文　献

1）阿部信行　1976　トドマツ人工林の施業法に関する研究（Ⅰ）疎關木の相対生長　北林試報　14：27～36
2）―――　1977　トドマツ人工林の密度による相対生長関係の変位　88 回目林学会　発表
3）安藤　貴　1968　同齢単純林の密度管理に関する生態学的研究林試研報　210：153P
4）ARNEY，J．D，1972．Computer simulation of Douglas－fir tree and stand growth．Canandian Forestry service, Pacific Forest Research Centre,Victoria，B．C．Internal Rep.BC-27,79p.
5）BELLA，I．E．1971．A new competion model for individual trees．Forest Sci．17：364-872.
6）BITTERLICH，W．1947．Die Winkelzahlmessung．Allg．Fors．u．Holzwirts．Ztg．58：97-96.
7）BOTKIN，D．B．J．F．JANAK，and J．R．WALLIS．1972．Some ecobgical consequences of a computer model of forest growth．J．Ecol．60：849-872.
8）BROWN，G．S．1965．Point density in stems per acre．N．Z．For．Res．Note No.38，11p.
9）BRAATHE，P．1957．Thinning in enen-aged stands：a summary of European literature．Faculty of For.，Univ．of New Brunswick，92p.
10）CLUTTER，J．L.，and B．J．ALLISON．1973．A growth and yield model for pinus radiata in New Zealand．Report I．U．F．R．O．Joint meeting of S4.01 and S6.02 Vancouner，B．C.，Canada.
11）DEMING，W．E．1943．Statlstlicail adjustment of data John Wlney&Sons．(邦訳；森口繁一，推計学によるデータのまとめ方，岩波書店．(1950).198P)
12）DRESS,P.E.1968.Stochastic models for the simulatlon of even-aged forest stands.Unpublished material presented at 1968 Soc．Amer Forest Annual meeting.Philadelphia.Pa.17p.
13）EK,A.P.,andR.A.MONSERUD.1974.Availability of a computer model for simulating growth and repemduction of forest stand of mixed species.(Announcement)Forest Sci,20：259-260.
14）藤森隆郎　1975 枝打ちの技術体系に関する研究林試研報 273：1～74
15）権　五福・鈴木太七　1973　林木の直径生長の変動に関する研究（Ⅰ）日林誌 55：346～351
16）GOULDING,C.J.　1972.　Simulation techniques for a stochastic model of the growth of Douglas fir Ph.D.Thesis. Univ.Brtish ColumbiaVancouver.234p.
17）峰屋欣二　1967　葉群の垂直的紀列と生産量　78 回目林講：114～115
18）宝月欣二　1958　原野の生態系　生物と環境　現代生物学講座 5　共立出版 270～300
19）北海道林務部　1972　立地級調査要領　12P
20）細井　守・山本久二雄　1954　強度の枝打ちによるアカマツ肥大生長の減退　日林誌 36：42～44
21）堀田正逸　1927　測樹学三浦書店　350P
22）石田正次　1974　森林の保全と自然環境の変化に関する研究－天然林の生長モデルとそのコンピューターシミュレーション統数研彙報　22(1)：69～86
23）JACK.，W.H.　1967.　Single tree sampling in even-aged plantations for survey andexperimentation.I.U.F.R.O Sec.25：375-403.
24）柿原道書　1967　九州地方におけるカラマツ林の施業上の特性に関する研究　九大演報　41：1～107
25）河田　杰，金谷与十郎　1949　アカマツ及びカラマツ植栽の疎密が成林状態に及ぼす影響(終結報告)林試研報 41：29～62
26）KEISTER,T.D.　1972.　Predicting individual tree mortality in simulated southern pine plantation .Forest Sci.18：213-217.
27）木梨謙吉　1974　Growth mode1 について　85 回目林講：61～62
28）吉良竜夫　1965　樹形のパイプモデル　北方林業　17:69～74
29）―――　(編)　1957　密度・競争・生産大阪営林局　31P
30）小林正吾　1968　小面積林分の地位樹高層の定義とその推定法　北林試報　6：157～171
31）―――　1973　北海道におけるカラマツ施業法に関する研究(1)カラマツ育林経営上の自然的立地区分　北林試報 11：1～18
32）阿部信行　1974　カラマツ高齢林の生長解析　カラマツ高齢林の生長と材質　北海道カラマツ対策協議会 10～33
33）―――　1674　高齢カラマツ人工林の林分生長解析－直経変動の推移－　85 回目林講：53～55
34）小林正吾　1975　占有面積の推移によるカラマツ人工林の林分生長モデル（1）閉鎖林分の樹高対直径の相対生長モ

