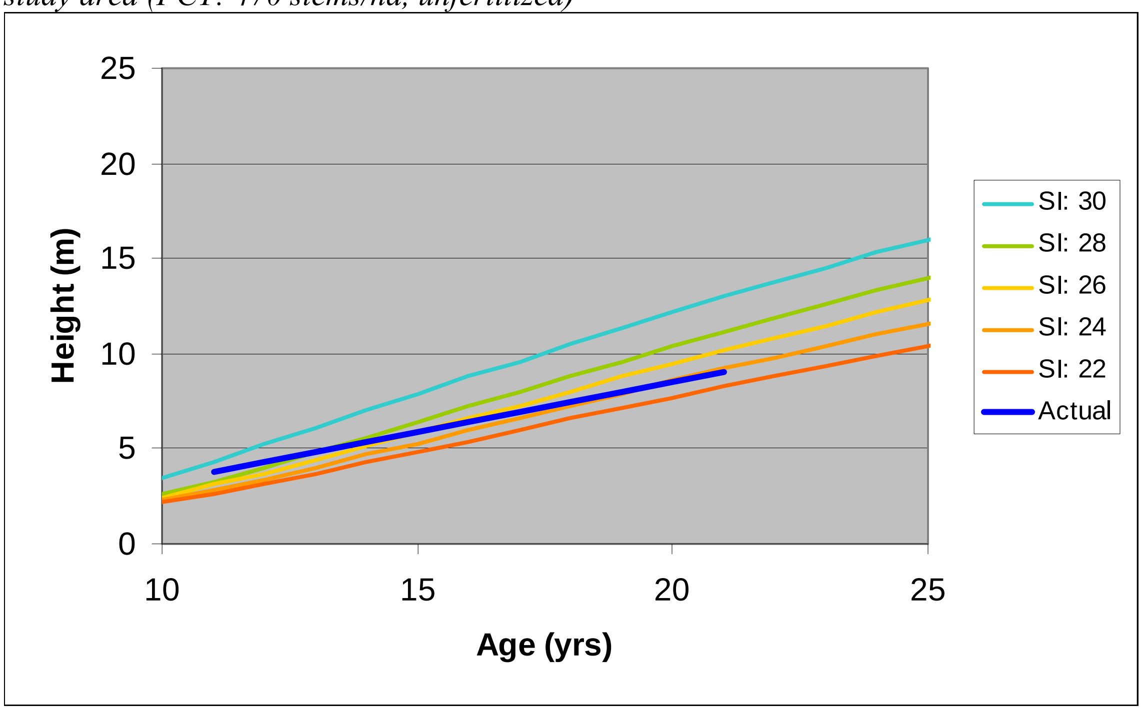


***Figure A.16**: Comparison of TIPSY results to observed height of all trees in the Cariboo study area (PCT: 470 stems/ha, fertilized)*

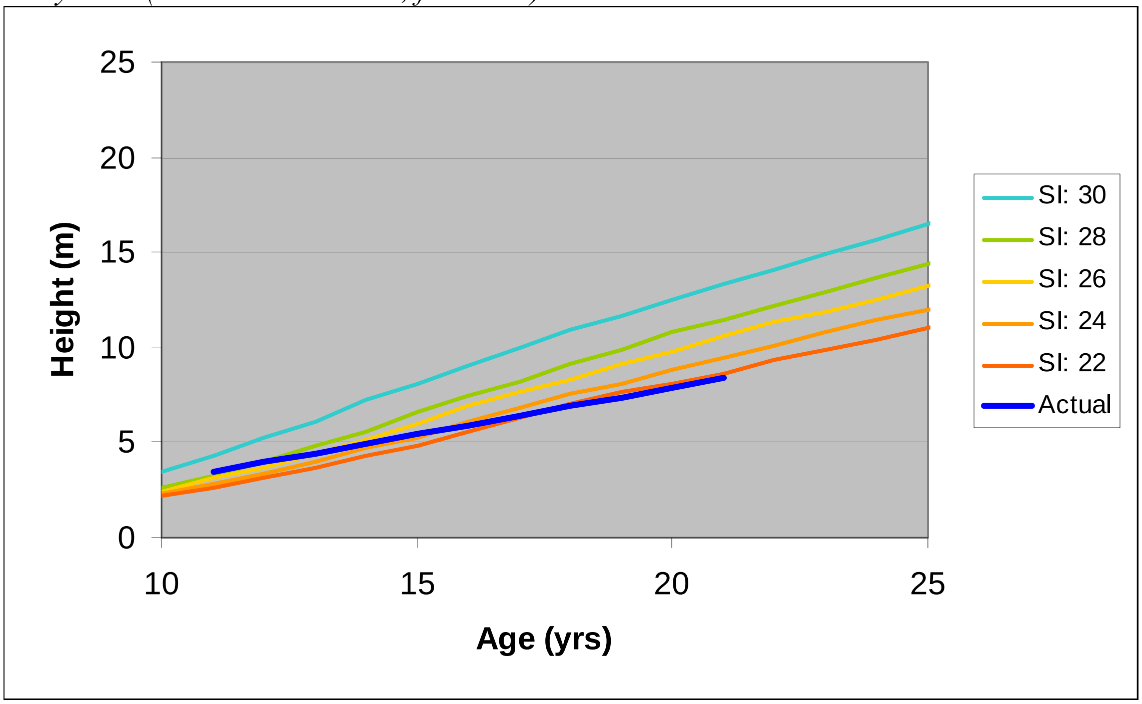


***Figure A.17:** Comparison of TIPSY results to observed height of all trees in the Cariboo study area (PCT: 980 stems/ha, unfertilized)*

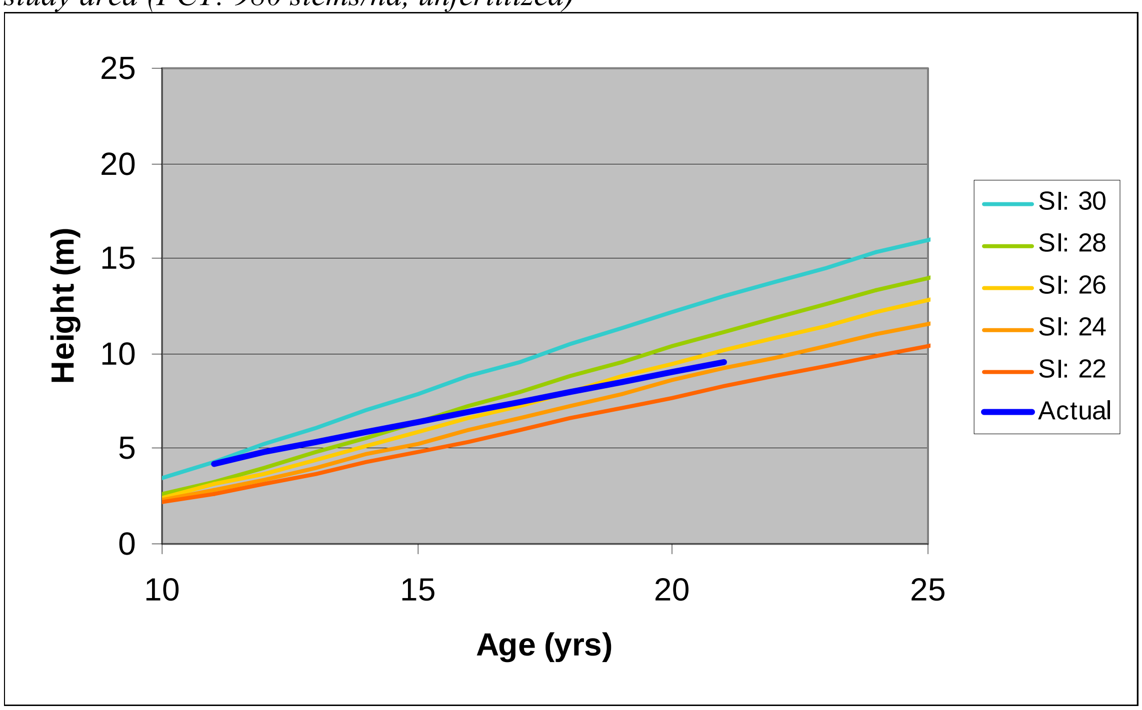


Figure A.18: *Comparison of TIPSY results to observed height of all trees in the Cariboo study area (PCT: 980 stems/ha, fertilized)*

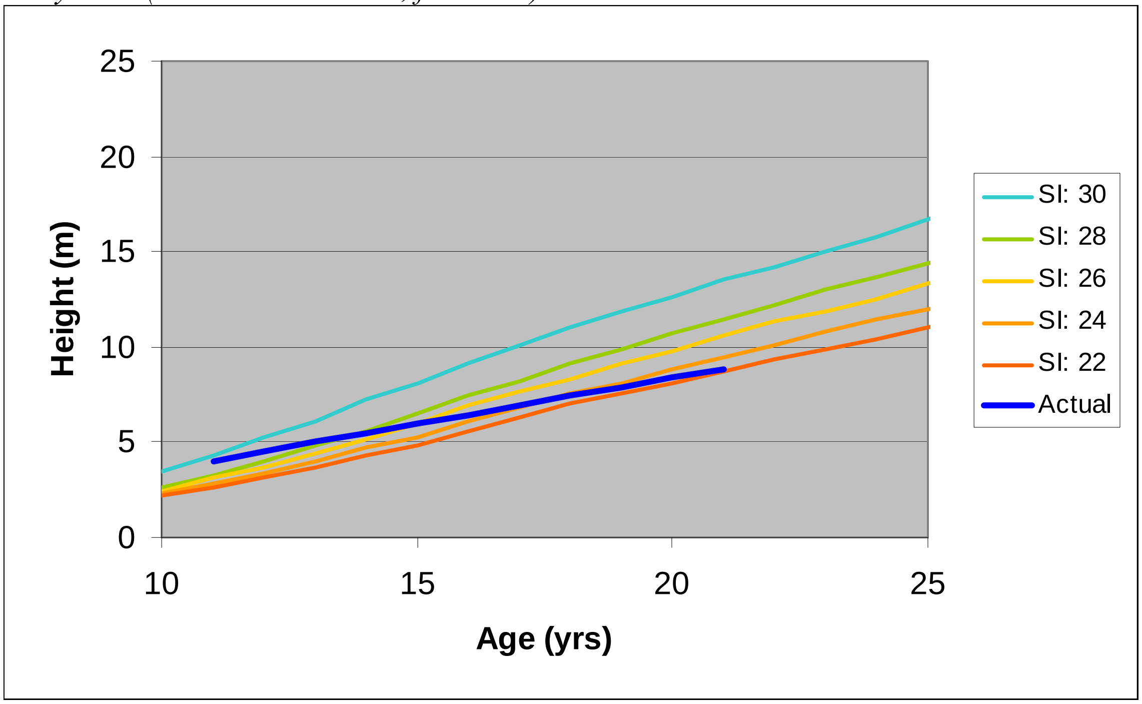


Figure A.19: *Comparison of TIPSY results to observed height of all trees in the Cariboo study area (PCT: 1240 stems/ha, unfertilized)*

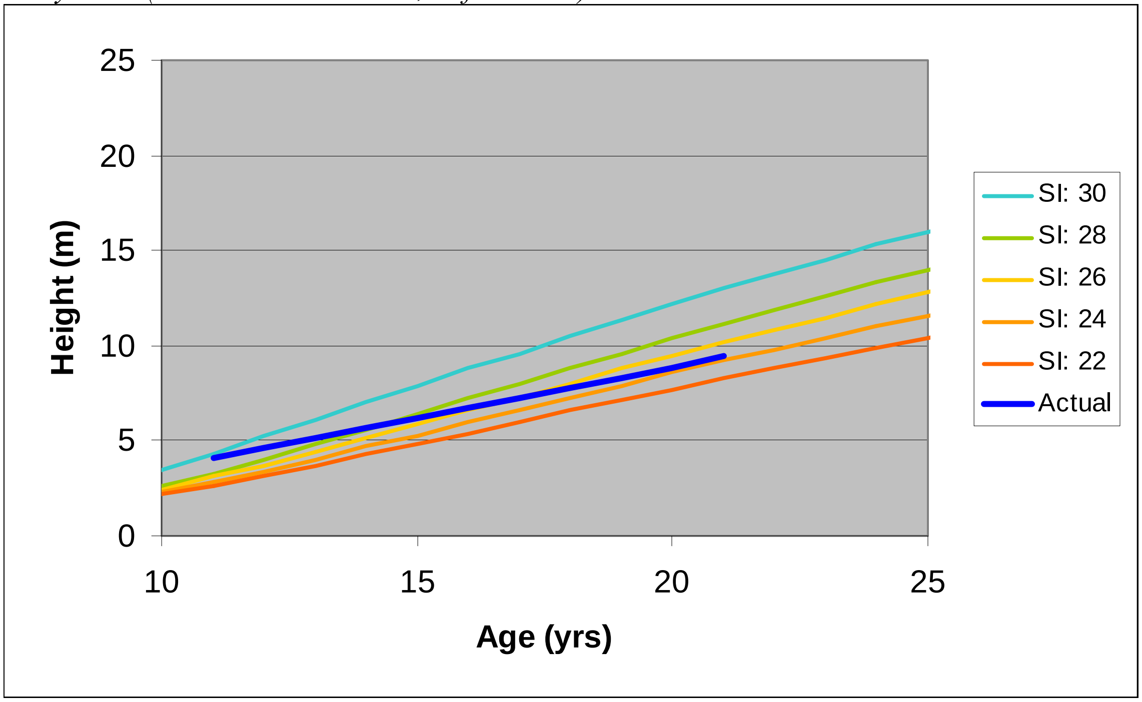


Figure A.20: *Comparison of TIPSY results to observed height of all trees in the Cariboo study area (PCT: 1240 stems/ha, fertilized)*

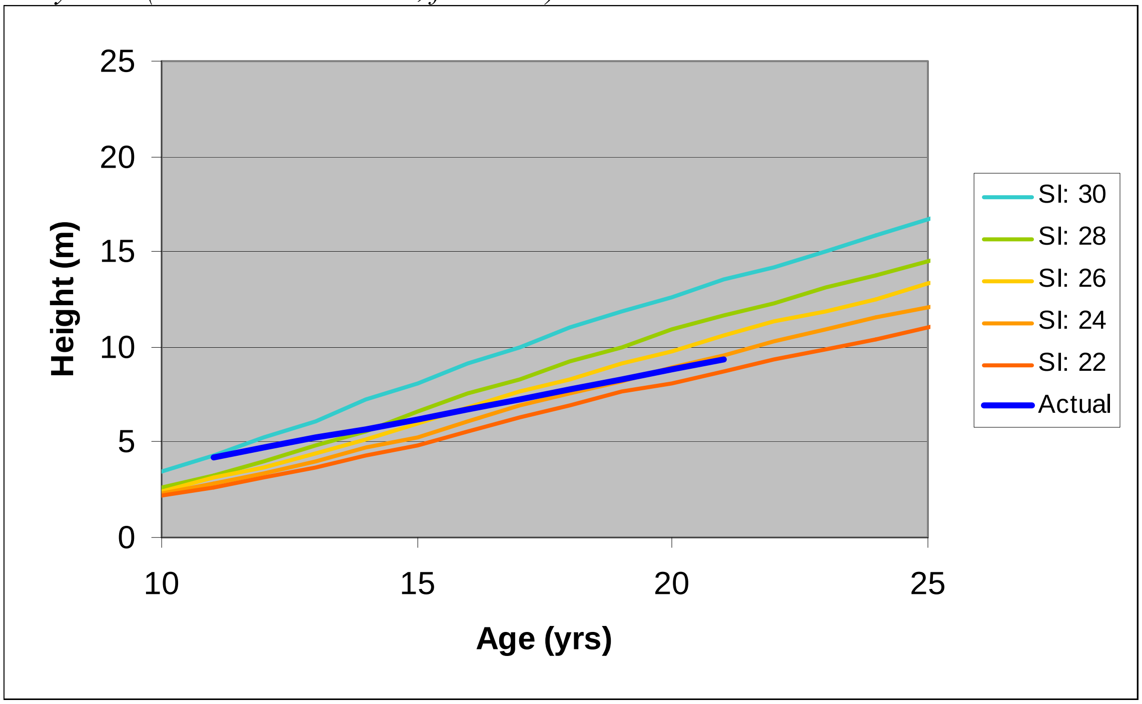


Figure A.21: *Comparison of TIPSY results to observed height of all trees in the Cariboo study area (PCT: control)*

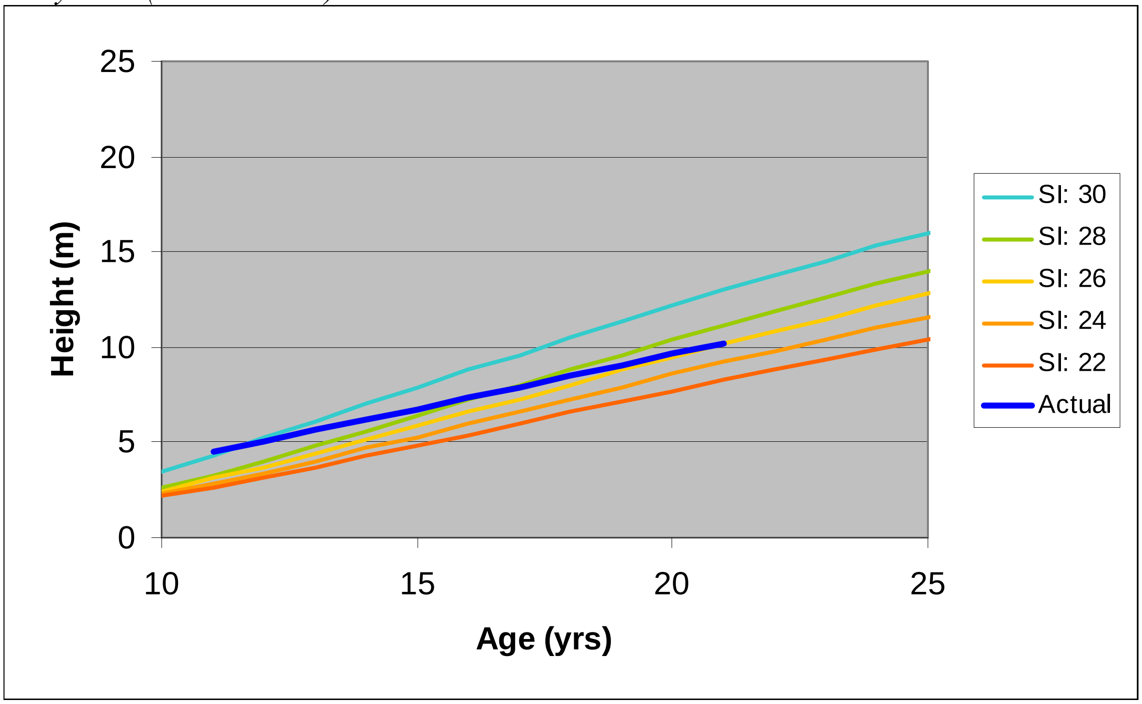


Figure A.22: *Comparison of TIPSY results to observed DBH of all trees in the Summerland study area (PCT: 511 stems/ha, unfertilized)*

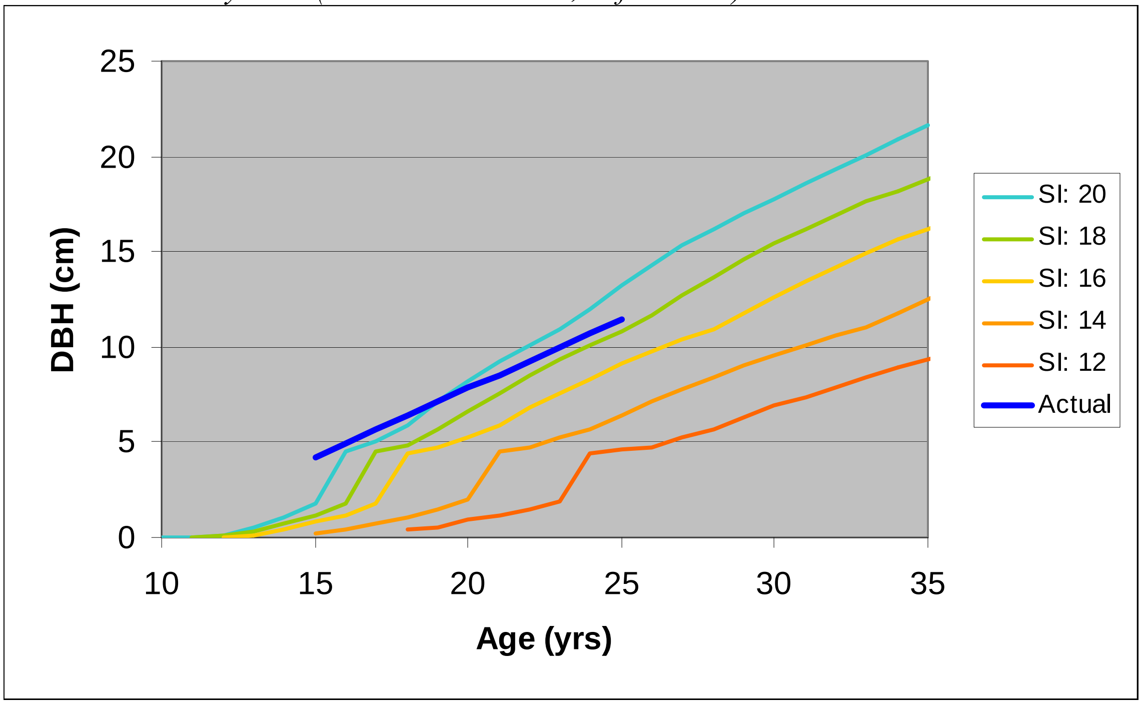


Figure A.23: *Comparison of TIPSY results to observed DBH of all trees in the Summerland study area (PCT: 511 stems/ha, fertilized)*

