PLANNING FOREST ESTABLISHMENT OPERATIONS WITH A COMPUTERISED DECISION-SUPPORT SYSTEM: A CASE STUDY ANALYSIS OF DECISION-MAKING OVER A FULL ROTATION

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ABSTRACT

Existing components of a forest establishment decision-support system (DSS), including a model of the initial growth of *Pinus radiata* D.Don sensitive to site preparation, a knowledge-based module for designing establishment strategies, and a knowledge-based system for selecting herbicides, were combined with the STANDPAK stand modelling system (which integrates growth and yield models with models of stem defect and log valuation) and a spreadsheet in order to design a cost-effective establishment regime for *P. radiata* on a specific site. The exercise showed that there were some important deficiencies in models, and software components need to be better integrated.

Keywords: forest establishment; artificial intelligence; decision-support systems.

INTRODUCTION

Pinus radiata is the predominant species in New Zealand's forest plantations, occupying approximately 1.4 million ha throughout the country. Managers have been growing the species for well over 100 years, but they often make decisions about how best to establish plantations with no explicit analyses of the long-term benefits of any treatments adopted. Analyses of cost-effectiveness of site preparation which evaluate only the short-term effects of treatments have been advocated (Payandeh 1987; Belli 1987), but these vary in their rankings of alternatives. A decision-support system (DSS), under development since 1989, allows an informed analysis of alternatives as well as knowledge-based advice about the process of plantation establishment (Mason 1992, 1994). Components which currently exist are:

(1) A knowledge-based module which assists managers in designing establishment regimes using heuristics;

(2) The Vegetation Management Tools (VMT) computer program which assists with choices of alternative treatments to meet specific objectives of the regime with a consideration of costs and effectiveness; and

(3) An initial growth model (IGM) which predicts the responses of young crops of *P. radiata* to weed control, ripping, mounding, nitrogen and phosphorus fertiliser, initial stocking, and macrosite variables represented by altitude.

These components are represented in stand-alone computer packages, and it is planned that they will be integrated with models of growth later in a rotation, stand record systems (or geographic information systems), and an appropriate financial analysis package to provide a comprehensive, user-friendly, decision-support system for establishing forest plantations (Mason 1994). The Vegetation Management Tools program is implemented as a decision-framework, and the validity of its recommendations is very highly dependent on the validity of the data which local experts in vegetation management can enter without altering any program code. Some of the information currently entered describing weed behaviour in the central North Island region is not fully validated, and studies are being carried out to improve this (B. Richardson, pers. comm.). The effects of applying chemical mixtures to weeds in different physiological states, however, have been tested scientifically (Preest 1985; Preest & Davenhill 1986).

The study described here involved using existing DSS components, growth and yield models, and cash-flow analyses, as envisaged by Mason (1994), to make decisions about how best to establish *P. radiata* on a specific site. The aim of the study was to identify whether the existing framework was easy to use, what problems arose, what assumptions were required, and whether the DSS design was sound.

The case study also provided a site-specific assessment of the financial value of weed control on one site, but this was an incidental result, and far less valuable than the evaluation of the decision-making system.

SITE DESCRIPTION

The site posited for the study was typical of the central North Island region of New Zealand at 180 m a.s.l. The soils were pumice sands, and weed growth comprised grasses, gorse (*Ulex europaeus* L.), and broom (*Cytisus scoparius* L.). A site index of 35 m was expected, and basal area productivity was initially set at "high" within model EARLY (*see below*).

The crop planned was *P. radiata* managed on a direct-sawlog regime with a final crop stocking of 300 stems/ha. The tending regime (Table 1) was designed using the New Zealand Forest Research Institute STANDPAK modelling system (Whiteside 1990; Goulding 1994).

TABLE 1–Tending regime selected for the case study

Year (month)	Treatment
4 (July)	Prune 500 stems/ha to leave 3.5 m of crown
4 (July)	Thin to waste, leaving 500 stems/ha
5 (June)	Prune 500 stems/ha, leaving 3.5 m of crown
6 (October)	Prune 300 stems/ha to 6.2 m
6 (October)	Thin to waste, leaving 300 stems/ha
10 (July)	Switch from model EARLY to model PPM88

DSS RECOMMENDATIONS

Designing an establishment regime with the DSS involved using a knowledge base with ESTA, a knowledge-based shell (Prolog Development Centre 1993). The knowledge base consisted of a large set of rules, and these were used with a backward chaining inference engine which operated within sections. Each section was accessed via a simple form of forward chaining, with users of the system being asked a series of questions about their sites (Appendix 1). The system combined their answers with the knowledge base to design regimes to suit their sites. There was provision for the system to explain why any particular question was being asked and why any specific advice was offered. The interface made as much use of pictures as possible, and almost all responses could be made by pointing and clicking with a mouse. The program was implemented under the Microsoft Windows operating system.