デル　86 回目林講：68～69
35）――― 1976a 占有面積の推移によるカラマツ人工林の林分生長モデル(II) 無間伐モテル林分の樹高対直径の相対生長モデル 87 回目林論：95～96
36）――― 1976b 占有面積の推移によるカラマツ人工林の林分生長モデル(Ⅲ) 間伐モデル林分の樹高対直経の相対生長モデル 87 回目林論：97～98
37）――― 1976c カラマツ人工林の施業の現状と問題 北方林業 28：312～318
38）――― 1977 占有面積の推移によるカラマツ人工林の林分生長モテル(IV) ―立木の幹形と相対生長モデル― 88 回目林学会 発表
39）小木和彦 1973 カラマツ幼齢林の樹高の生長変動について 84 回目林講：64～65
40）KOZLOWSKI,T.T.1962.Tree growth.Ronald press.442p.
41）KRAJICEK,J.E.,andK.A.BRINKMAN.1957.Crown devebpment:：index of stand density.Sta.Note cent.St. For.Exp.Sta.No.108,2p.
42）――― K,A. BRINKMAN, and S.F.GINGRICH1 1961 Crown competltlon―a measure of density.Forest Sci. 7：35-42
43）LARSON,P.R. 1963. Stem form development of forest trees.Forest Sci.Monogr.5,42p.
44）LEE,Y. 1967. Stand models for lodgepole pine and limits to their application.For.Chron.43：387-388.
45）LEMMON,P.E.,and F.X.SCHUMACHER 1962, Volume and diameter grwoth of ponderosa pine trees as influence by site index,density,age and size.Forest Sci.8：236-249.
46）LIN,J.Y. 1970. Growing space index and stand simulation of young western hemlock Oregon.D.F.Thesis. Duke Univ,Durham,NorthCarolina.193p.
47）真辺 昭 1971 林分上層高について 日林北支講 20：77～79
48）松井善喜 1957 カラマツ経営編 北方林業叢書 8 140P
49）――― 1966 北海道の森林の取扱いに関する研究II 北海道における各樹種の植栽沿革とその造林成績に対する考察 林試研報 189：1～160
50）嶺 一三 1952 測樹 相倉書店 150P
51）――― 1955 収穫表調製に関する基礎的研究と信州地方カラマツ林収穫表の調製 林野庁 林業試験場 収穫表調製業務研究資料 12：201P
52）MITCHELL.,K.J, 1969. Simulation of growth of even-aged stands of white spruce.Yale Univ .Sch.For.Bul.l 75, 48p.
53）MONSI,M. und T. SAEKI. 1953. Uber den Lichtflanzengesell schaften und seine Bedeutung fur Stoff-produktion.Jap.J.Bot.,14：2-52.
54）MUNRO, D.D. 1973, Forest growth models－a prognosis.Report I.U.F.R.O.Joint meetng of S4.01 and S6.02 Vancouver,B.C.,Canada.15p.
55）MYERS,C.A. 1968. Simulation the management of even-aged tlmber stands U.S.D.A.Forest Serv.Res.Paper RM-42.32p.
56）中島広吉 1926 落葉松の胸高樹幹形数表 北海道林業会報 24：224～226
57）――― 1943 北海道立木幹材積表 興林会北海道支部叢書 1 46P
58）NEWNHAM,R.M 1964. The development of a stand model for Douglas-fir..Ph.D.Thesis,Univ.British Columbia,Vancouver.201p.
59）――― ,and J.H.G. SMITH. 1964 Development and testing of stand models or Douglas for and Lodgepole Pine Forest Chron.40：494-502.
60）―――. 1965 Stem for and the variation of taper with age and thinning regime Forestry 38：218-224
61）―――. 1968 Simulation models forest management and harvestingForest Chron.44：7-13
62）西沢正久 1959 森林測定法 地球出版 302P
63）――― 1961 林分成長量の推定および予測方法に関する研究 林試研報 291：1～159
64）――― 1963 土壌と結びついた林分調査法－ポイントサンプリングと地位指数曲線の作成法－森林立地 IV(2)：12～20
65）西沢正久・真下育久・川端幸蔵 1965 数量化による地位指数の推定法 林試研報 176：1～49
66）―――・――― 1966 地位指数による林地生産力の測り方 林業科学技術振興所 53P
67）――― 1966 角度測定法の応用について Bitterlich 法に関する研究報告 林業統計研ー1：29～46
68）―――・川端幸蔵 1969 ラジア一タ松の単木の生長と周囲密度の関係 80 回目林講：67～69