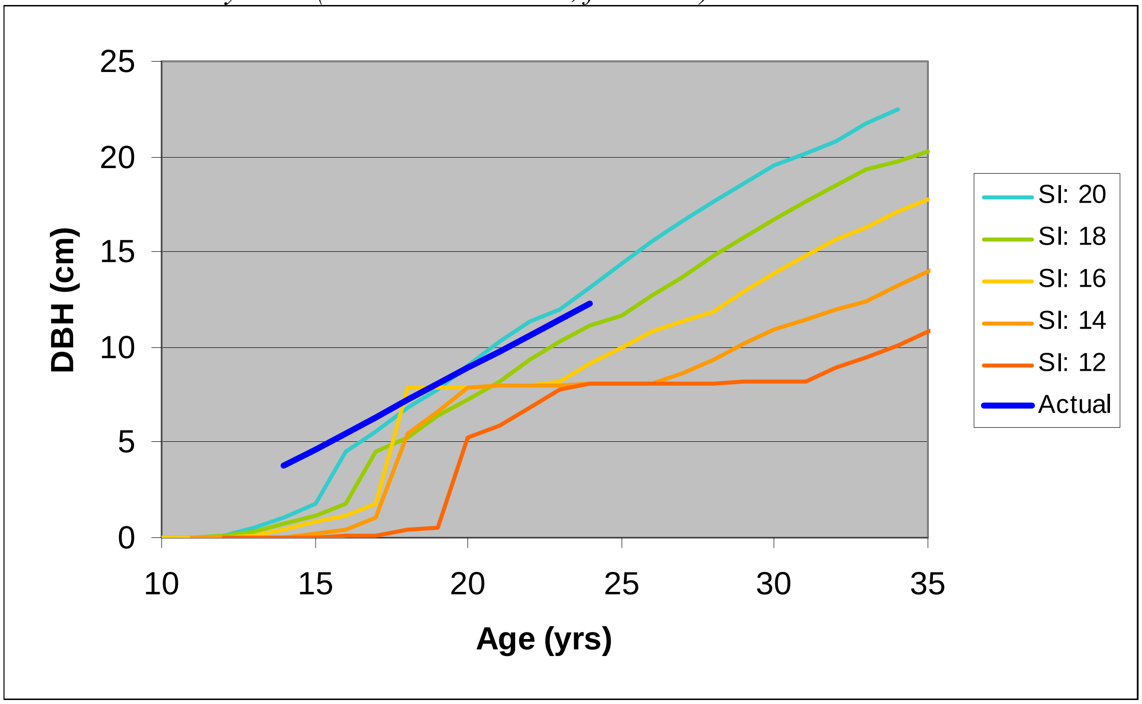


Figure A.24: *Comparison of TIPSY results to observed DBH of all trees in the Summerland study area (PCT: 936 stems/ha, unfertilized)*

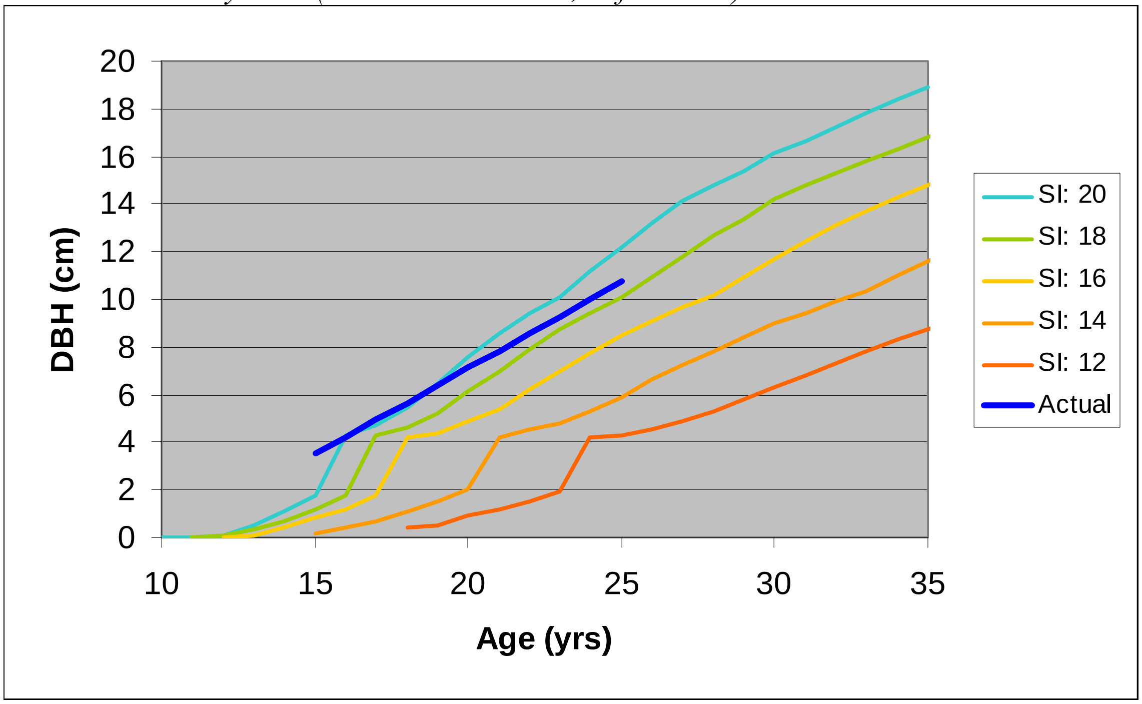


Figure A.25*: Comparison of TIPSY results to observed DBH of all trees in the Summerland study area (PCT: 936 stems/ha, fertilized)*

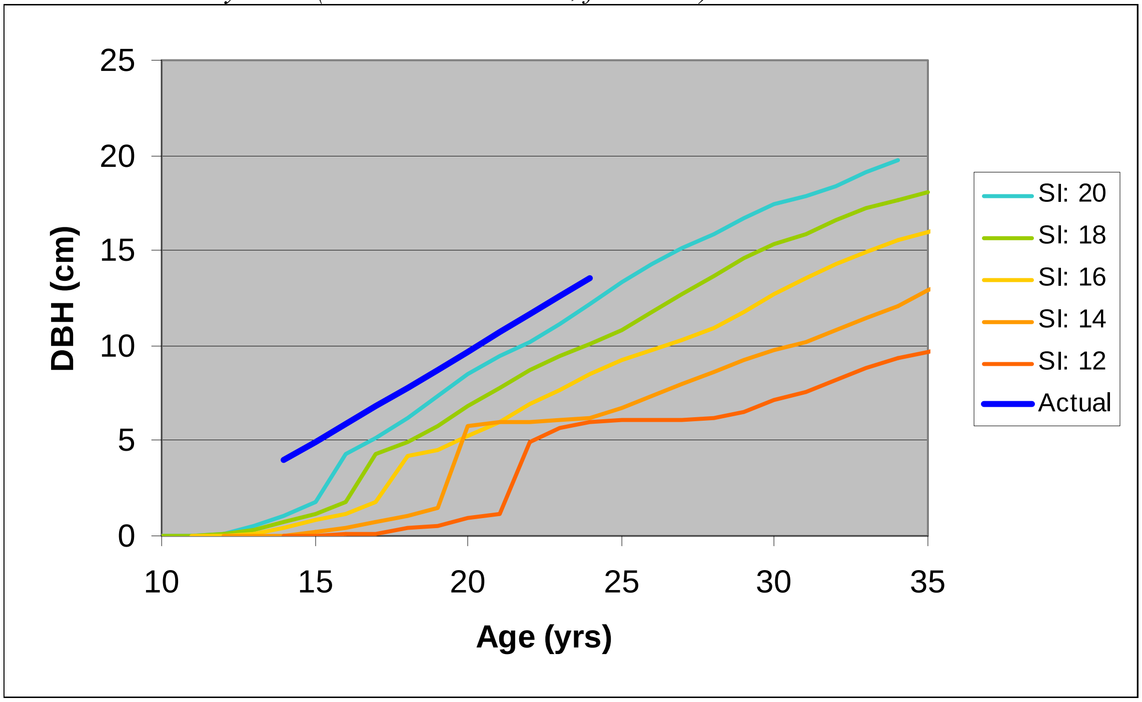


Figure A.26: *Comparison of TIPSY results to observed DBH of all trees in the Summerland study area (PCT: 1774 stems/ha, unfertilized)*

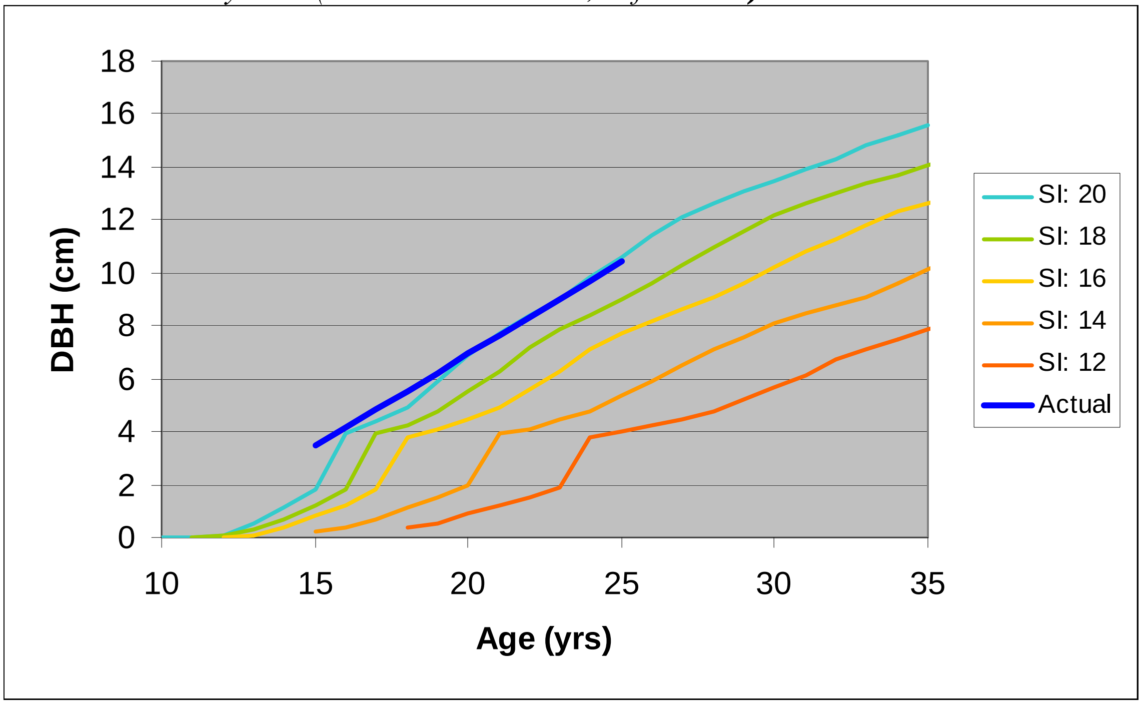


Figure A.27*: Comparison of TIPSY results to observed DBH of all trees in the Summerland study area (PCT: 1774 stems/ha, fertilized)*

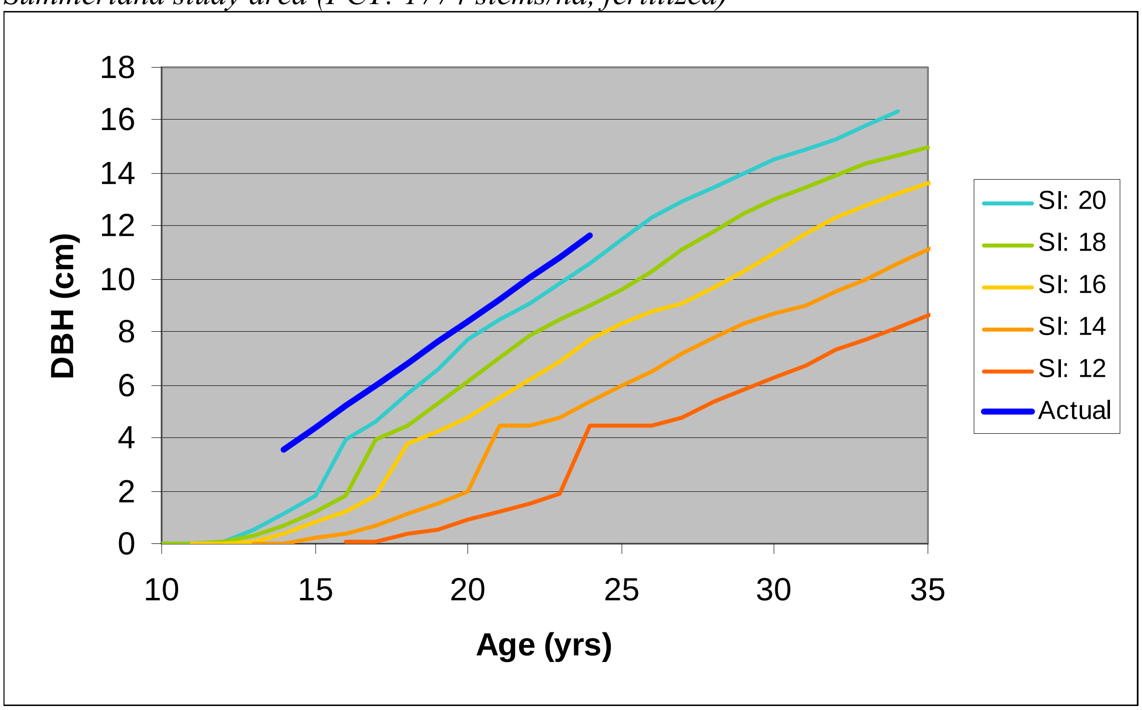


Figure A.28: *Comparison of TIPSY results to observed DBH of all trees in the Summerland study area (PCT: control)*

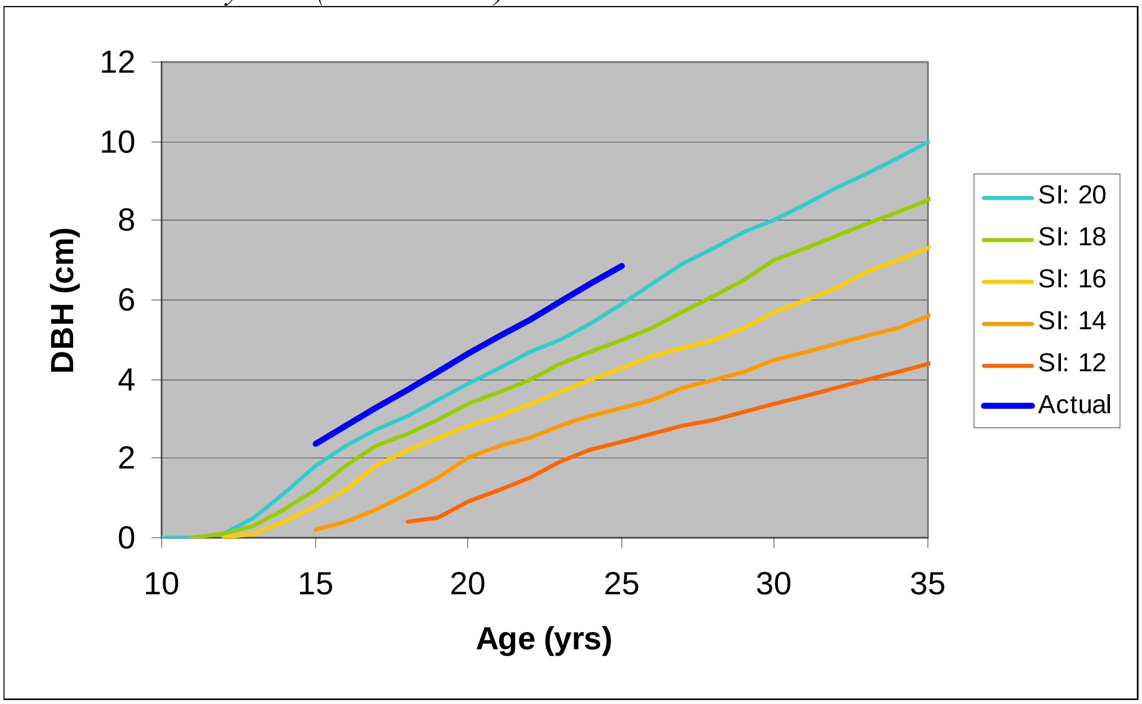


Figure A.29*: Comparison of TIPSY results to observed DBH of all trees in the Kelowna study area (PCT: 619 stems/ha, unfertilized)*

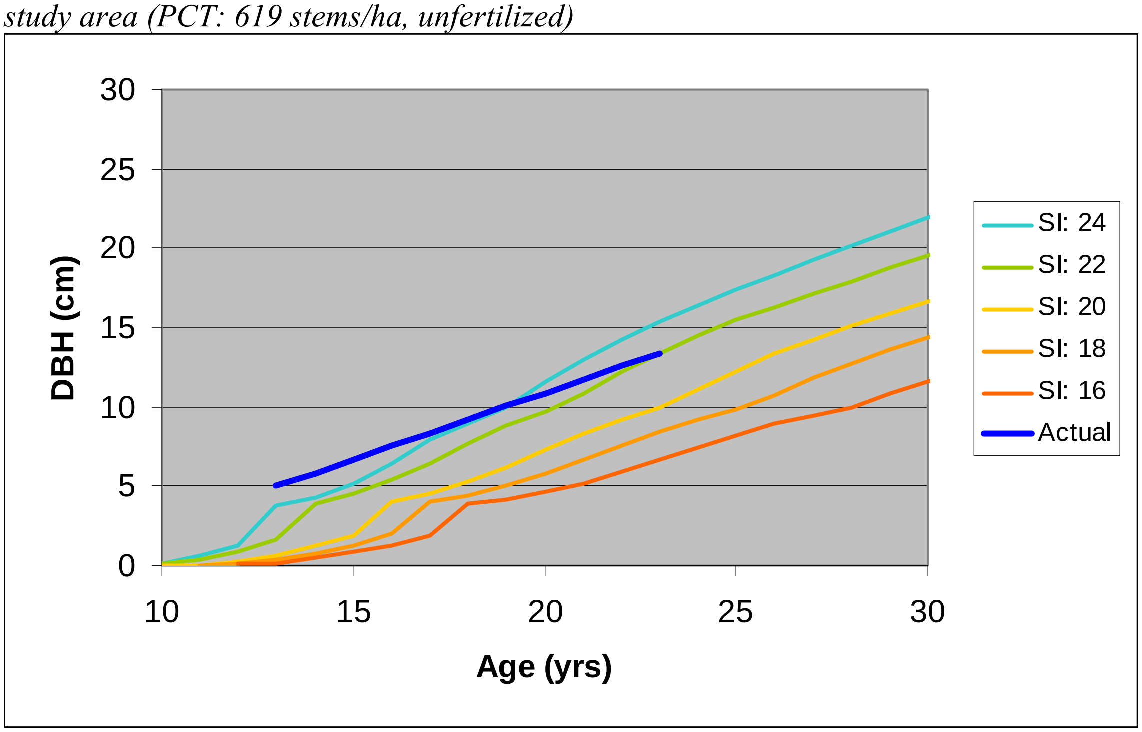


Figure A.30: *Comparison of TIPSY results to observed DBH of all trees in the Kelowna study area (PCT: 619 stems/ha, fertilized)*

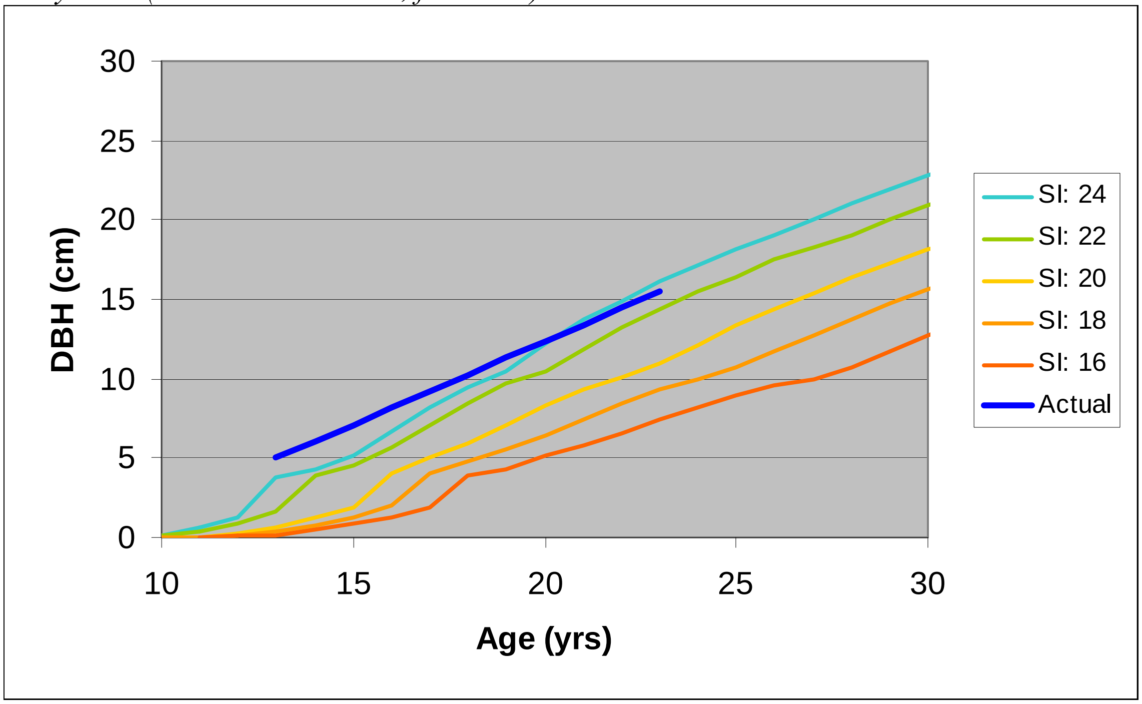


Figure A.31: *Comparison of TIPSY results to observed DBH of all trees in the Kelowna study area (PCT: 1004 stems/ha, unfertilized)*