This module did not optimise numerically. Instead, the rationale that might be used by an experienced forest manager was modelled within the knowledge base, after a series of detailed interviews with the manager. Consideration of options was relatively abstract, but not to the point where the knowledge base could be safely used for decisions in other regions or for crop species other than *P. radiata*.

The establishment regime design module recommended:

(1) Aerial spraying a systemic herbicide during the spring prior to planting;

(2) Burning the desiccated weeds (the regime design module asked users if burning was feasible—it is often considered infeasible because of risk or environmental concerns);

(3) Aerial spraying juvenile weeds late in the summer prior to planting; and

(4) Spot spraying during the spring after planting.

This regime was then planned in detail with the assistance of VMT, moving the site through time and identifying the most cost-effective ways of implementing the recommendations of the regime module. VMT was written in PDC Prolog (Prolog Development Centre 1992), and used a combination of backward chaining, frames, and numerical analyses to design treatments to perform specific tasks recommended by the regime module. Users specified the extent of particular plant species on the site, the plants' heights, the season, the dimensions of any tree crop on the site, and whether each species should be retained or killed. The system predicted other information, such as the physiological state of each species and the coverage of seeds from each species. Users could override any predictions made by the software. Output from VMT (*see* Appendix 2 for an example of a herbicide prescription provided by VMT) included recommendations concerning specific mixtures of any chemicals required, the costs of chemicals and any physical treatment methods, the effects of any treatment on each of the weeds present, the length of time the treatment would take, and any effects on other parts of the site (such as soil compaction, slash removal, and exposure of mineral soil). The system could print a prescription sheet to be sent to a field crew.

Integration of the regime module with VMT and automation of the growth of sites through time would have made the task easier. In addition, links with a forest management information system would have reduced the amount of input required.

STAND GROWTH MODELS

The initial growth model (IGM) (Mason 1992; Mason & Whyte in press) was represented in PDC Prolog under MS-DOS, with a graphical user interface (MS-Windows and OS/2 PM versions are also available). Users began by entering the expected mean height, maximum height, and variance of the heights of their seedlings immediately after planting. A control window allowed users to enter the altitudes of their sites and the initial stockings of their crops, and buttons could be clicked to indicate whether or not weeds were controlled, soil was ripped, soil was mounded, or 80 g diammonium phosphate had been placed in a slit next to each tree. Four different sites or site preparation regimes could be compared on the screen simultaneously. Graphs of mean height, basal area, survival, height distribution, and diameter were created for the first 5 years after planting.

The IGM predicted that weed control would add 1 year's growth (almost 2 m in height) by age 4 and make the crop more uniform. An additional small gain in survival was predicted if the soil were cultivated. It should be noted that for the Kaingaroa region, only limited validation of the IGM has been carried out (Mason 1992), and whilst this validation showed that the model fitted well to measurements of actual tree growth in Kaingaroa Forest, more comprehensive validation of the model for the Kaingaroa region is needed.

A model sensitive to different levels of weed competition would have been more desirable, but the predicted differences were similar to those observed at a site with grass and brushweeds in the central North Island (Mason *et al.* 1995).

Choosing a selection ratio (ratio between numbers of stems planted and numbers left in the final crop) requires an estimate of the frequencies of stem defects within the crop prior to thinning. As all models apart from PPM88 (Garcia 1990) assumed relatively unimproved genotypes, and no predictions of stem defect were available, a selection ratio of 3.33 for the site without weed control was chosen. This selection ratio was typical in the region prior to the advent of highly improved breeds and the use of cuttings from aged parents.