69）――― 1972 森林測定 農林出版 348P
70）農林省林業試験場 1972 森林の構造と成長の関係解析に関する研究－収穫試験地施行要綱による試験地の設定と経過についてー収穫試験報告 17：337p
71）OGAWA,H.，K. YODA.K，OG1NO,and T．KIRA 1965 Comparative ecologicaI studies on tree main types of forest vegetation in Thailand II.plant biomass.Nature and life in southeast Asia Ⅳ：49-80.
72）尾中文彦 1950 樹木の肥大生長の縦断的配分 京大演報 18：1-53
73）小野寺重男・高橋政治・鎌田昭吉・大山幸夫・米田昌世・千葉宗昭・吉田弥明・高谷典良・山本宏・川口信隆・河島 弘・奈良直哉・橋本博和・小合高規・野崎兼司・田口 崇 1976 新得産カラマツの材質と加工試験 北林産試験研報 64：1～115
74）OPlE,J.E 1968. Predlctability of individual tree growth using various definitions of competing basal area. Forest Sci.14：314-323.
75）大隅真一・北村昌美・菅原聡・大内幸雄・梶原幹弘・今永正明 1971 森林計測学 養賢堂 415P
76）PIENAAR.L.V. ,andKJ.TURNBULL,1973-The Chapman-Richards generalization of Von Bertalanffy's growth model for basal area growth and yield in even-aged stands.Forest Sci.19：2-22
77）斉籐秀樹・四手井綱英・菅 誠 1968 樹幹形についての考察 2,3 の幹形の表わし方および幹における同化物質の垂直分布についての考え方 京大演報 40：93～110
78）斉藤昌宏 1976 「森林の成長モデル」に関する Biologica1 な側面 林業統計研究会誌 創刊号 61～63
79）佐籐大七郎・中村賢太郎・扇田正二 1955 林分生長論資料 1 立木密度のちがう若いアカマツ林 東大演報 48：65～90
80）坂口勝美 1961 間伐の本質に関する研究 林試研報 131：1～95
81）von SCHULZ,B. 1968.Program zur Bcrechnung draumes in einschictigen Bestanden(APAC).Allgemeine Forst-und Jagdzeitung l0：232-234
82）四手井綱英 1956 林分密度の問題 林業解説シリーズ 86 日本林業技術協会 38P
83）―――・只木良也 1960 材積生産構造図(仮称)の提案(2)－その利用方法と検討－70 回目林講：295～297
84）―――（偏）1963 アカマツ林の造成－基礎と実際－地球出版 326P
85）清水三雄 1959 相対成長 協同医書出版 269P
86）SHINOZAKI,K,,K,YODA,KHOZUMI,and T.KIRA.. 1964. A quantitaive analysis of plant form-the pipe mode1 theory I, basic analysis.Jap.Ecol.14:97-105
87）SJOLTE-JORGENSEN,J. 1967. The influence of spacing on the growth and development of codferous plantation. International review of forestry resarch.2：43-94.
88）SPURR,S.H. 1952. Forest Inventory.Ronald Press Co.,New York,476p.
89）STAGE,AR. 1973 Prognosis model for stand development. U.S.D.A.Forest Serv. Inter, Forest and Range Exp.Sta..Res.Pap.INT-137：32p.
90）只木良也 1963 森林の生産構造に関する研究(IV)－林分及び単木の薬量についての若干の考察－日林誌 45：249～256
91）高橋松尾 1960 カラマツ林業総説 日本林業技術協会 381P
92）高田和彦 1961 受光量に基づく成長過程の擬態分析 13 回目林関東支部講演
93）――― 1963 シミュレーションの林業への応用北方林業 15：65～68
94）――― 1967a 林学における電子計算機による Slmulatlon の研究(Ｉ) 人工林分模型の作製 新潟農林研究 15：98～106
95）――― 1967b 林業における電子計算機による Slmulatlon の研究(II) 天然林の樹木位置図の作製 78 回目林講：63～64
96）――― 1967c 林業と電子計算機 新しい林業統計 日本林業協会 93～135
97）――― 1968 林学における電子計算機による Slmulatlon の研究(III) 針葉樹林分における Bitterlich 法による各種林分材秘推定の比較 79 回目林講：25～26
98）――― 1969 林業における電子計算機による Slmulatlon の研究(4) 断面積推定における Plot samplmg と Point sampling の比較 新大演報 3：27～30
99）――― 1970 林学における Slmulatlon の研究（5）天然針葉樹林の生長モデルにおける胸高断面積生長と関係のある因子について新大浪演報 4：17～20
100）――― 1971 林学における SlmuIatlon の研究(6) 天然針葉樹林分における生長モテルによる短期間の生長予測について 新潟農林研究 23：45～52