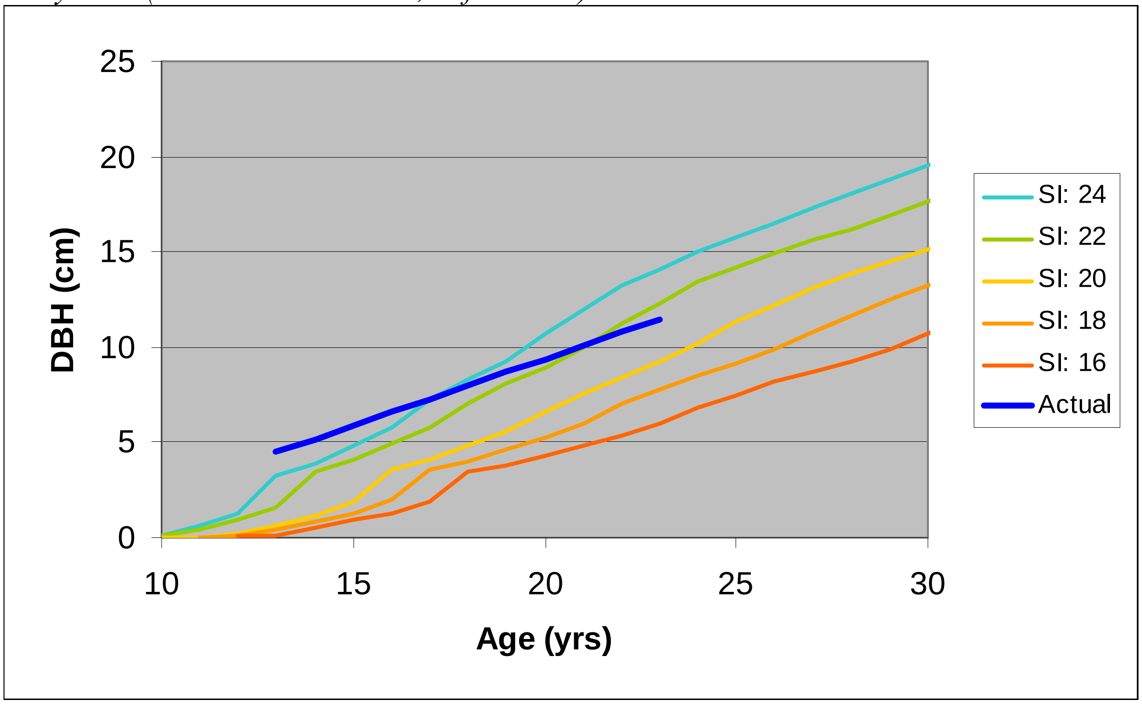


Figure A.32*: Comparison of TIPSY results to observed DBH of all trees in the Kelowna study area (PCT: 1004 stems/ha, fertilized)*

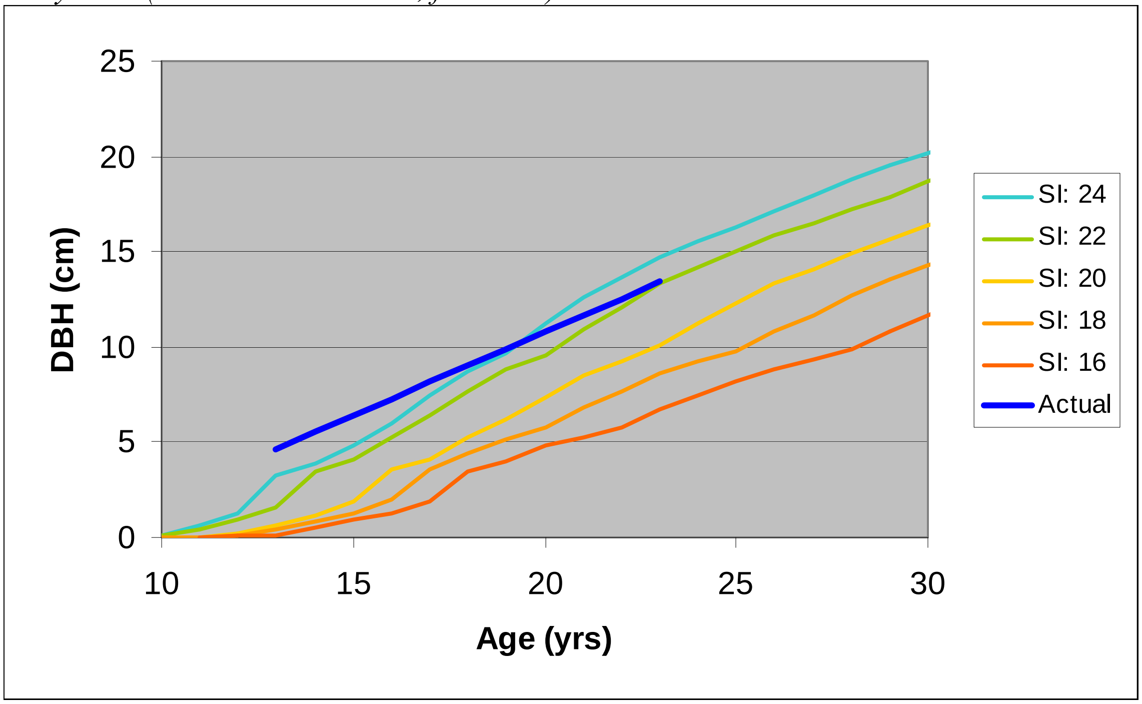


Figure A.33: *Comparison of TIPSY results to observed DBH of all trees in the Kelowna study area (PCT: 1739 stems/ha, unfertilized)*

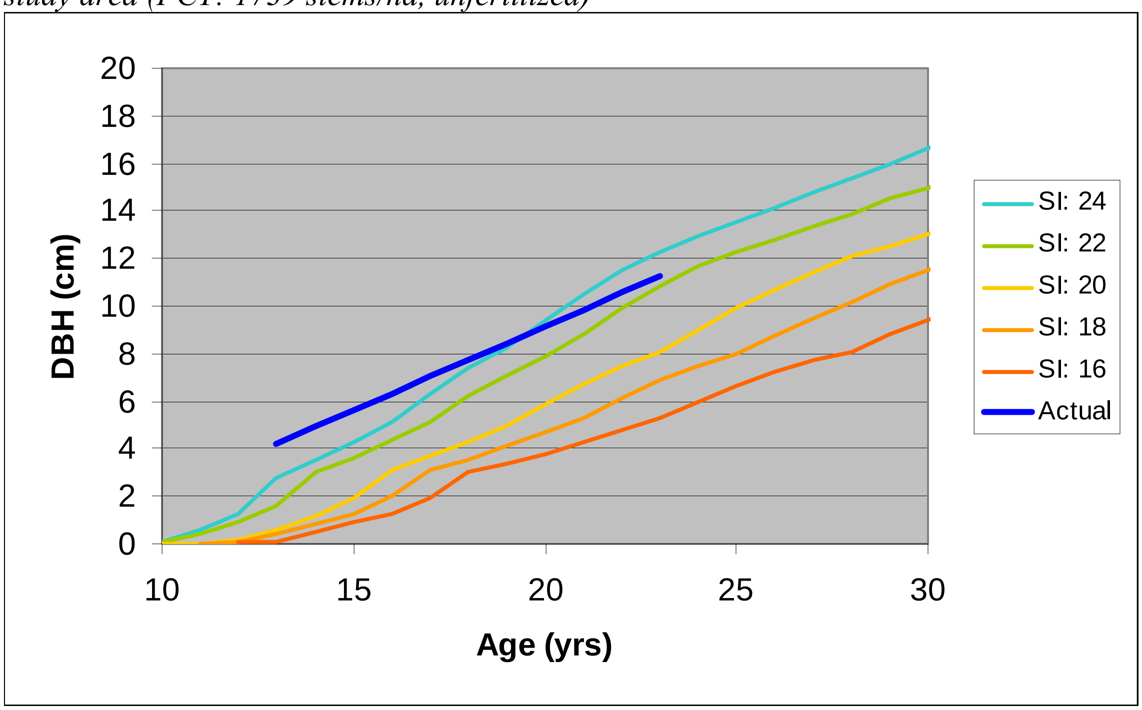


Figure A.34: *Comparison of TIPSY results to observed DBH of all trees in the Kelowna study area (PCT: 1739 stems/ha, fertilized)*

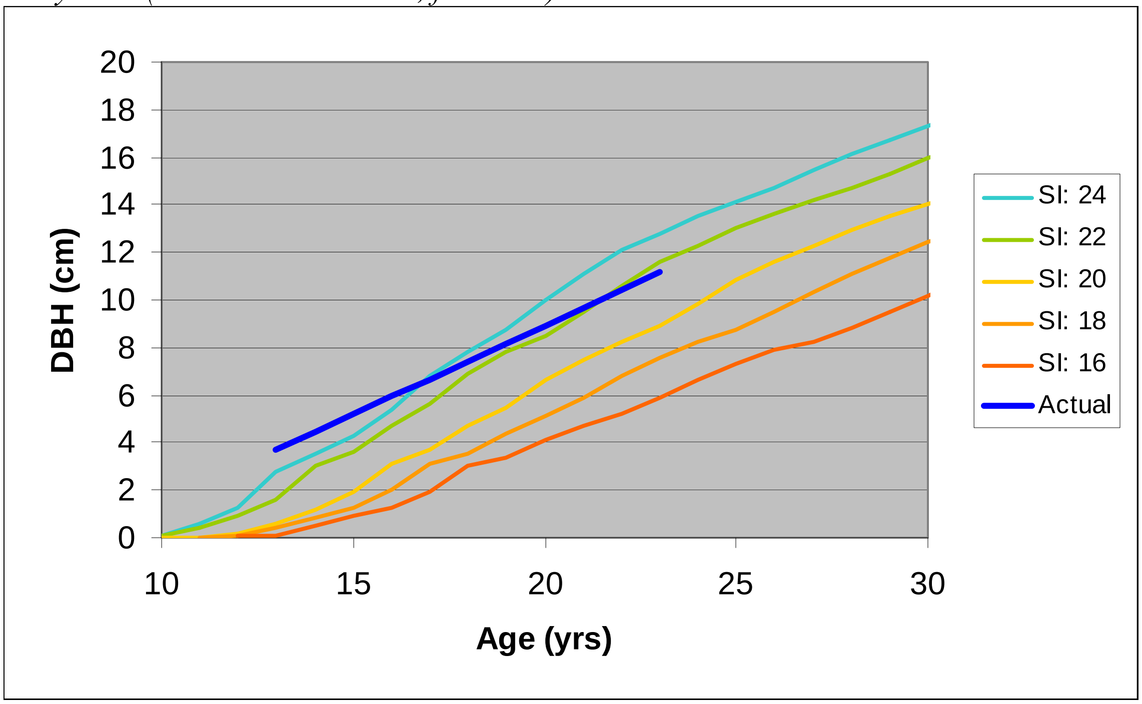


Figure A.35: *Comparison of TIPSY results to observed DBH of all trees in the Kelowna study area (PCT: control)*

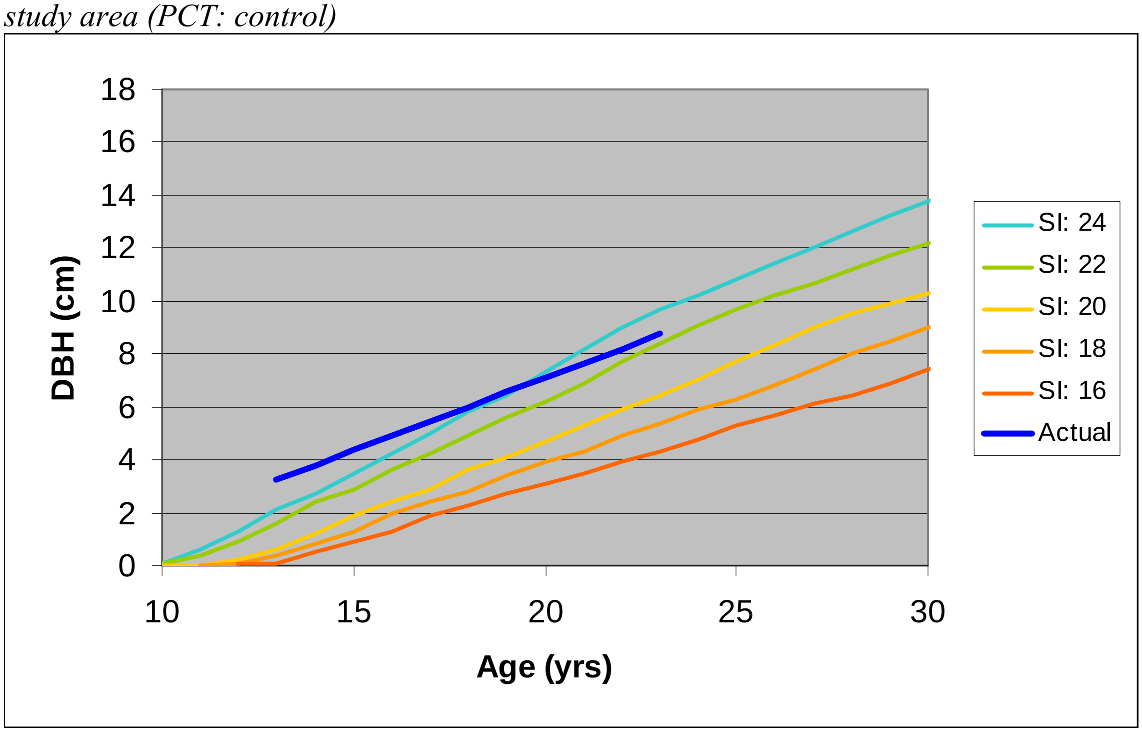


Figure A.36: *Comparison of TIPSY results to observed DBH of all trees in the Cariboo study area (PCT: 470 stems/ha, unfertilized)*

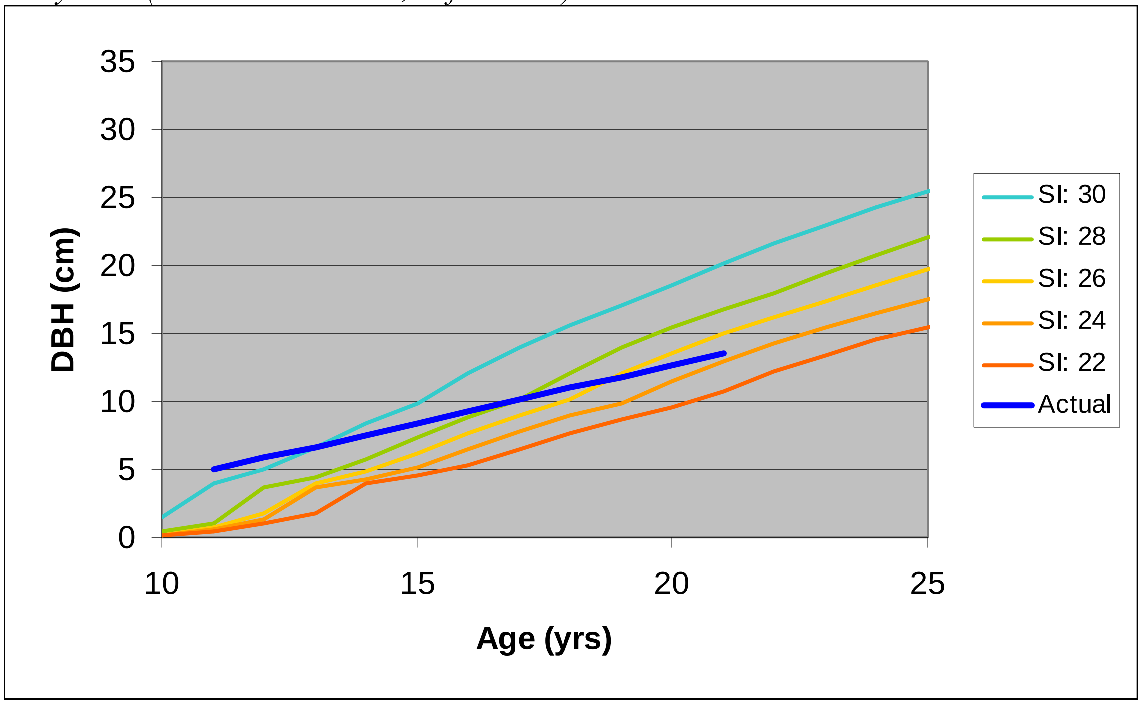


Figure A.37: *Comparison of TIPSY results to observed DBH of all trees in the Cariboo study area (PCT: 470 stems/ha, fertilized)*

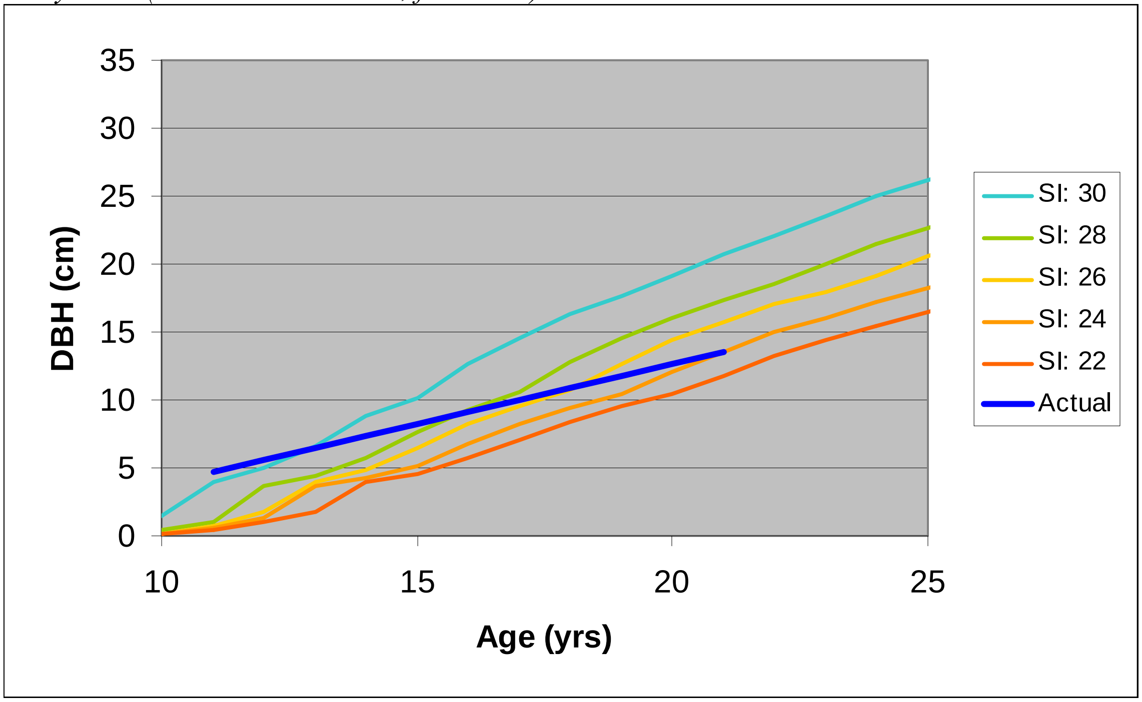


Figure A.38: *Comparison of TIPSY results to observed DBH of all trees in the Cariboo study area (PCT: 980 stems/ha, unfertilized)*

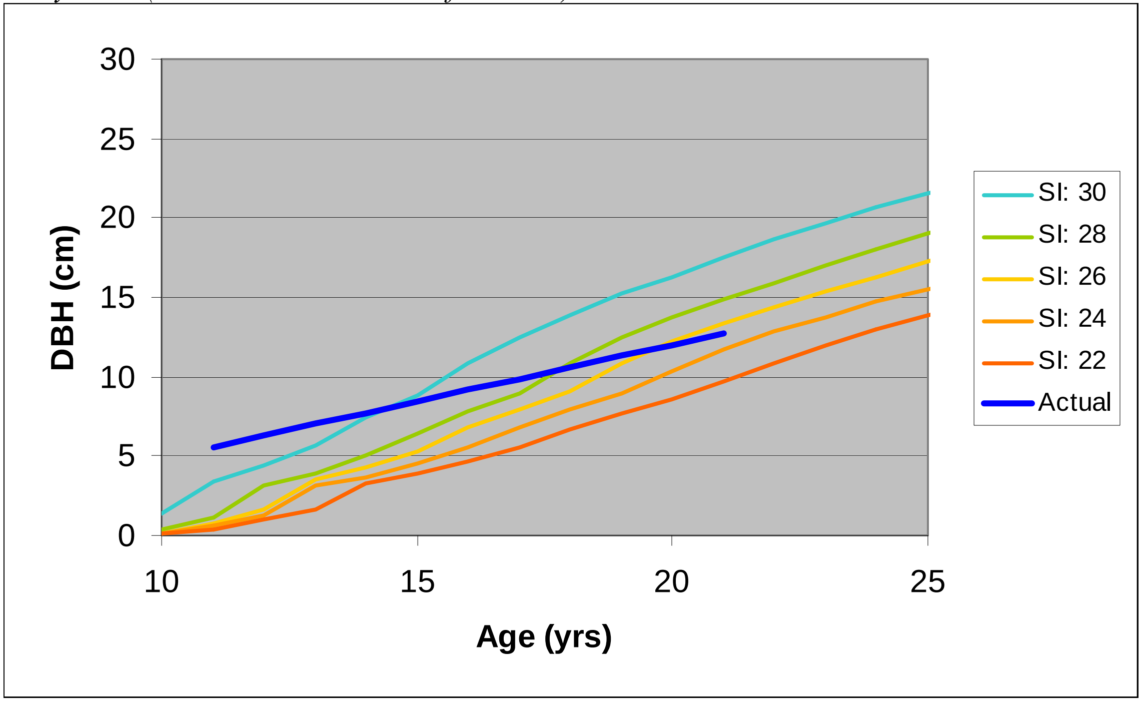


Figure A.39: *Comparison of TIPSY results to observed DBH of all trees in the Cariboo study area (PCT: 980 stems/ha, fertilized)*