In order to evaluate effects over a rotation, models within the STANDPAK (Whiteside 1990) framework were employed. The STANDPAK system contains several integrated modules which represent the growth of *P. radiata* from age 3 to harvest, and forecasts the log assortments resulting from a variety of tending practices, final-crop stockings, and rotation lengths on a variety of sites. Links were necessary between the IGM and model EARLY (West *et al.* 1982), and between EARLY and model PPM88 (Garcia 1990). The latter linkage is automated within the STANDPAK program, but users must ensure the basal area growth predictions match at the point of linkage, as predictions of growth made by different models should be the same at those ages where they are linked. The first link attempted between EARLY and PPM88 was highly unsatisfactory (Fig. 1) suggesting that the "high" level of basal area growth selected by the user for EARLY was incorrect. However, it was found that the IGM and PPM88 were in close agreement (Fig. 2), and so basal area growth was adjusted in EARLY until a reasonable match was achieved with the predictions of the other two models (this occured when basal area was set at "high –20%") (Appendix 3). The EARLY growth model is meant to be adjusted in this way, but getting the models to match was an interactive procedure of adjusting EARLY, transferring model outputs from STANDPAK to a spreadsheet, and then inspecting graphs of basal area increment; it should be completely automated with knowledge-based code so that users do not need to check that the derivatives match.

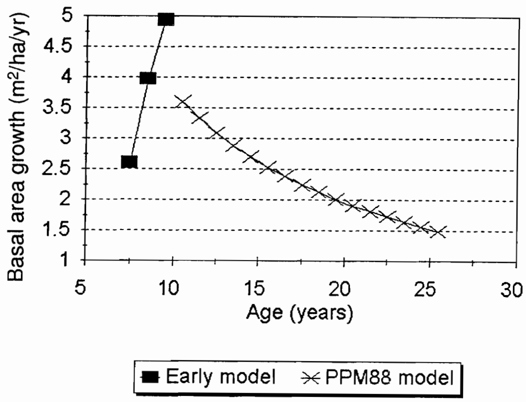

FIG. 1–Basal area growth initially predicted by EARLY and PPM88 models.

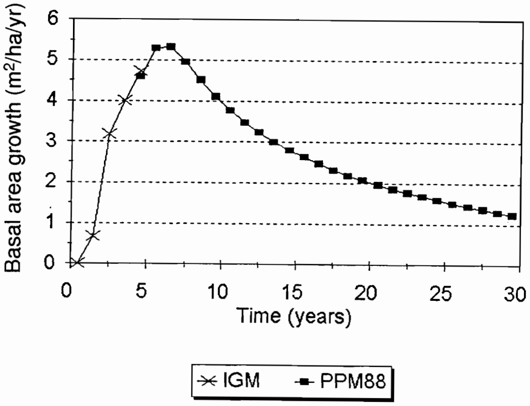

FIG. 2–Basal area growth predicted by IGM and PPM88 (no thinning)

As EARLY and PPM88 do not model changes in stand size distributions through time, it was necessary to assume that the dbhob distribution was unaffected by weed control, contrary to the prediction of the IGM. The selection ratio was lowered to 2.5 for the predictions with weed control to take the reduced variability predicted by the IGM partly into account. The practical effect of this change was to lower establishment and thinning costs.

ECONOMIC ANALYSES

Gains in yield due to establishment practices such as site preparation and weed control are likely to be poorly estimated by simply changing site index (Glass 1985). Some changes may be temporary, while others might affect growth throughout a crop rotation. An establishment DSS should either incorporate models sensitive enough to predict the effects of such practices throughout a rotation or allow users to test assumptions about the long-term effects. As suitable models were available only for crops between ages 0 and 5, the latter method was used for this case study.

Comparisons between stands treated during the establishment phase and those untreated have been classified as parallel, divergent (Snowdon & Waring 1984), or convergent (Richardson & West 1993). Mason (1991, 1992) defined parallel growth trajectories as those which retain a consistent difference in the times taken to reach equivalent yields. He proposed that the following assumptions were required if a change in management was considered to produce a yield trajectory parallel to that of an otherwise equivalent stand (following an initial divergent response):

(1) The change in growth inputs due to the new management practice must be temporary, with site quality in the treated and untreated blocks returning to an equivalent potential after a time;

(2) The site should be capable of supporting more rapid growth—that is, the growth input increase should not result in some other deficiency at some point during the crop rotation;

(3) Future treatments, such as thinning, should not bring about a resumption of the treatment effect;

(4) There should be no significant change in allometric relationships caused by the treatment, such as ratios between root and leaf surface areas; and

(5) There should be no significant physiological age differences between the treated and untreated stands at respective times of equivalent yields.

In order to evaluate long-term effects of establishment practices on productivity and returns with current models, it makes sense to use an approach which involves shifting time (Mason 1992, 1994). Given the likelihood that some of the assumptions listed above would be violated, software used to test the effects of alternative establishment practices on financial productivity should allow users to test alternative assumptions about changes in yield trajectories with different treatments.