101）高田和彦・畠村良二　1972b　林学における　Simulation 研究(7)　ヒバ単木葉量の推定モデル　新大演報　6：
102）———　1972b　林学における Slmulation の研究(8)　スギ,.ヒノキ人工林分における生長モデルによる短期間の生長予測について新大演報　6：51〜60
103）———　1974a　林学における Slmulation の研究(9)　樹高測定における測定不能地点について　新大演報　8：17〜21
104）———　1974b　林学における Simulation の研究（10）Leaf trap の形について　新大演報　8：23〜28
105）坪井睦定　1969　天然林施業のための数量化法について林野庁　研修報告書
106）依田恭二　1971　森林の生態学　築地書館　331P
107）吉田正男　1930　測樹学要論　成美堂　420P

Summary

In recent years, Japanese larch (*Larix leptolepis* GORD.) has been planted as principal species and their plantation area now amounts to ca. 500,000 hectare in Hokkaido district. However, cultural practices such as planting density, thinning schedule and final cutting age are not yet setiled because we have hat a little experience of silviculture.

The object of this study is to develop the simulation model for stand growth of Japanese larch plantation, based on biological observations, which can be used in testing a wide range of the forest treatments.

The stand growth m odel reported here is constr.ucted by incorporating three partial models on the growth of individual trees in the stand (see Fig. 3.1). The outline of each model is as follows;

(1) Height growth model

The differences in height arnang individual trees in the stand of Japanese larch plantation increase with age (see Fig. 2.42). Though the variations in height growth are generally affected by the factors such as planting care, microsite variation, snow damage and genitic origen, etc., it is not possible to relate them to any variables that can be quantified in model terms. Therefore, it has been assumed that the differences are caused by random variation of individual trees. From the assumption following regression equation can be statistically formed:

$$\Delta H'_t = \Delta \bar{H}'_t + \rho_{H'_{t-1}\Delta H'_t} \frac{\sigma_{\Delta H'_t}}{\sigma_{H'_{t-1}}} (H_{t-1} - \bar{H}'_t) + \varepsilon_t \text{ or } -|\varepsilon_t| \qquad \cdots (2.82)$$

This model indicates that height increment of individual tree in the stand on the given site at age t (ΔH_t) depends on its total height at the beginning of the growth period and is simultaneously influenced by random variation. Each symbols in Eq. (2.82) are as follows:

$\bar{H}'_t$; Mean upper.tree height, which depends on stand age and site. The upper-tree is defined as tree of which height growth does not reduce due to suppression or damage.

$\Delta\bar{H}'_t$; Increment of mean upper-tree height at age t $(\bar{H}'_t - \bar{H}'_{t-1})$

$r_{H'_{t-1}\Delta H'_t}$; Correlation coefficient between upper-tree heights at the end of age t- 1 and their increments at age t. The approximate value of $r_{H'_{t-1}\Delta H'_t}$ was estimated to be 0.30 from Fig. 2.46.

$s^2_{\Delta H'_t}$; Variance of annual increments of the upper-tree heights at age t. Their variation depends on a normal distribution (see Fig. 2.44) and variation coefficient was estimated to be 20% from Fig. 2.47.

$s^2_{\Delta H'_t}$; Variance of the upper-tree heights at age t, which can be expressed by the recurrence formula as follows

$$\sigma^2_{H'_t} = \sigma^2_{H'_{t-1}} + \sigma^2_{\Delta H'_t} + 2(\sigma_{H'_{t-1}} \sigma_{\Delta H'_t} \rho_{H'_{t-1}\Delta H'_t}) \qquad \cdots (2.79)$$

ε_t ; Random variable depended on normal distribution with mean=0, variance=. $s^2_{\Delta H'_t}\left(1-r^2_{H'_{t-1}\Delta H'_t}\right)$ It is given, $+\varepsilon_t$ when H≧mean clear length of the stand and $-|\varepsilon_t|$ when H ＜mean clear length. From above model, heightof each tree at age t is given by

$$H_t = H_{t-1} + \Delta H_t. \qquad \cdots (2.83)$$

(2) Area occupancy model for individual tree

In present thesis, the area occupancy is defined as area available to a tree in the stand. The determination of the area occupancy can be made by the mesh method the stand map is covered by the mesh with short intervals and the tree occupying a given point is judged by maximum value in judgment factors from the point to neighboring trees, then the area occupancy of a tree could becalculated from number of points occupied by its tree (see Fig. 2.32-2.34 and 2.36).