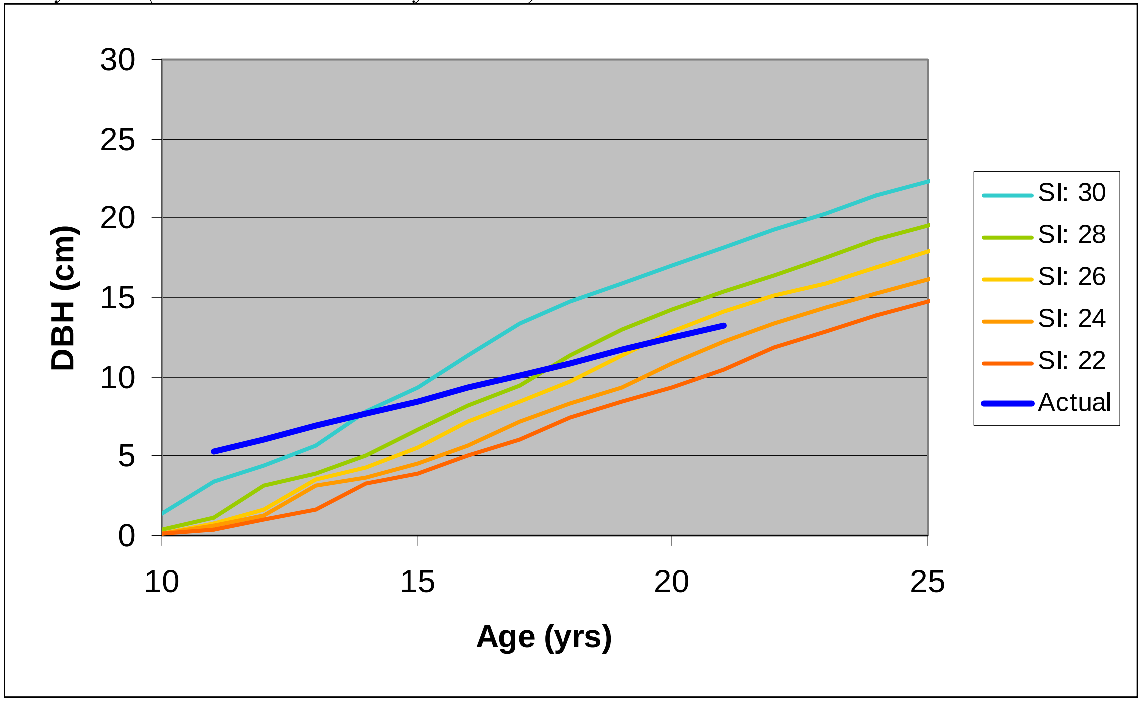


Figure A.40: *Comparison of TIPSY results to observed DBH of all trees in the Cariboo study area (PCT: 1240 stems/ha, unfertilized)*

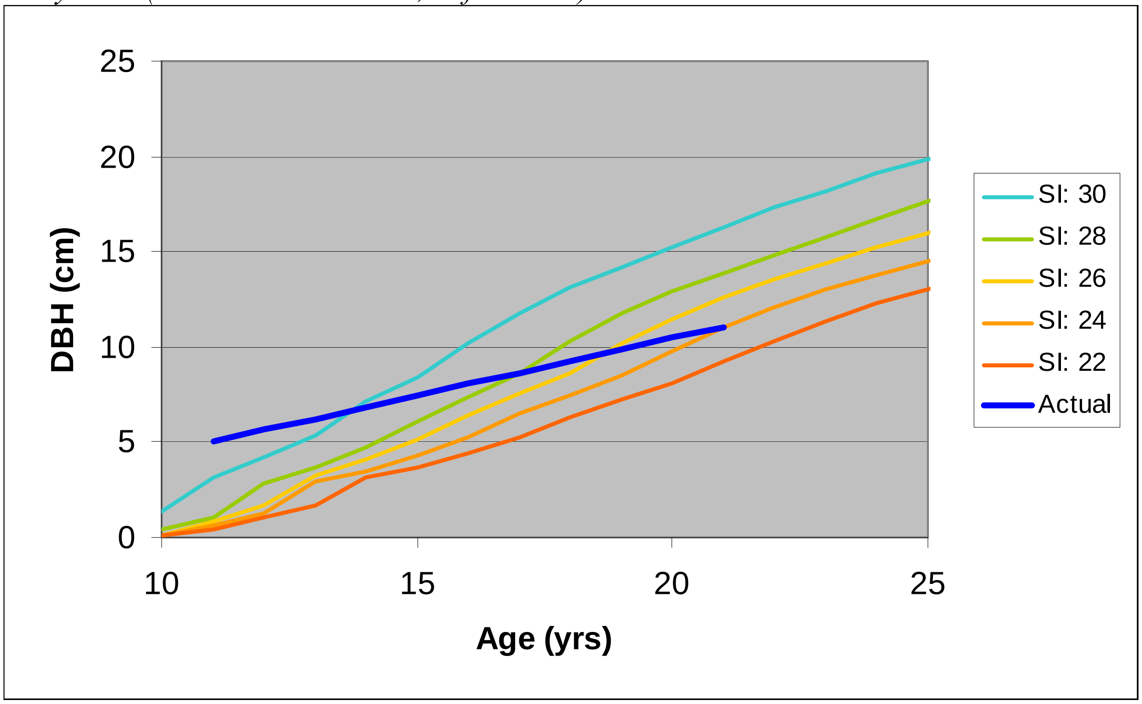


Figure A.41: *Comparison of TIPSY results to observed DBH of all trees in the Cariboo study area (PCT: 1240 stems/ha, fertilized)*

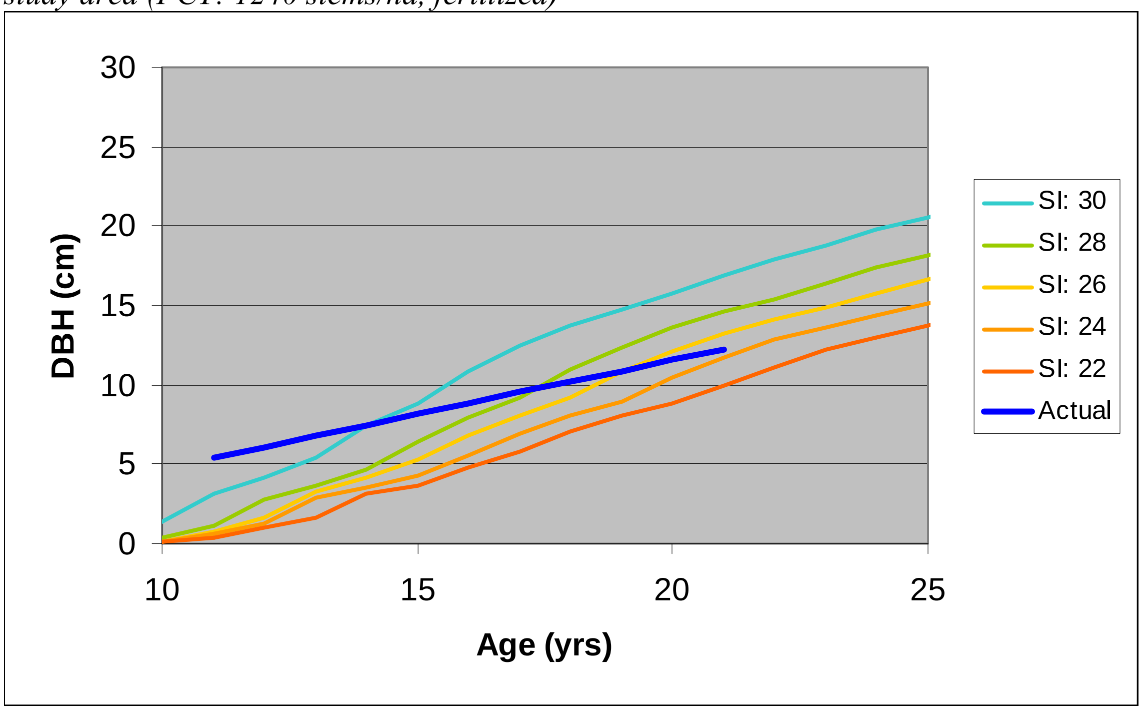


Figure A.42: *Comparison of TIPSY results to observed DBH of all trees in the Cariboo study area (PCT: control)*

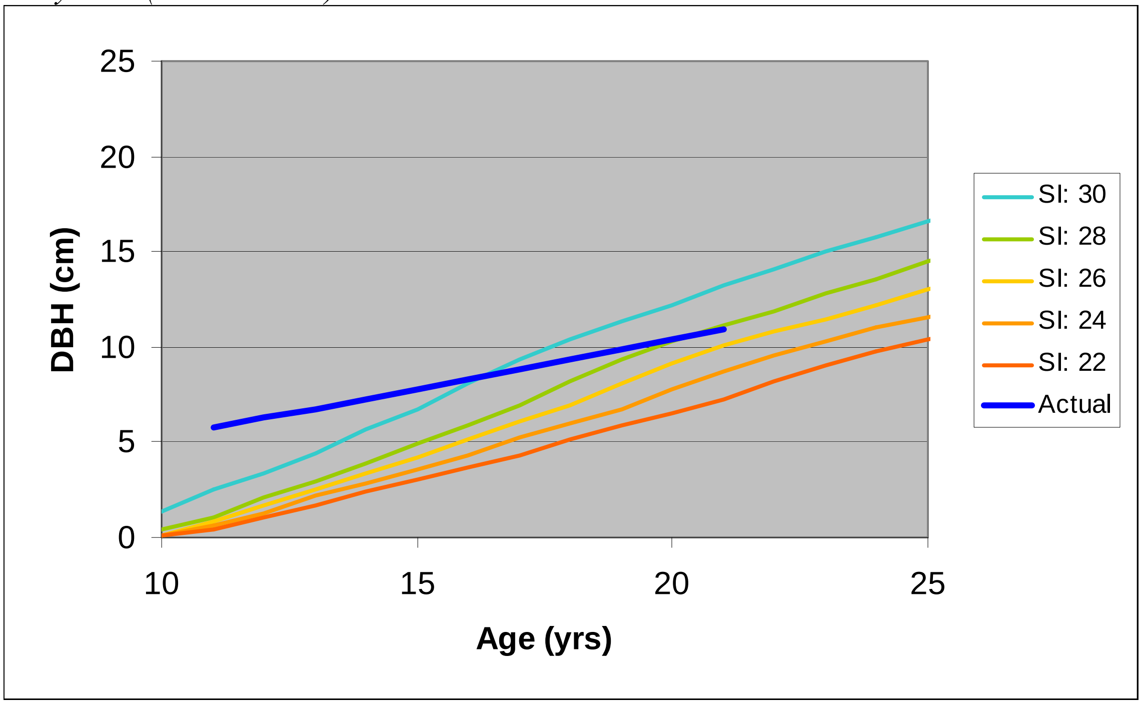


Figure A.43*: Comparison of TIPSY results to observed height of crop trees in the Summerland study area (PCT: 511 stems/ha, unfertilized)*

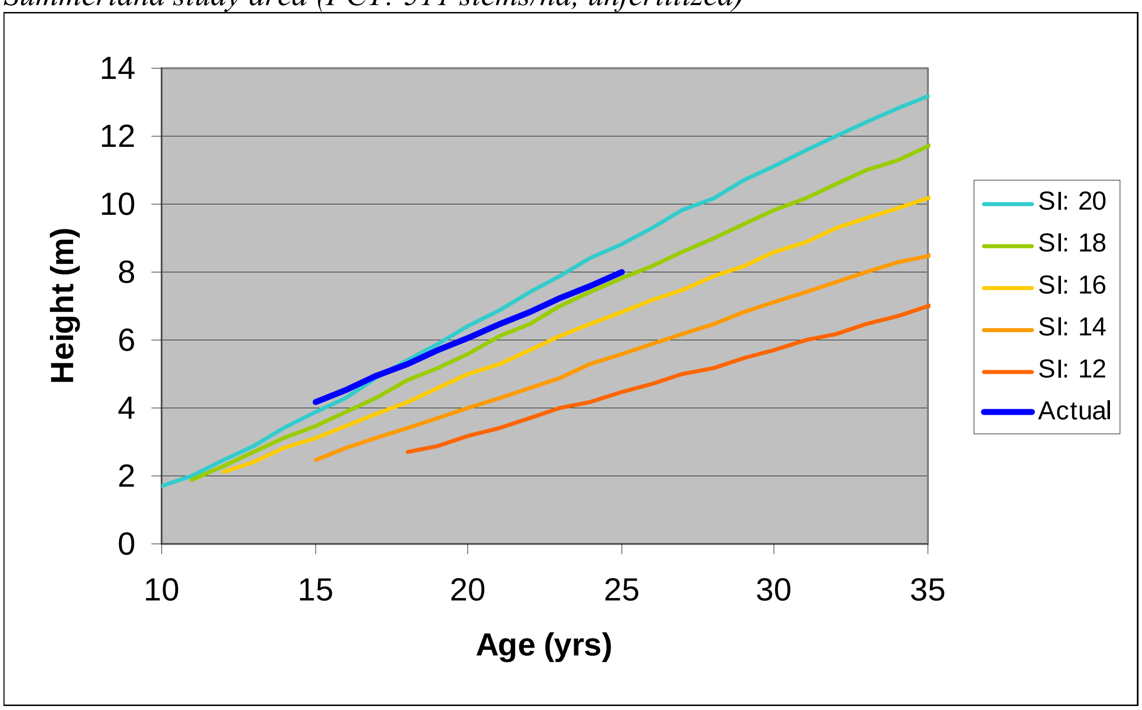


Figure A.44: *Comparison of TIPSY results to observed height of crop trees in the Summerland study area (PCT: 511 stems/ha, fertilized)*

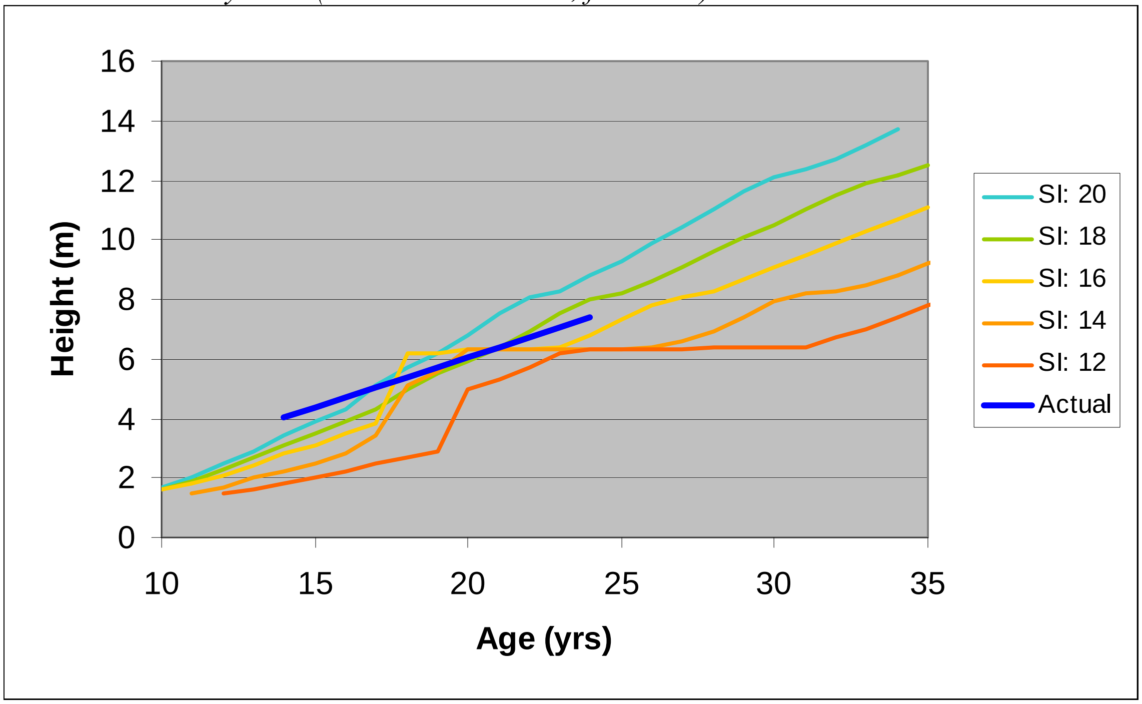


Figure A.45*: Comparison of TIPSY results to observed height of crop trees in the Summerland study area (PCT: 936 stems/ha, unfertilized)*

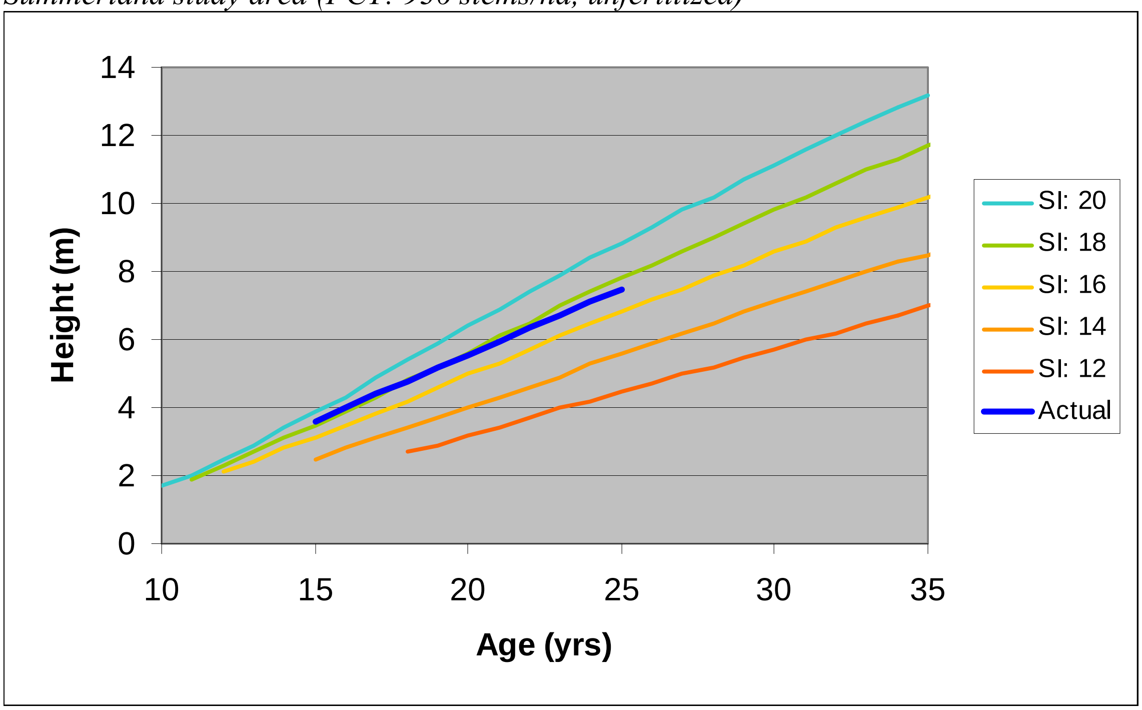


Figure A.46: *Comparison of TIPSY results to observed height of crop trees in the Summerland study area (PCT: 936 stems/ha, fertilized)*

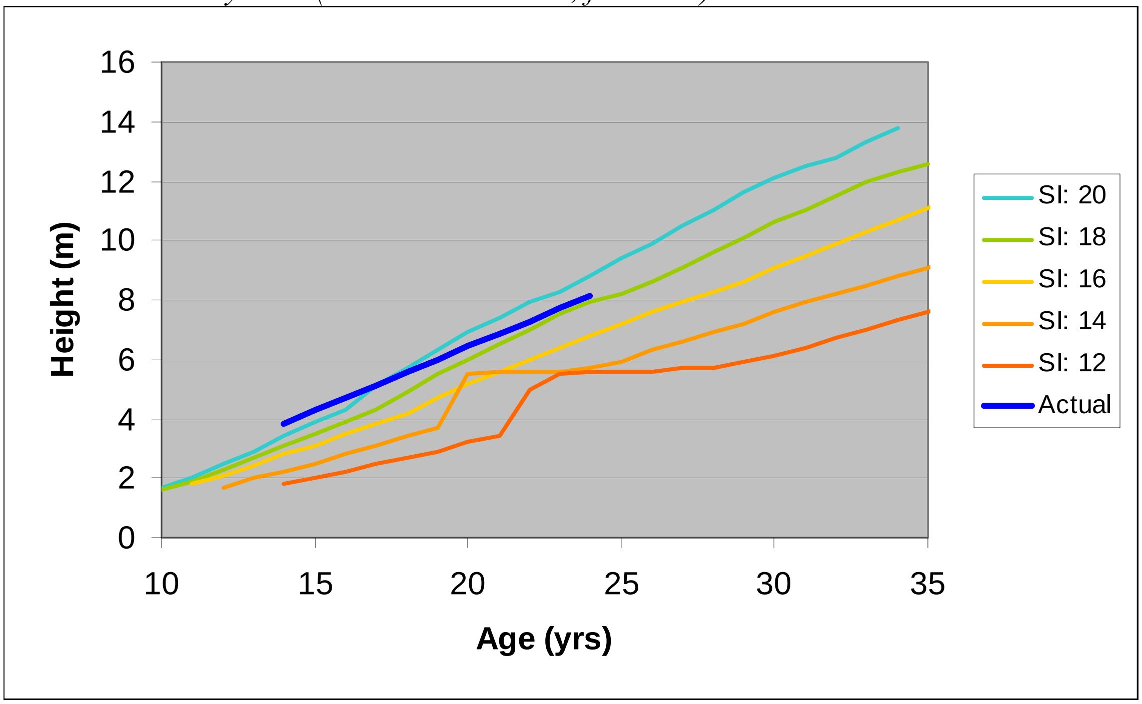


Figure A.47: *Comparison of TIPSY results to observed height of crop trees in the Summerland study area (PCT: 1774 stems/ha, unfertilized)*