The economic analysis module in STANDPAK was not designed to make comparisons based on time shifts, and so a spreadsheet was programmed to accept log grade outputs from the STANDPAK system. The spreadsheet allowed users to plot net present values (NPV) of projects assuming parallel, divergent, or convergent time gains for different treatments. This process requires that one assume assortments of logs are equivalent after different establishment treatments for any given yield, as neither EARLY nor PPM88 represent crop size distributions through time.

Plots of NPV against rotation age with and without weed control, assuming parallel yield trajectories at a 7% interest rate (pre-tax), are shown in Fig. 3. Given the conservative assumption that trajectories of treated and untreated crops would be parallel after the initial growth gain, weed control would be financially worthwhile on this site. Given that weed control would also make the crop more uniform and that there could be some further divergence of the two growth trajectories, a manager could confidently spend the $730/ha required after the analysis described above.

CONCLUSIONS

Existing tools allow decision-making related to crop establishment which takes full advantage of current knowledge and models, but further work is required to make the knowledge-based programs and stand models compatible.

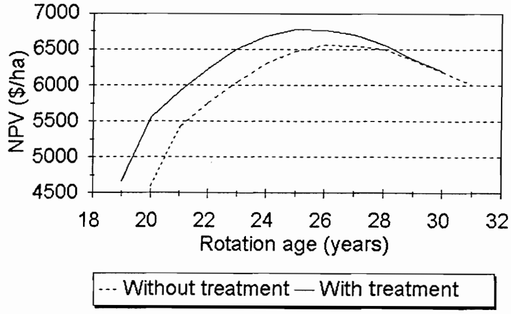

FIG. 3–Net present value per hectare of the project with and without weed control, assuming parallelism and a 1-year time gain due to weed control at a 7% rate of interest.

The vegetation management DSS works, but better integration of the regime design and specific treatment selection components, as well as validation, are essential. Models IGM and PPM88 made almost identical predictions of basal area growth on this site, and model EARLY was adjusted to fit reasonably. Such links and adjustments should be automated, and not left to the discretion of users.

Models are needed which represent sites over the lengths of rotations in detail, including such variables as crop size distributions, weed behaviour, and site productivity, with more sensitivity to site management practices than most existing models.

ACKNOWLEDGEMENTS

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APPENDIX 1

THE USER'S DIALOG WITH THE REGIME ADVISOR

System: "This system will assist you in designing a strategy for vegetation management. It is not meant to provide precise treatment prescriptions with costs, but it will indicate what are generally thought to be good strategies for your site.

Simply answer the questions the system asks, but please do NOT use the unknown option in the menus with this version.

When you have a strategy sorted out, you can use the program called Vegetation Management Tools to explore detailed treatments within your strategy.

Responsibility for decisions made with this system lies entirely with the user."

System: "What is the predominant cover on your site?"
User: "Brushweeds"
System: "Has the tree crop been planted?"
User: "No"
System: "What is the current season?"
User: "Spring"
System: "Has the site been oversown?"
User: "No"
System: "Is grass present on the site?"
User: "Yes"
System: "Are out-of-season frosts likely to occur on the site?"
User: "No"
System advice: "Use a herbicide that does not kill the grass but kills the brushweeds."

System: "What is the average slope of the site (in degrees)?"
User: "2"
System: "What is the level of slash and debris on the site?"
User: "None"
System: "Is burning feasible on the site?"
User: "Yes"
System advice: "Clear the site during the summer by crushing and burning.

During the late summer or early autumn after the brushweed seeds germinate, you should apply a chemical to kill the brushweeds while they are still juvenile.

Graze the grass heavily if possible, but retain a good grass cover if you can.

Plant during the winter, and apply a spot spray of a chemical which kills grasses but does not affect trees in the spring.

If there is any further germination of the brushweeds, you may have to spray again during the summer."

System: "Is the site fenced, or can it be fenced?"

User: "No"

System advice: "Brushweeds are likely to germinate on this site, and you should be prepared to control them every time you attempt other vegetation control. Use program Vegetation Management Tools to find treatments for controlling mixtures of weeds."

System: "Are summer grasses present on the site?"

User: "No"

System advive: "Spot spray during the early spring to kill the grass around trees."

System: "Are herbaceous broadleaves present on the site?"