The judgment factor used here is

$$SF_{ij} = (R_{0j}/L_{ij})\, CF_j.$$

Where each symbols are as follows:

Ro_j ; Radius available to a tree j in terms of area occupied by an open-grown tree,

$$R_{0j} = \frac{1}{2} H_j^{0.8961} \qquad \cdots (2.75)$$

L_{ij} ; Distance from point to tree j.

CF_j ; Competition factor of tree j, weighting to take into account the intensity of competition between trees, where total height of tree j is taken as weight,

$$CF_j = H_j. \qquad \cdots (2.76)$$

Hence, judgment factor is as follows :

$$SF_{ij} = H_j^{1.8961}/2L_{ij}. \qquad \cdots (2.77)$$

An example applied the mesh method to an unthinned, overcrowded stand of Japanese larch is shown in Fig. 2.37. The result shows that area occupancies computed by the model are proportional to crown projectional area (see Fig. 2.37, 2.38).

(3) Allometric model between height and diameter

From meaurements of the open-grown trees of Japanese larch ranged in height from 2 to 30 meter (Table 2.1), the allometric relations were found between height and diameter, crown sizes as shown in Fig. 2.5, 2.9, 2.10 and Eq. (2.23) respectively. The results indicate that the open-grown tree maintains growing in a certain tree form with growth stage and especially, note that relation between height above brest height (H_B) and diameter at brest height (Do) is of isometric $(dD_o/D_o = dH_B/H_B)$ and constant ratio of crown length (crown length/total height) of 0.785 is keeped over all growth stage.

On the other hand, from survey for actual crowded stand it could be concluded that the live crown of close-grown tree limited in area occupancy will recede from its base to upper stem with height growth and stem radial growth will decrease progressively downward, and then the tree will stop growing and begin to die when ratio of crown length reaches at 0.160, e. i. limit height H*（see Fig. 2.16, 2.17, and Table 2.8).

Based on above observations, the following model can be formed for individual trees in the closed stand

$$\frac{dD_{ij\cdots n}}{D_{ij\cdots n}} = \frac{dH_B}{H_B}\gamma_{ij\cdots n}\{1-P'_{ij\cdots n}(H)\}. \qquad \cdots (2.69)$$

Where subscript ij...n represents that area occupancy of the tree has been changed from S_i to $S_{j,\cdots,}S_n$ according to the release by death or thinning of neighboring trees. $P'_{ij\cdots n}(H)$ shows the closing grade defined basically by Eq. (2.28) which indicates the amount of relative reduction of crown width of the close-grown tree to the open-grown tree at the identical growth stage in height H. $\gamma_{ij\cdots n}$ is the opening coefficient defined by Eq. (2.68) which indicates a increase of assimilation rate of the tree according to the release by thinning of neighboring trees.

A computer simulation system for the stand growth was composed of three basic models disscused above (see Fig. 3.2). The program for computer simulation were written by the author in Fortran IV and named SMSGL for short.

Besides both basic data, planting interval and mean upper-tree height over age (Fig. 2.51), some additional parameters as shown in Table 3.1 are inputted to job of the SMSGL

The SMSGL inputted above data outputs the tree arrangement of initial stand of 5 years originally (see Table 3.2), and then simulates subsequent stand developments in the order of height growth, area occupancy and diameter growth based on the individual trees at every years up to 30 years and at intervals of 5-year after 30 years. When thinning schedule such as time and number of released trees inputs, the SMSGL is able to simulate stand growth under given schedule.

The efficiency of the SMSGL was examined for unthinned stands with different initial density on the same site (see Table 3.3) in chapter 3 and thinned stands under the two kinds of thinning schedules on the three site classes (see Table 4.2) in chapter 4 respectively.

Simulated results proved that the SMSGL could depict the effect of different density control of stand with reasonable accuracy. Now, the SMSGL is prepared for predicting growth and yield or testing any silvicultural tretments that the forest manager wishes to test.