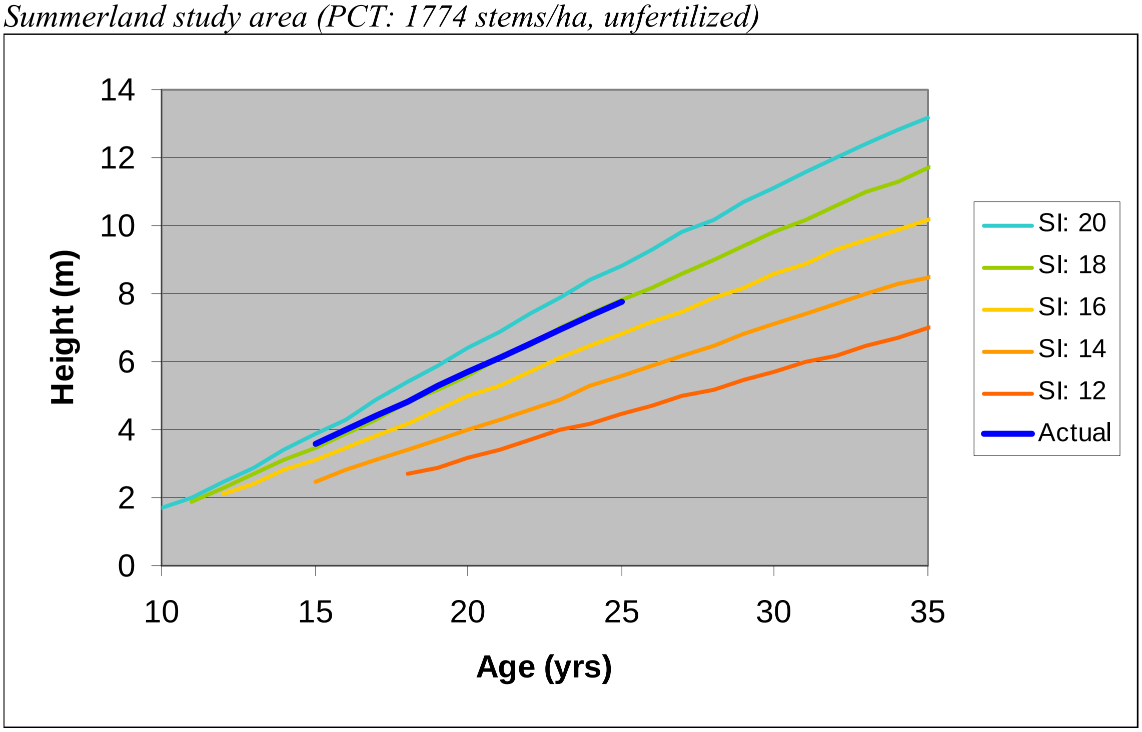


Figure A.48: *Comparison of TIPSY results to observed height of crop trees in the Summerland study area (PCT: 1774 stems/ha, fertilized)*

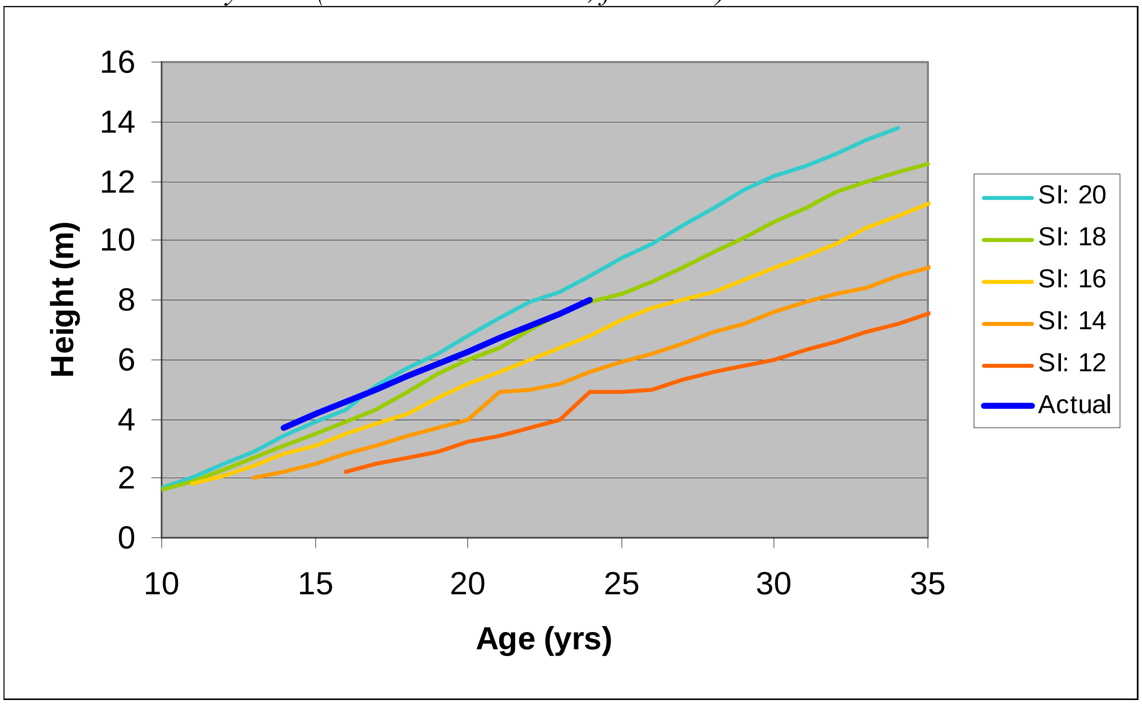


Figure A.49: *Comparison of TIPSY results to observed height of crop trees in the Summerland study area (PCT: control)*

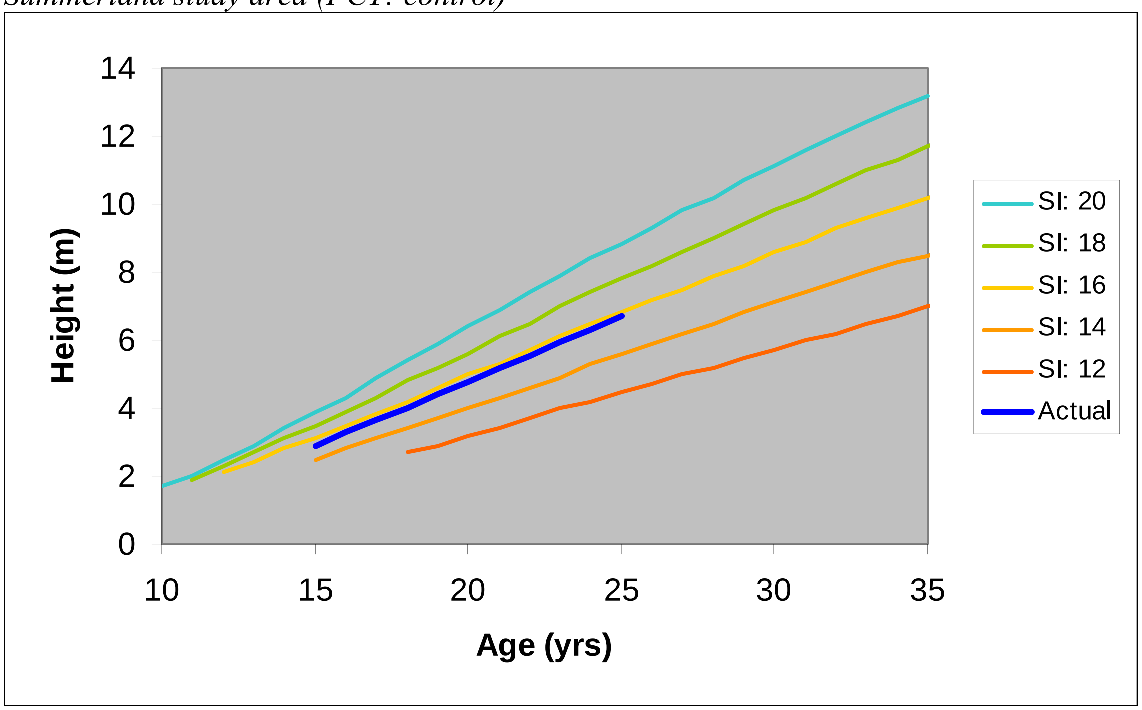


***Figure A.50**: Comparison of TIPSY results to observed height of crop trees in the Kelowna study area (PCT: 619 stems/ha, unfertilized)*

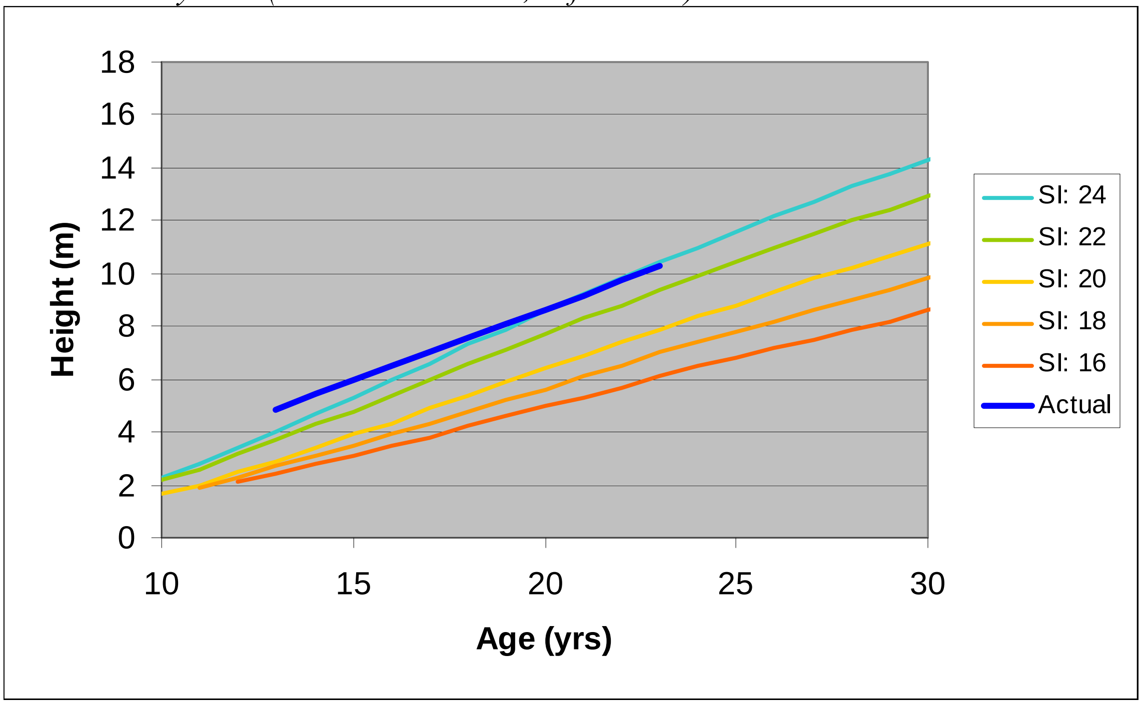


***Figure A.51:** Comparison of TIPSY results to observed height of crop trees in the Kelowna study area (PCT: 619 stems/ha, fertilized)*

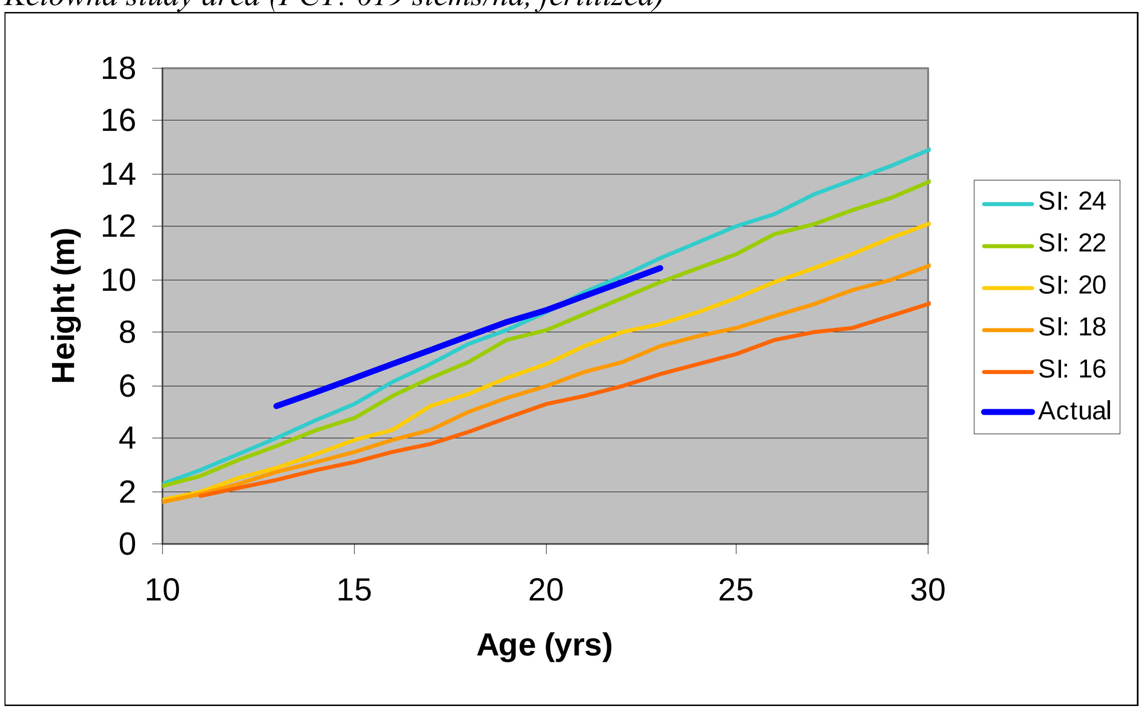


***Figure A.52**: Comparison of TIPSY results to observed height of crop trees in the Kelowna study area (PCT: 1004 stems/ha, unfertilized)*

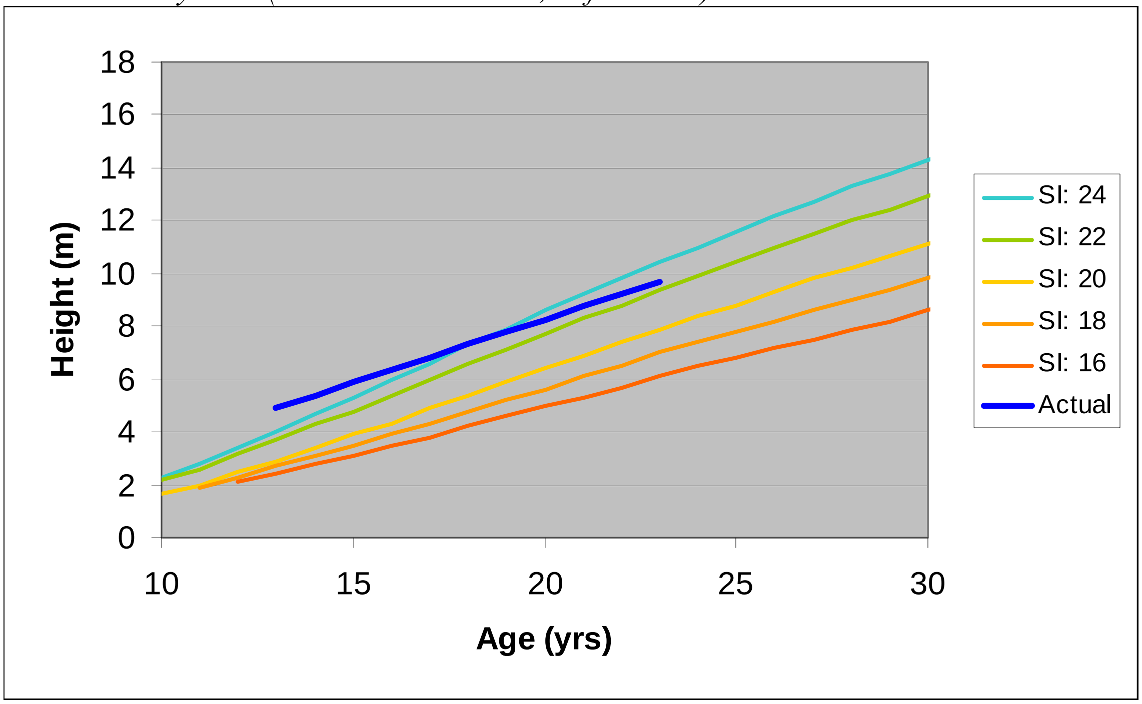


***Figure A.53:** Comparison of TIPSY results to observed height of crop trees in the Kelowna study area (PCT: 1004 stems/ha, fertilized)*

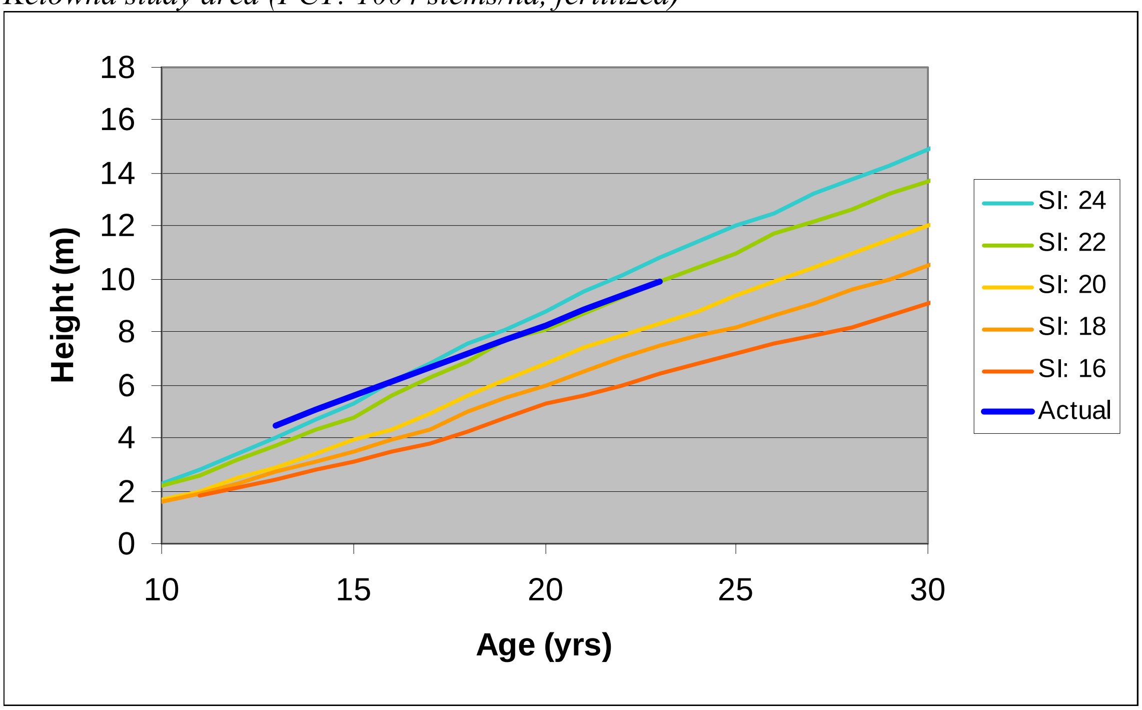


Figure A.54: *Comparison of TIPSY results to observed height of crop trees in the Kelowna study area (PCT: 1739 stems/ha, unfertilized)*

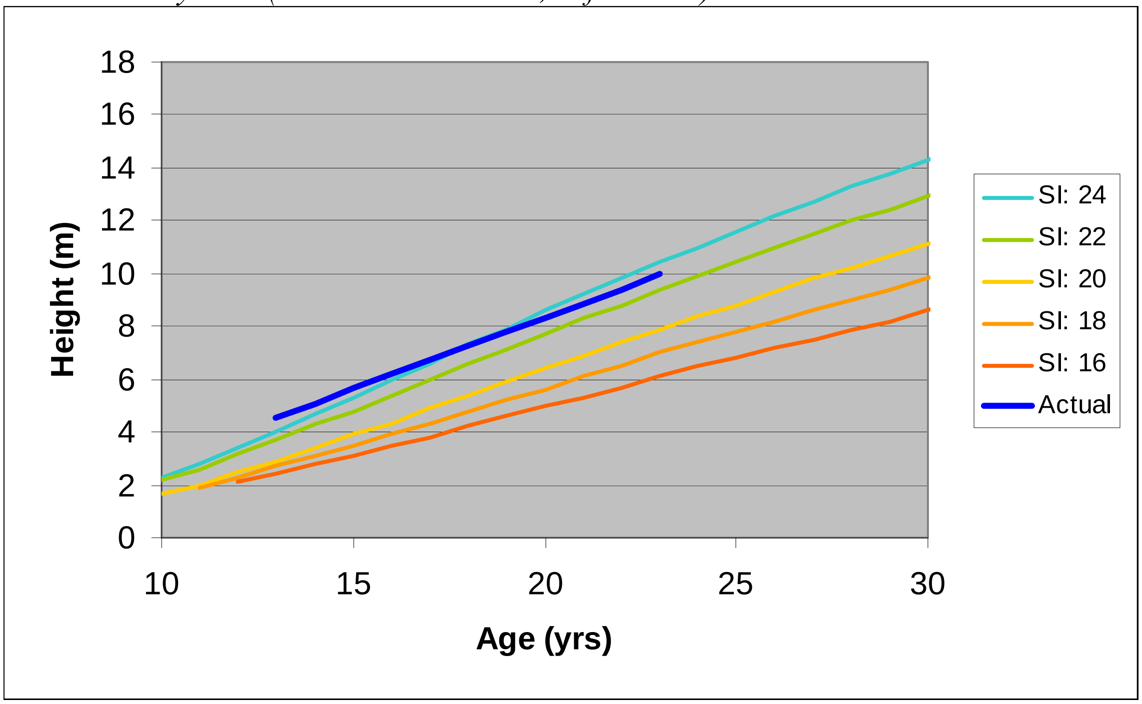


Figure A.55: *Comparison of TIPSY results to observed height of crop trees in the Kelowna study area (PCT: 1739 stems/ha, fertilized)*

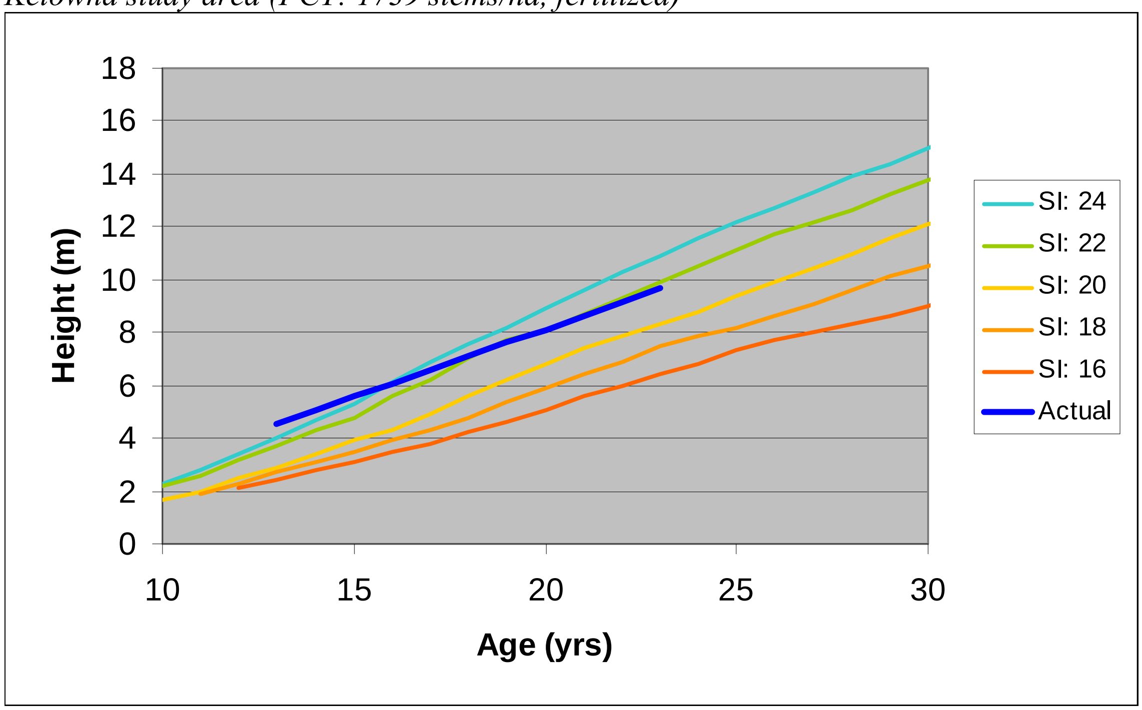


***Figure A.56**: Comparison of TIPSY results to observed height of crop trees in the Kelowna study area (PCT: control)*

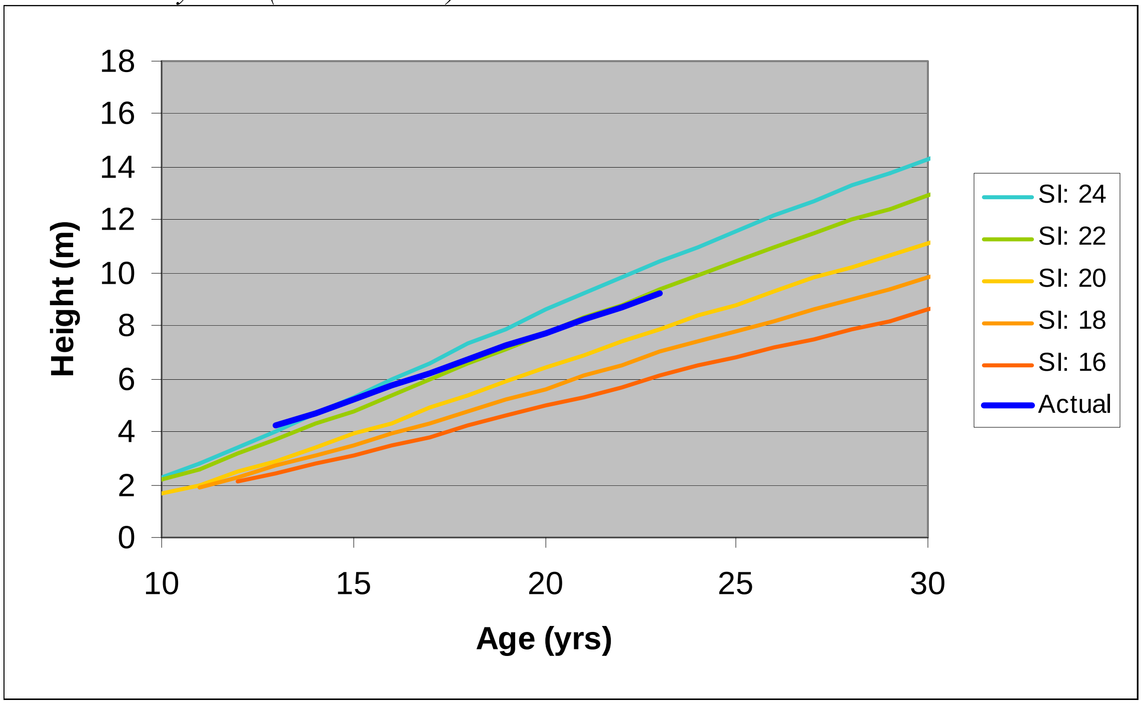


***Figure A.57:** Comparison of TIPSY results to observed height of crop trees in the Cariboo study area (PCT: 470 stems/ha, unfertilized)*

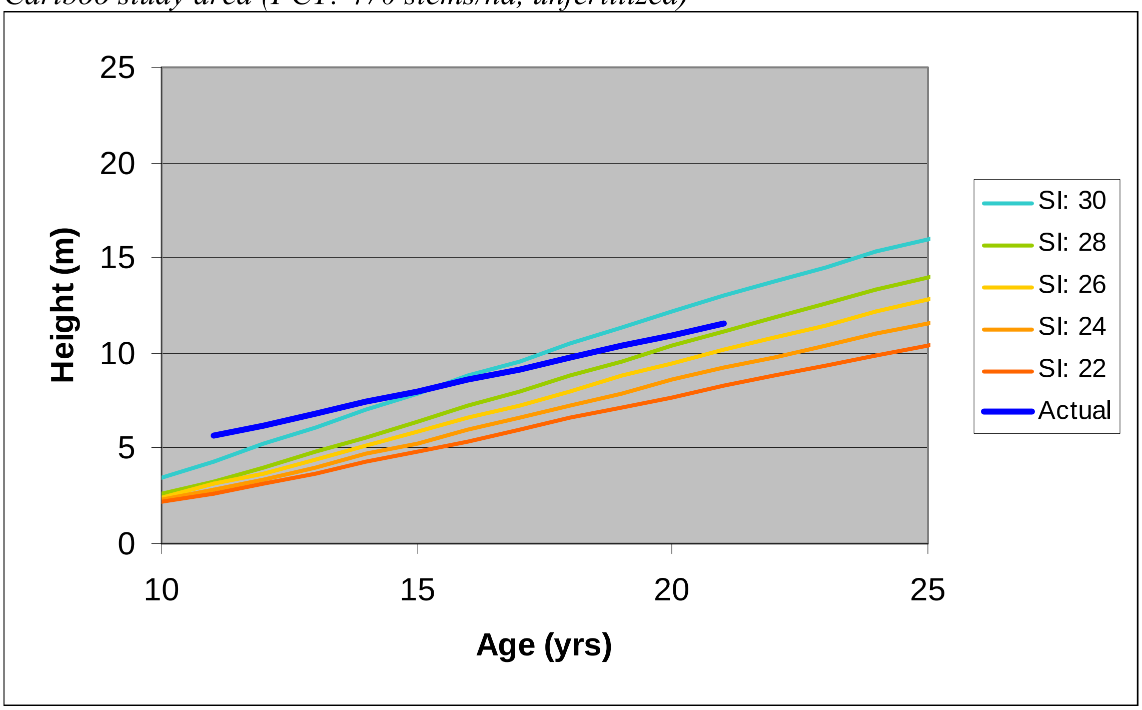


Figure A.58: *Comparison of TIPSY results to observed height of crop trees in the Cariboo study area (PCT: 470 stems/ha, fertilized)*

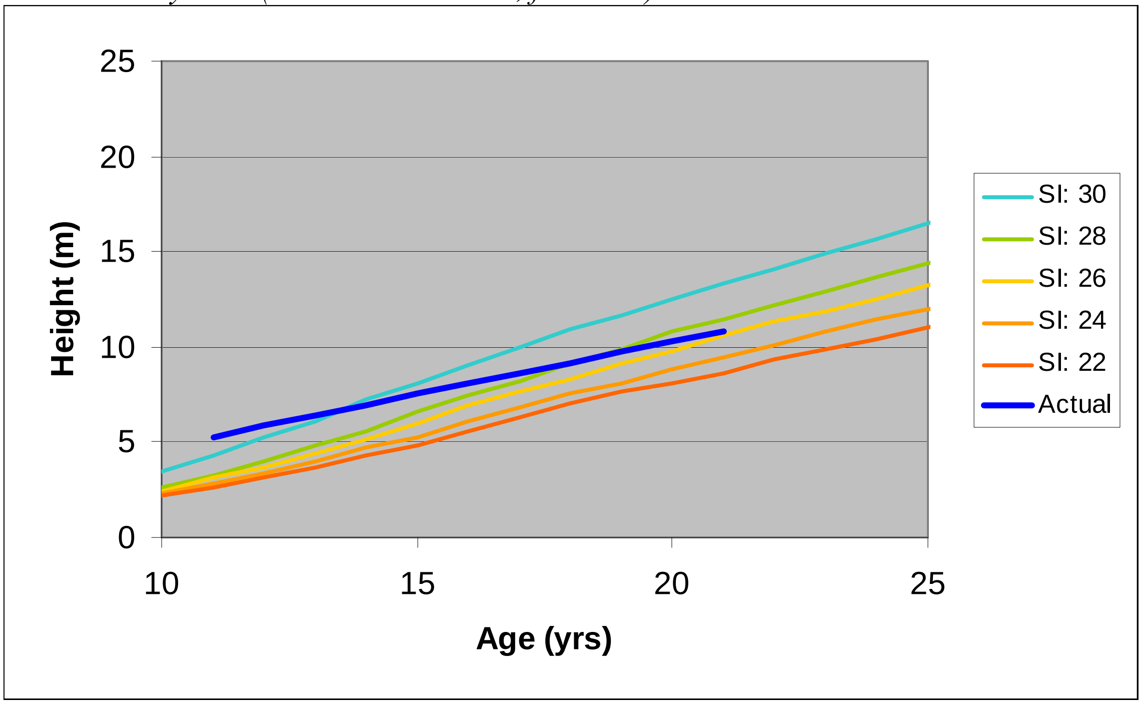


Figure A.59*: Comparison of TIPSY results to observed height of crop trees in the Cariboo study area (PCT: 980 stems/ha, unfertilized)*

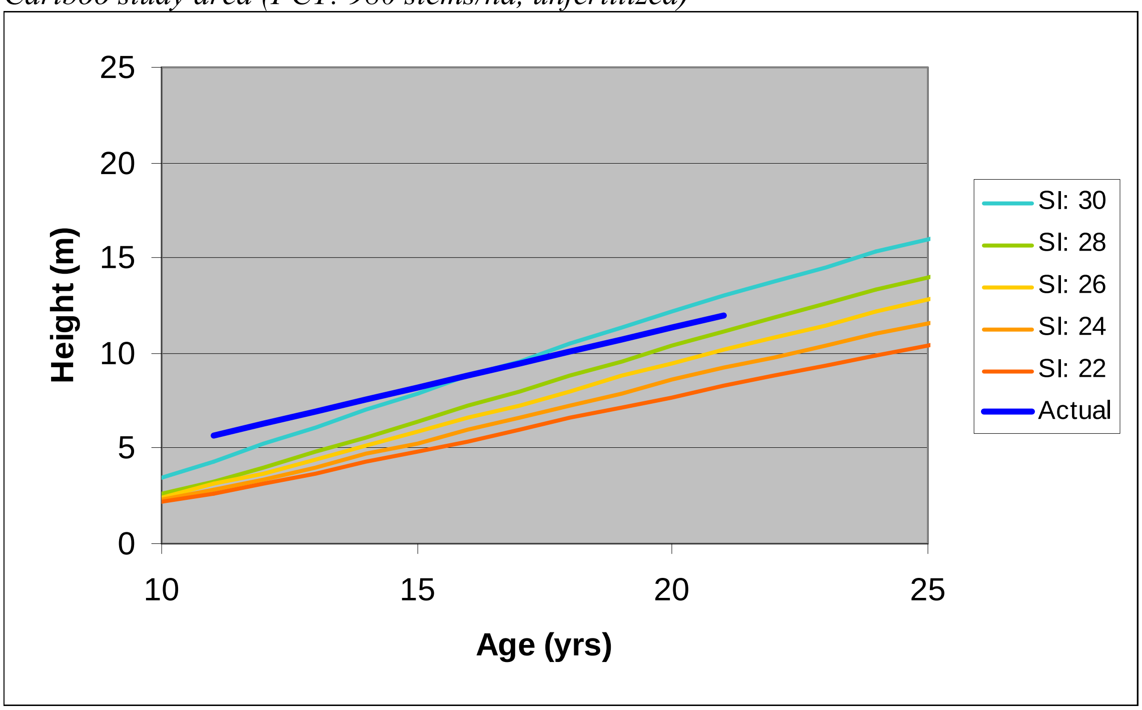


Figure A.60: *Comparison of TIPSY results to observed height of crop trees in the Cariboo study area (PCT: 980 stems/ha, fertilized)*

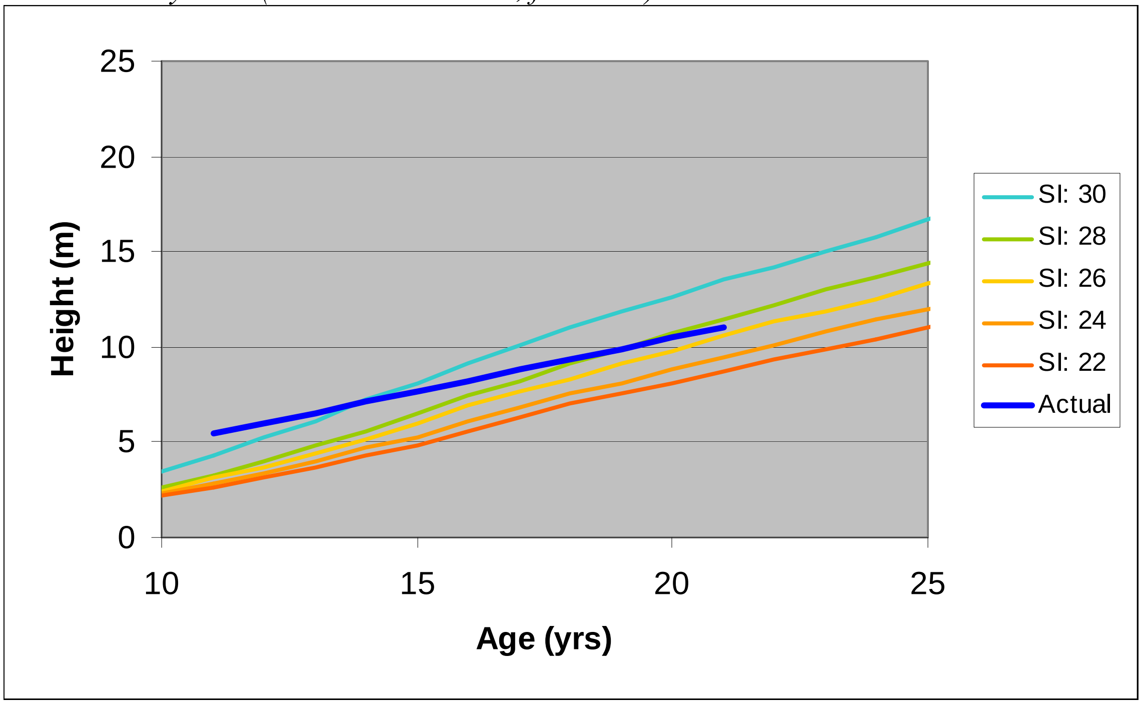


Figure A.61: *Comparison of TIPSY results to observed height of crop trees in the Cariboo study area (PCT: 1240 stems/ha, unfertilized)*

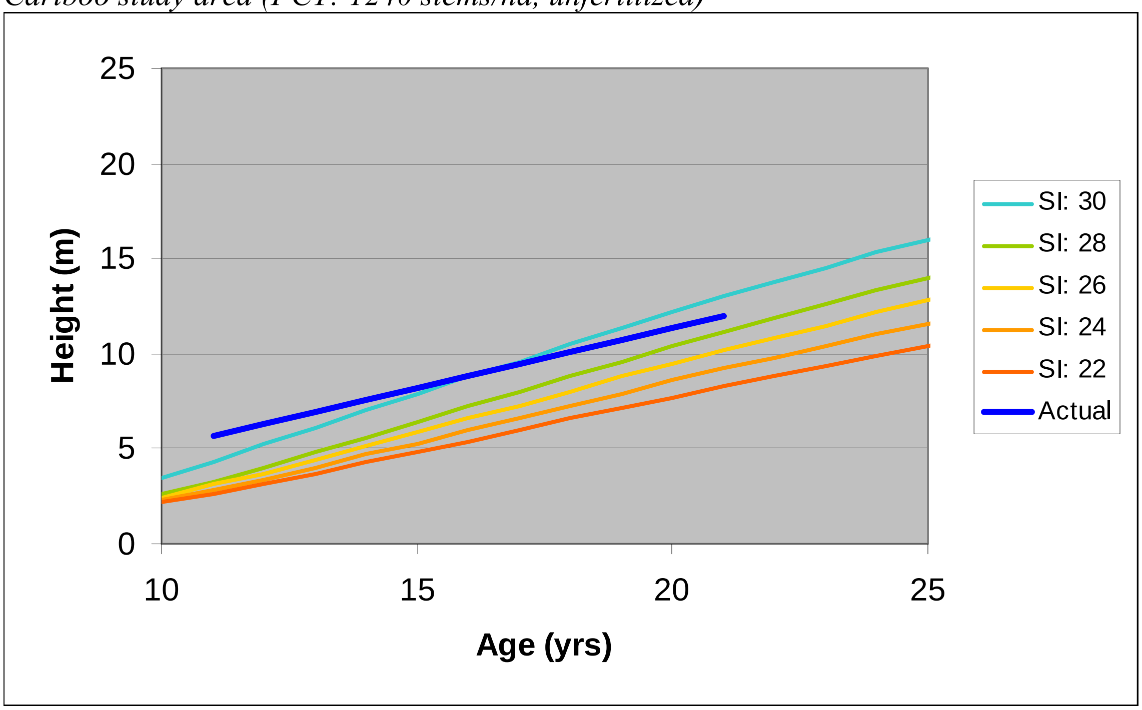


Figure A.62: *Comparison of TIPSY results to observed height of crop trees in the Cariboo study area (PCT: 1240 stems/ha, fertilized)*

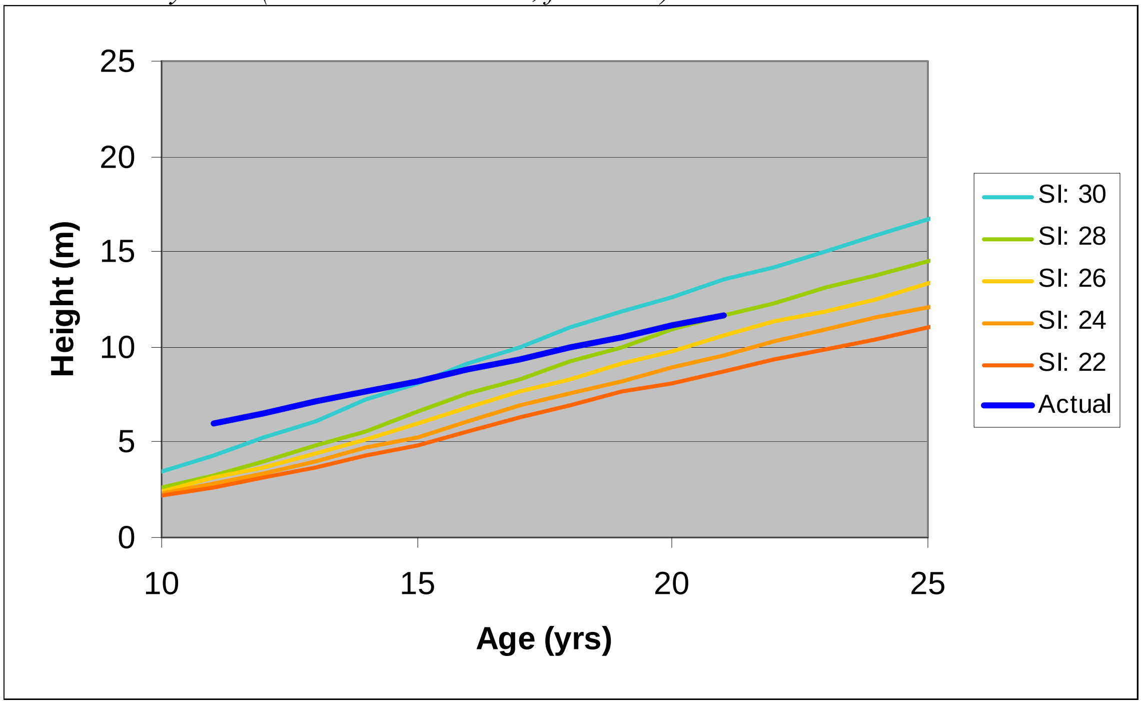
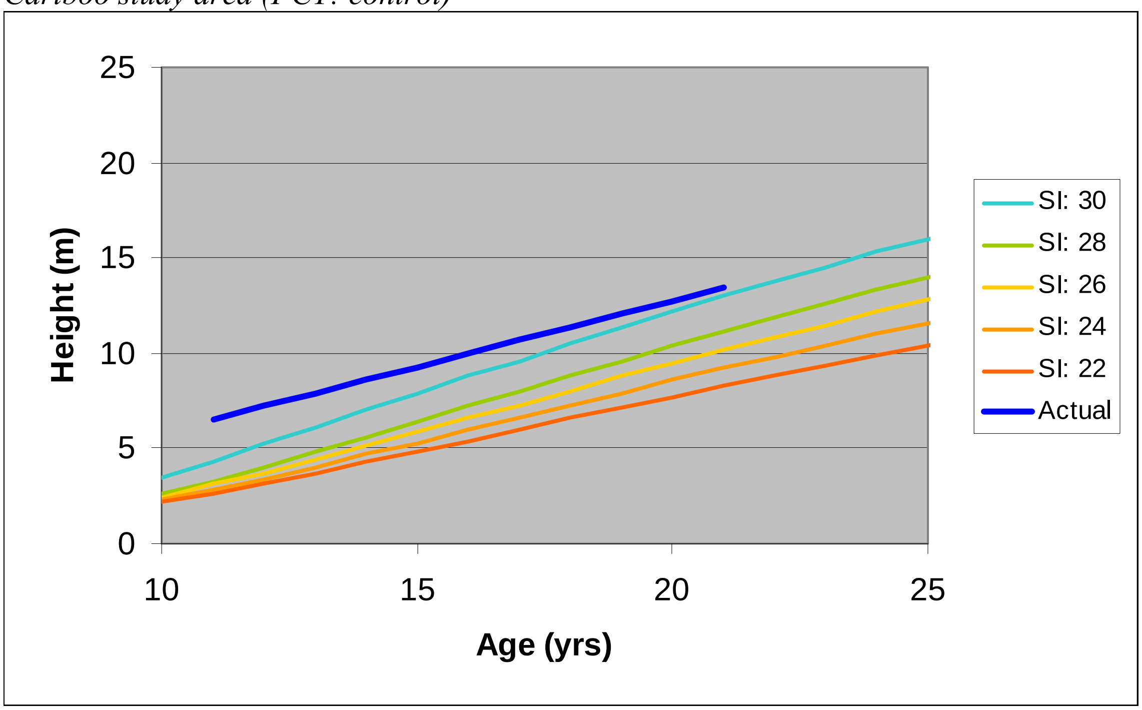


Figure A.63*: Comparison of TIPSY results to observed height of crop trees in the Cariboo study area (PCT: control)*



APPENDIX B: SENSITIVITY ANALYSIS

***Table B.1**: Comparison of LEV between various site indices in stands in the Summerland study area*

Stand	Site Index: 12	14	16	18	20
511 sph, unfert.	138	65	17	81	208
511 sph, fert.	-340	-402	-448	-325	-201
936 sph, unfert.	-5	-90	-140	-47	133
936 sph, fert.	-452	-565	-550	-463	-267
1774 sph, unfert.	236	206	228	361	591
1774 sph, fert.	-95	-179	-162	-17	249
10700 sph, control	446	452	505	643	862

***Table B.2:** Comparison of LEV between various site indices in stands in the Kelowna study area*

Stand	Site Index: 16	18	20	22	24
619 sph, unfert.	-368	-279	-130	102	468
619 sph, fert.	-878	-805	-660	-385	9
1004 sph, unfert.	-476	-369	-189	82	520
1004 sph, fert.	-986	-888	-614	-356	110
1739 sph, unfert.	-42	102	329	687	1150
1739 sph, fert.	-474	-320	-61	298	815
3928 sph, control	149	302	537	917	1373

***Table B.3:** Comparison of LEV between various site indices in stands in the Cariboo study area*

	Site Index: 20	22	24	26	28	30
470 sph, unfert.	1376	1520	1831	2186	2731	3531
470 sph, fert.	1005	1186	1514	1886	2478	3364
980 sph, unfert.	1206	1422	1861	2352	3051	4088
980 sph, fert.	963	1156	1623	2158	2955	4182
1240 sph, unfert.	1655	1946	2396	2939	3642	4701
1240 sph, fert.	1398	1699	2199	2775	3629	4858
2900 sph, control	1820	2146	2602	3182	3878	4909

Table B.4: *Comparison of LEV between discount rates in stands in the Summerland study area*

Study Area	Site Index	Stand	Discount Rate: 3% LEV	Rotation	Discount Rate: 6% LEV	Rotation	Discount Rate: 9% LEV	Rotation
Summerland	16	511 sph, unfert.	755	79	17	65	20	60
		511 sph, fert.	163	83	-448	63	-307	59
		936 sph, unfert.	735	78	-140	63	-91	58
		936 sph, fert.	217	77	-550	62	-368	57
		1774 sph, unfert.	1456	77	228	62	131	58
		1774 sph, fert.	995	75	-162	60	-130	56
		10700 sph, control	1746	78	505	65	323	60

Table B.5: *Comparison of LEV between discount rates in stands in the Kelowna study area*

Study Area	Site Index	Stand	Discount Rate: 3% LEV	Rotation	Discount Rate: 6% LEV	Rotation	Discount Rate: 9% LEV	Rotation
Kelowna	20	619 sph, unfert.	1859	70	-130	55	-262	51
		619 sph, fert.	1164	69	-660	55	-621	48
		1004 sph, unfert.	2154	66	-189	55	-341	50
		1004 sph, fert.	1687	66	-614	53	-625	47
		1739 sph, unfert.	3153	65	329	55	-22	50
		1739 sph, fert.	2841	65	-61	52	-295	47
		3928 sph, control	3443	65	537	55	119	51

Table B.6: *Comparison of LEV between discount rates in stands in the Cariboo study area*

Study Area	Site Index	Stand	Discount Rate: 3% LEV	Rotation	Discount Rate: 6% LEV	Rotation	Discount Rate: 9% LEV	Rotation
Cariboo	26	470 sph, unfert.	8773	58	2186	45	1010	39
		470 sph, fert.	8744	58	1886	44	745	38
		980 sph, unfert.	10496	56	2352	44	937	39
		980 sph, fert.	10886	56	2158	42	713	37
		1240 sph, unfert.	11403	55	2939	42	1326	38
		1240 sph, fert.	11914	55	2775	42	1114	37
		2900 sph, control	11648	54	3182	42	1483	38

Table B.7: *Comparison of LEV under various price conditions in stands in the Summerland study area*

Stand	Discount	Treatment Costs		Harvest Costs		Harvest Revenue		Cattle Revenue	
	Rate: 6%	+25%	-25%	+25%	-25%	+25%	-25%	+25%	-25%
511 sph, unfert.	17	-130	164	-41	98	127	-68	138	-103
511 sph, fert.	-448	-746	-149	-508	-361	-325	-538	-297	-599
936 sph, unfert.	-140	-329	48	-217	-36	7	-256	-32	-249
936 sph, fert.	-550	-876	-224	-635	-434	-380	-680	-416	-684
1774 sph, unfert.	228	136	319	140	346	391	98	328	128
1774 sph, fert.	-162	-384	62	-263	-26	35	-315	-41	-282
10700 sph, control	505	505	505	437	606	638	405	597	414

Table B.8: *Comparison of LEV under various price conditions in stands in the Kelowna study area*

Stand	Discount	Treatment Costs		Harvest Costs		Harvest Revenue		Cattle Revenue	
	Rate: 6%	+25%	-25%	+25%	-25%	+25%	-25%	+25%	-25%
511 sph, unfert.	-130	-270	10	-270	42	149	-371	-130	-130
511 sph, fert.	-660	-951	-368	-815	-467	-339	-932	-660	-660
936 sph, unfert.	-189	-370	-9	-352	8	141	-477	-189	-189
936 sph, fert.	-614	-931	-297	-800	-387	-223	-953	-614	-614
1774 sph, unfert.	329	270	387	153	538	677	20	329	329
1774 sph, fert.	-61	-256	134	-266	188	365	-436	-61	-61
10700 sph, control	537	537	537	365	742	873	237	537	537

Table B.9: *Comparison of LEV under various price conditions in stands in the Cariboo study area*

Stand	Discount	Treatment Costs		Harvest Costs		Harvest Revenue		Cattle Revenue	
	Rate: 6%	+25%	-25%	+25%	-25%	+25%	-25%	+25%	-25%
511 sph, unfert.	2186	2045	2328	1880	2523	2872	1532	2517	1856
511 sph, fert.	1886	1577	2195	1553	2243	2643	1165	2264	1508
936 sph, unfert.	2352	2145	2560	1972	2784	3283	1474	2646	2059
936 sph, fert.	2158	1780	2536	1742	2622	3197	1173	2498	1818
1774 sph, unfert.	2939	2874	3004	2540	3385	3892	2033	3228	2650
1774 sph, fert.	2775	2541	3009	2342	3254	3844	1754	3108	2442
10700 sph, control	3182	3182	3182	2765	3640	4154	2248	3457	2906

APPENDIX C: COMPARISONS OF FORAGE AND TIMBER LEV

Figure C.1: *Comparison of forage and timber contributions to LEV in the 511 sph, unfertilized stand in the Summerland study area*

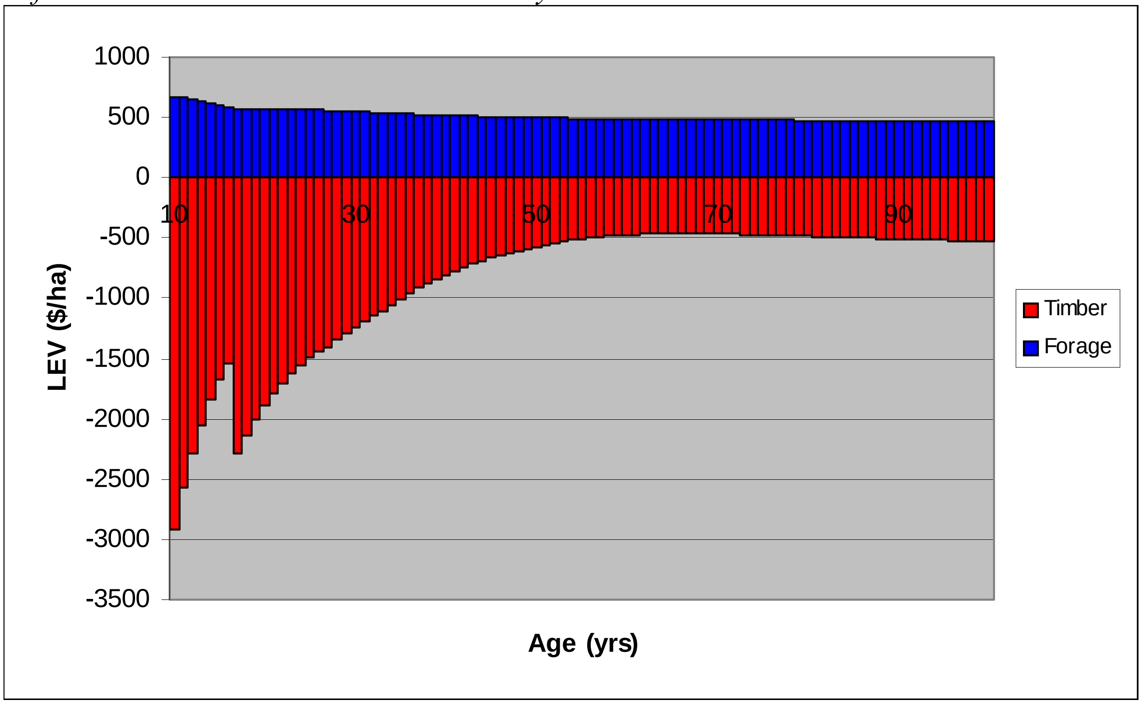


Figure C.2: *Comparison of forage and timber contributions to LEV in the 511 sph, fertilized stand in the Summerland study area*

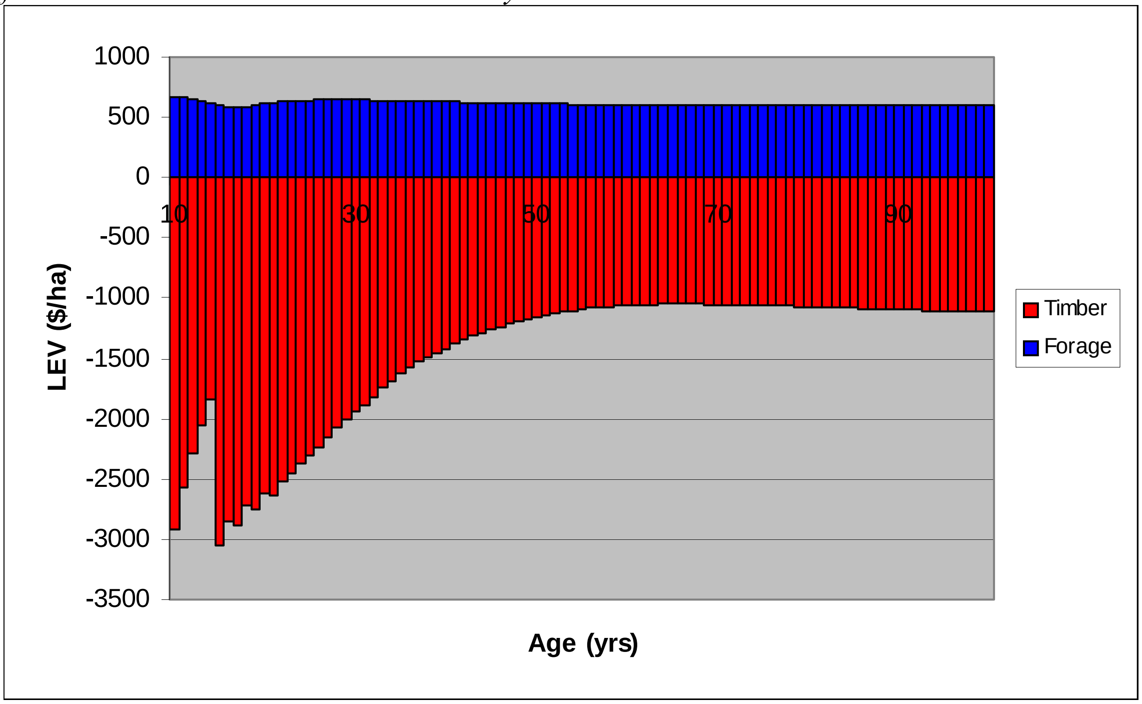


Figure C.3: *Comparison of forage and timber contributions to LEV in the 936 sph, unfertilized stand in the Summerland study area*

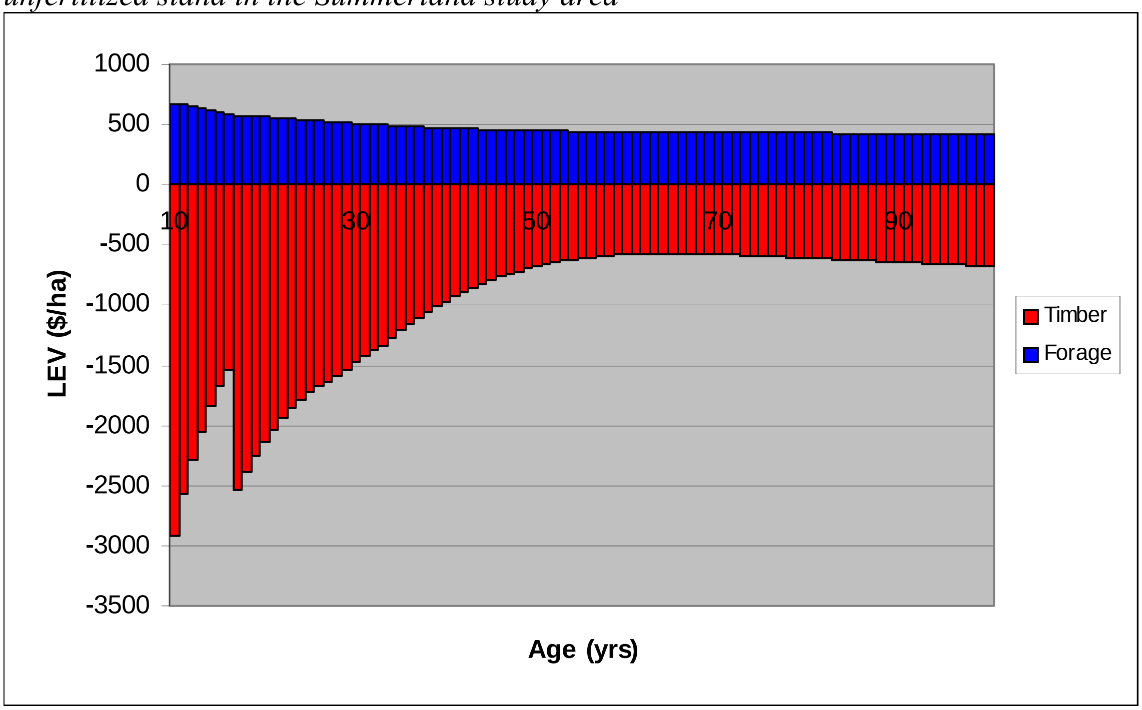


Figure C.4: *Comparison of forage and timber contributions to LEV in the 936 sph, fertilized stand in the Summerland study area*

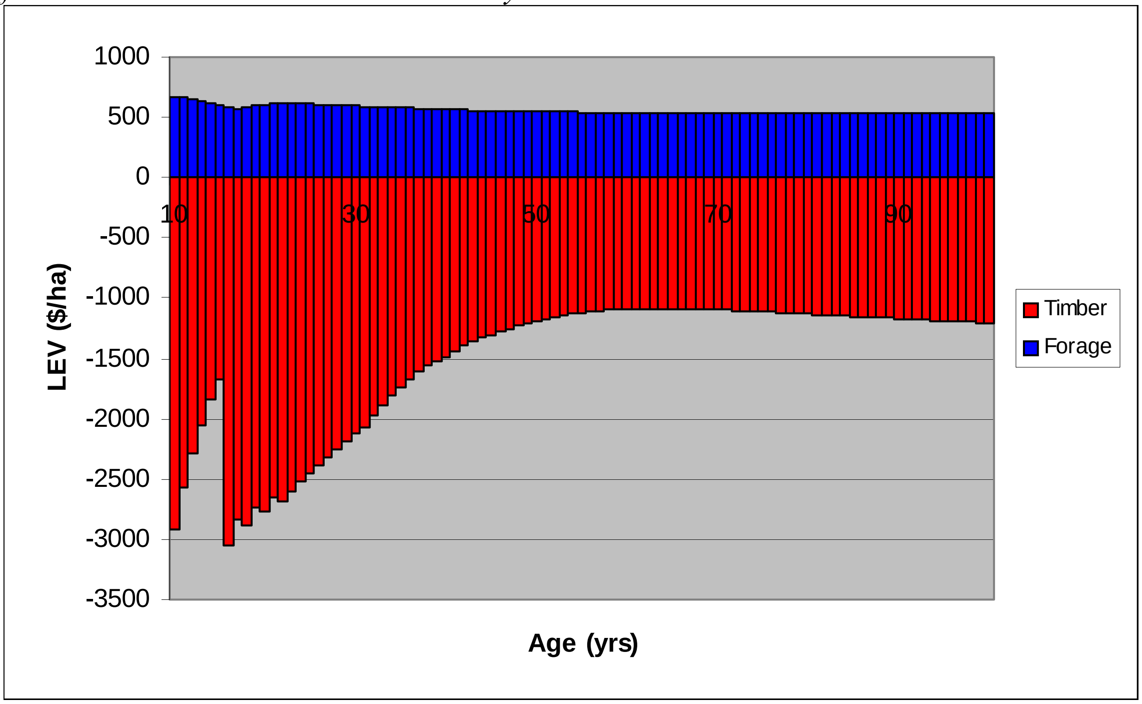


Figure C.5: *Comparison of forage and timber contributions to LEV in the 1774 sph, unfertilized stand in the Summerland study area*

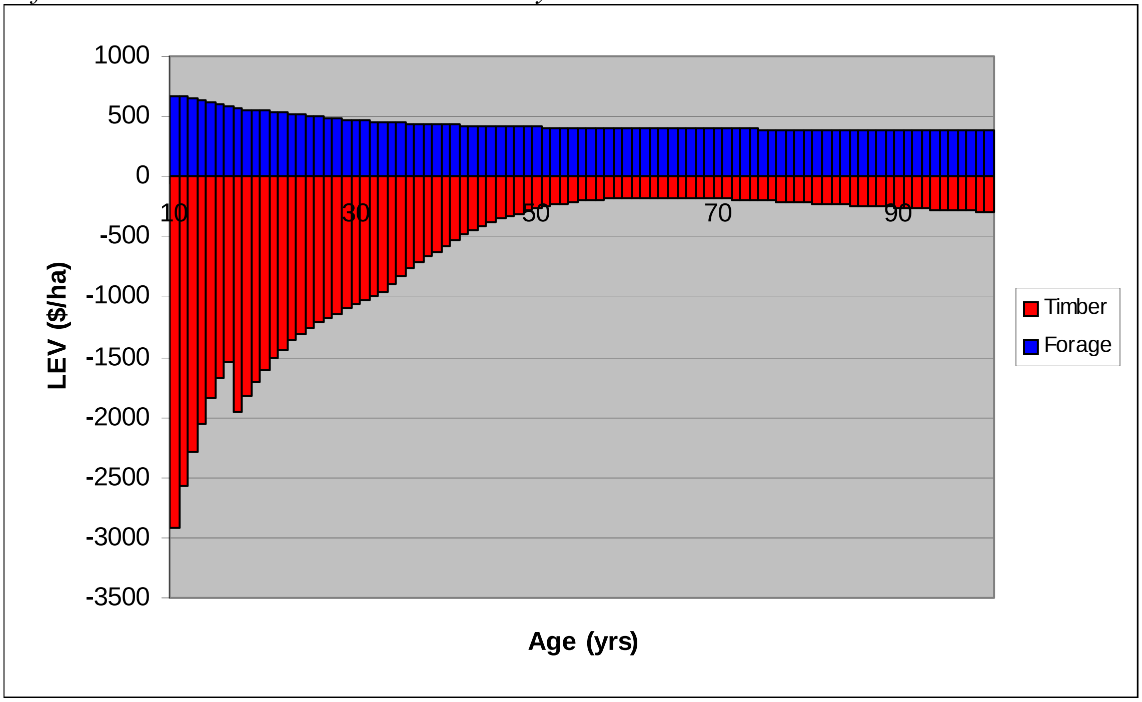


Figure C.6: *Comparison of forage and timber contributions to LEV in the 1774 sph, fertilized stand in the Summerland study area*

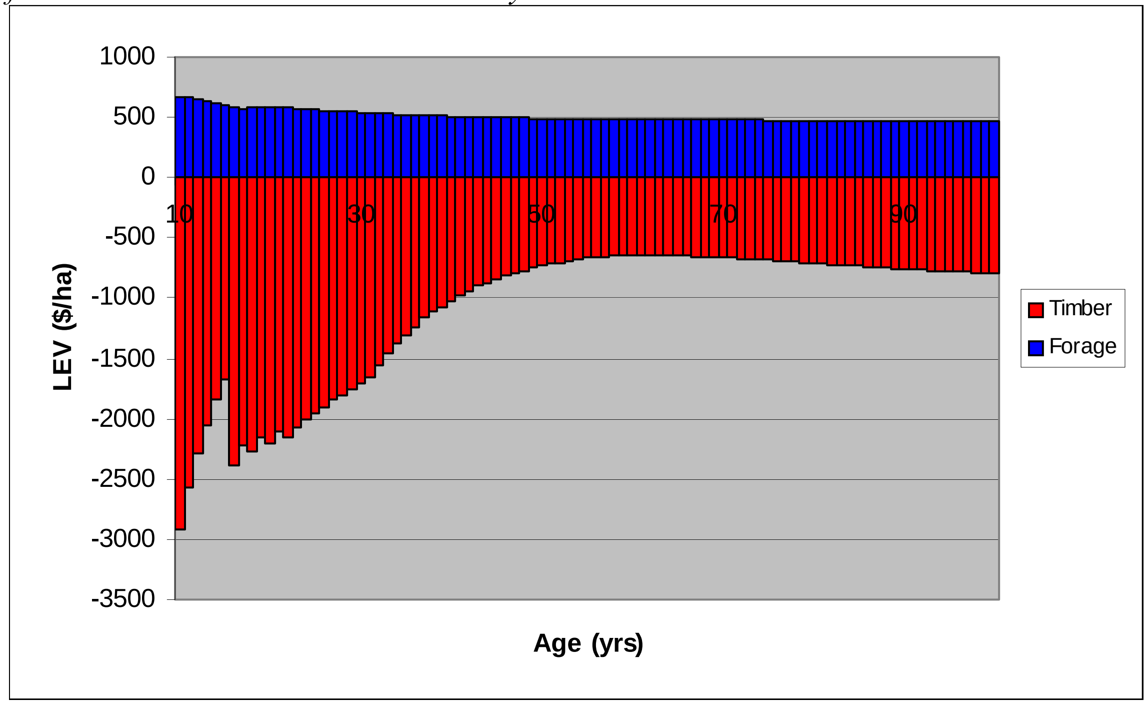


Figure C.7: *Comparison of forage and timber contributions to LEV in the Control stand in the Summerland study area*

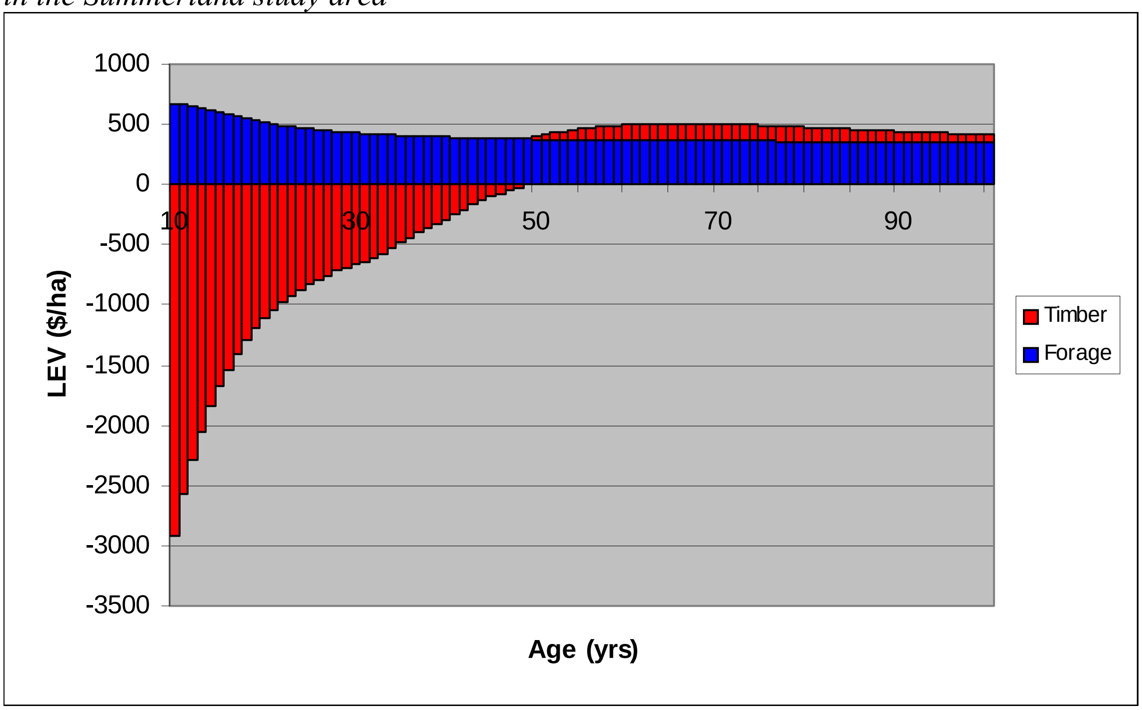


Figure C.8: *Comparison of forage and timber contributions to LEV in the 470 sph, unfertilized stand in the Cariboo study area*

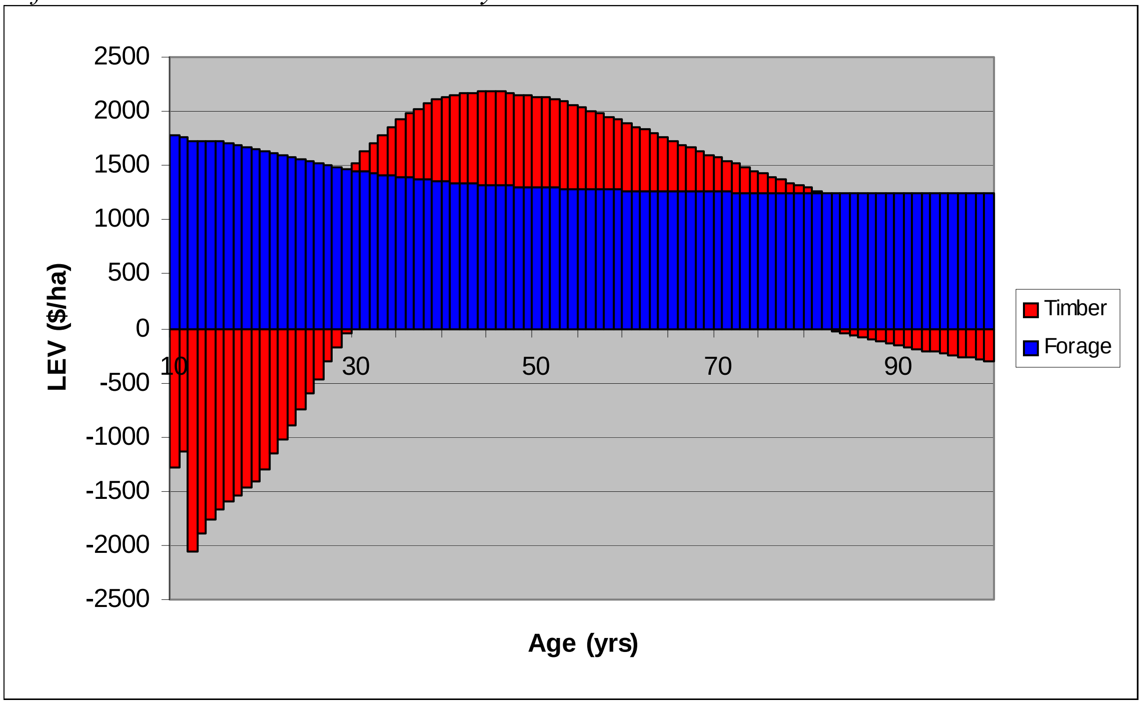


Figure C.9: *Comparison of forage and timber contributions to LEV in the 470 sph, fertilized stand in the Cariboo study area*

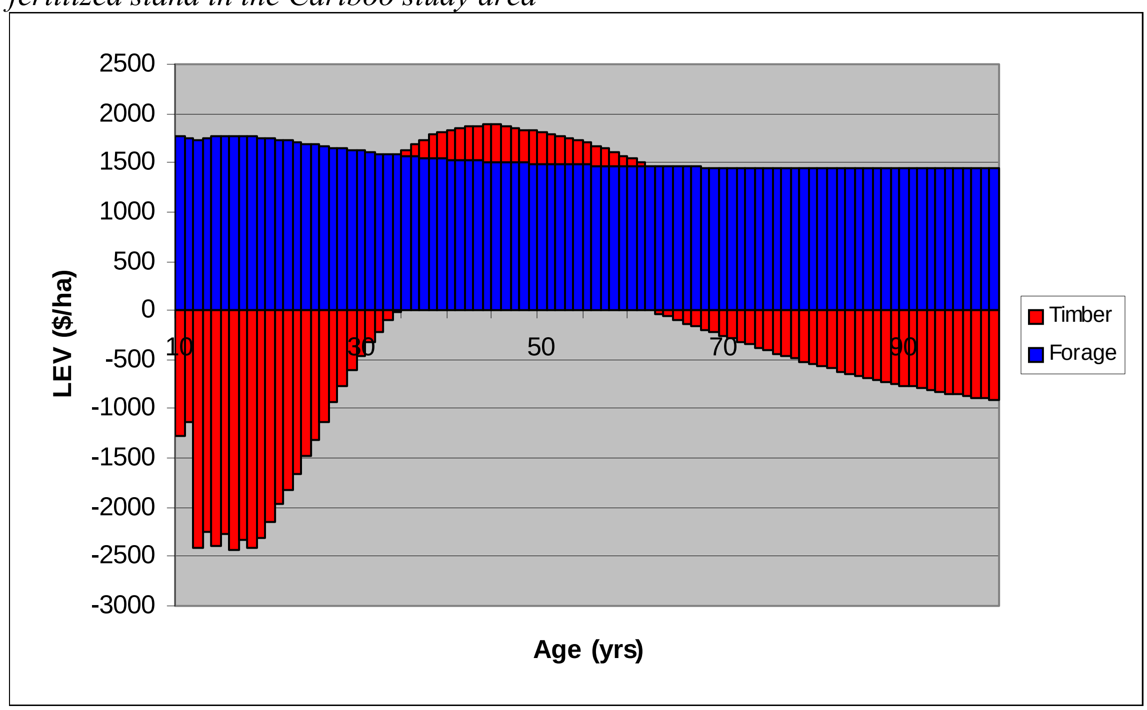


Figure C.10: *Comparison of forage and timber contributions to LEV in the 980 sph, unfertilized stand in the Cariboo study area*

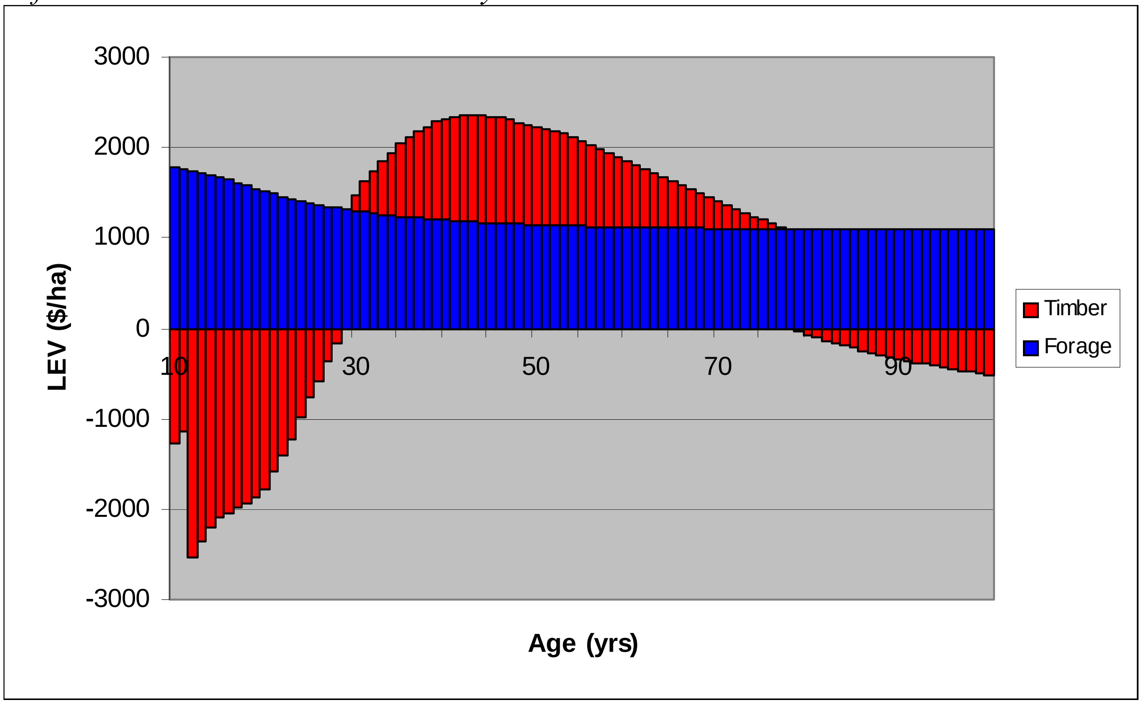


Figure C.11: *Comparison of forage and timber contributions to LEV in the 980 sph, fertilized stand in the Cariboo study area*

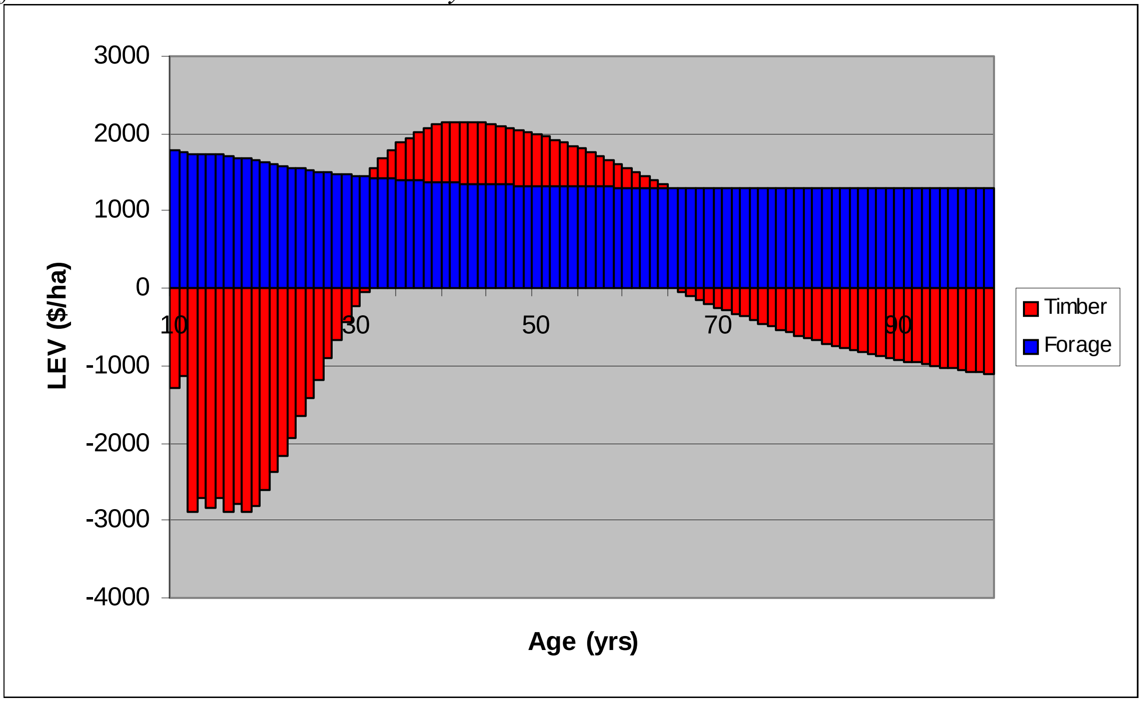


Figure C.12: *Comparison of forage and timber contributions to LEV in the 1240 sph, unfertilized stand in the Cariboo study area*

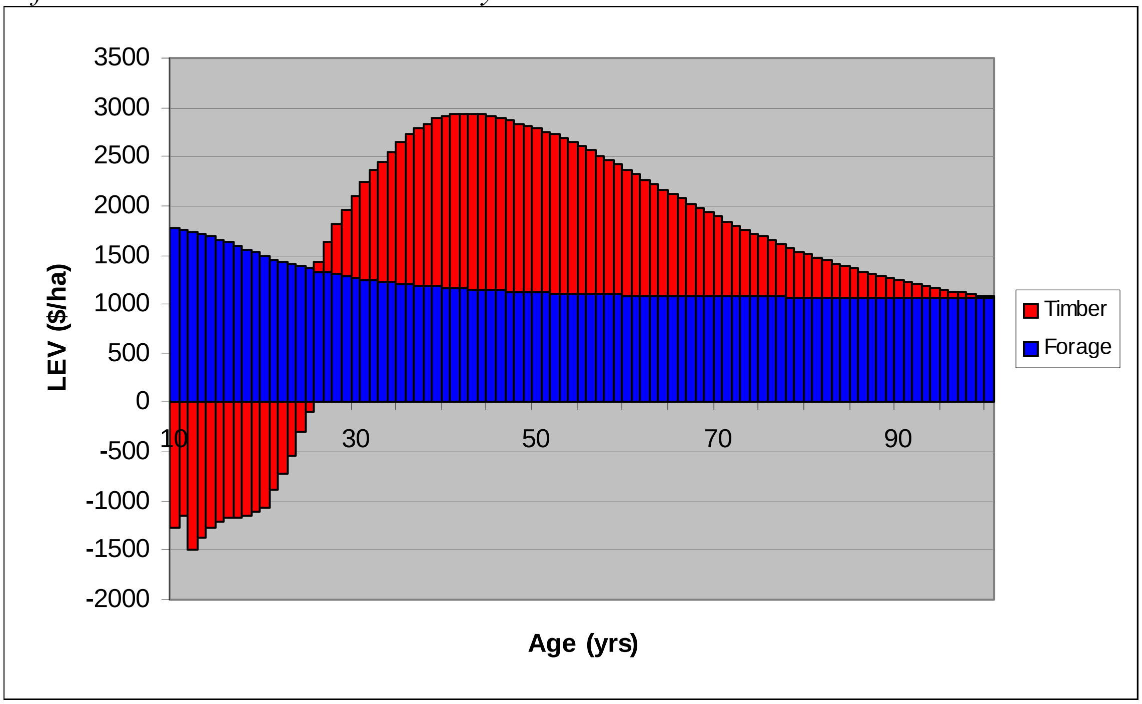


Figure C.13: *Comparison of forage and timber contributions to LEV in the 1240 sph, fertilized stand in the Cariboo study area*

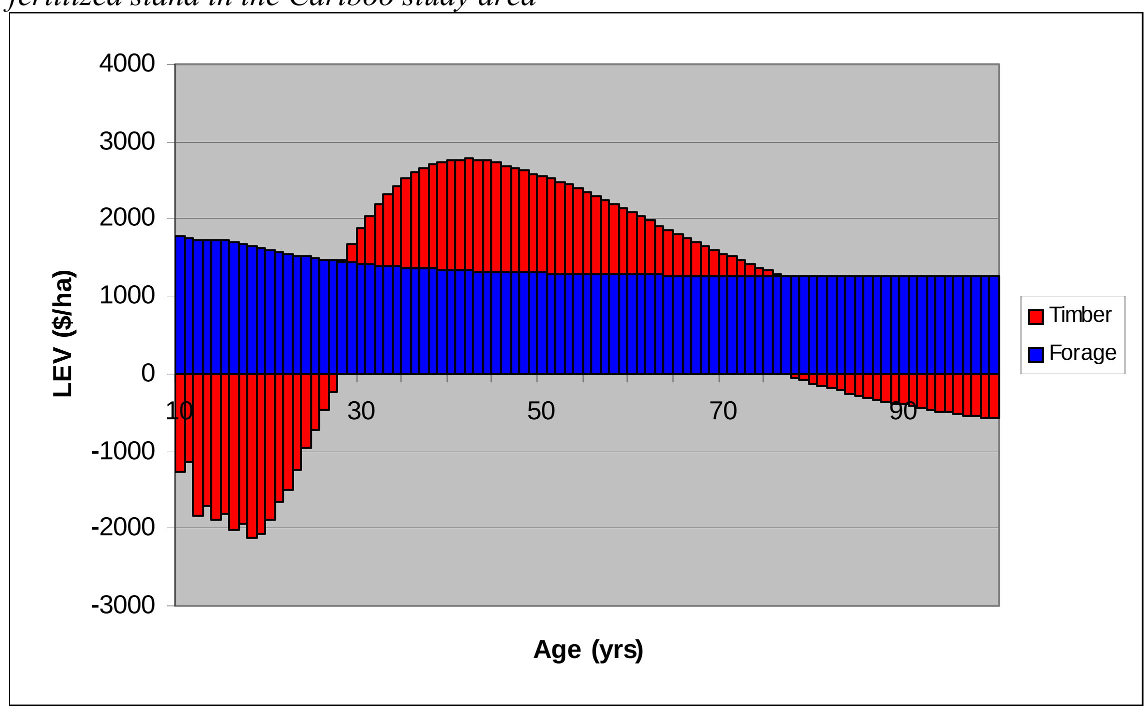


Figure C.14: *Comparison of forage and timber contributions to LEV in the Control stand in the Cariboo study area*