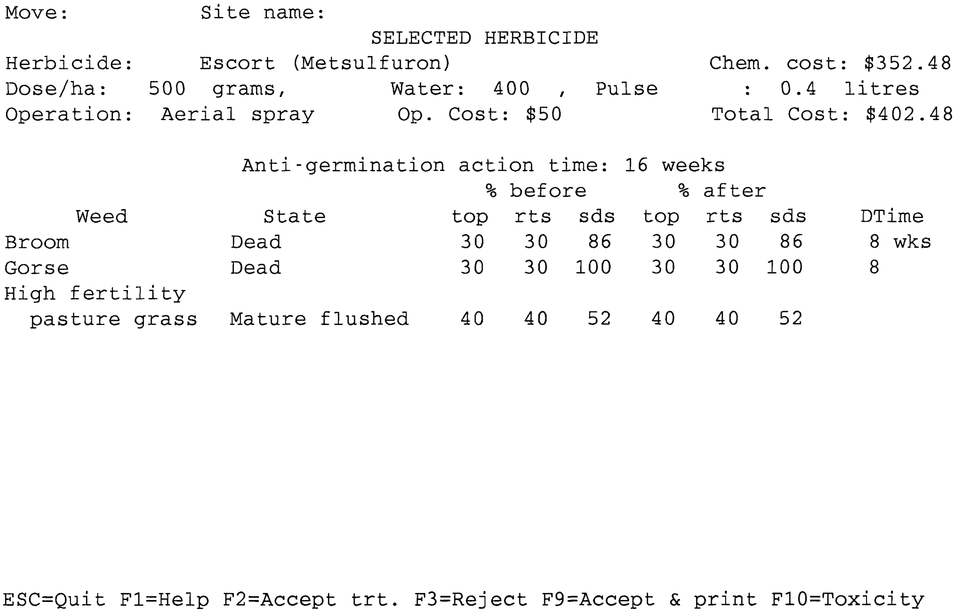
User: "No"

System advice: "You should keep the area around the base of trees clear for at least two years following planting. There are clear benefits of such a strategy, and even longer-term weed control may be worthwhile.

Goodbye"

APPENDIX 2

HERBICIDE RECOMMENDATION FROM VEGETATION MANAGEMENT TOOLS



```
Move:           Site name:
                                 SELECTED HERBICIDE
Herbicide:      Escort (Metsulfuron)                    Chem. cost: $352.48
Dose/ha:    500  grams,        Water:  400  ,  Pulse      :  0.4  litres
Operation:  Aerial spray       Op. Cost: $50            Total Cost: $402.48

                    Anti-germination action time: 16 weeks
                                   % before       % after
     Weed             State       top  rts  sds  top  rts  sds    DTime
Broom               Dead           30   30   86   30   30   86     8 wks
Gorse               Dead           30   30  100   30   30  100     8
High fertility
  pasture grass     Mature flushed 40   40   52   40   40   52





ESC=Quit F1=Help F2=Accept trt. F3=Reject F9=Accept & print F10=Toxicity
```

This text-based screenshot was taken from the MS-DOS version of VMT. VMT is now available for MS-Windows.

APPENDIX 3

SAMPLE OUTPUTS FROM MODELS USED IN THE CASE STUDY

Central North Island Initial growth model:

```
Alt: 180  Weed Control: Y Rip: N Disk: N DAP Ft.: N Init. Stems/ha.: 1000
Trees/Plot?: N

Age Stems/ha Height    Ht. Distribution       G          DBH Distribution
(yr)           (m)      a       b       c    (m2/ha)     a        b       c
 0     1000    0.30   0.40   0.112   1.858    0.00     0.00    0.000   0.000
 1      944    1.00   1.50   0.558   3.358    0.00     0.00    0.000   0.000
 2      925    2.29   3.26   1.088   3.017    1.92     0.00    0.000   0.000
 3      912    3.97   5.40   1.600   2.752    5.77    10.81    2.113   1.226
 4      901    5.97   7.81   2.072   2.525   10.59    15.54    3.908   1.646
 5      891    8.25  10.46   2.492   2.320   16.31    20.09    5.699   2.022

                   Distributions (trees/plot or trees/ha)
H:   1   2   3   4   5   6   7   8   9   10  11  12
Age
4    -   -   -  36 207 414 234   9
5    -   -   -   -   9  45 151 303 294  89

D:   1   2   3   4   5   6   7   8   9   10  11  12  13  14  15  16  17  18  19
Age
4    -   -   -   -   -   9  18  27  54  81 117 153 171 162  99
5    -   -   -   -   -   -   -   9  18  27  36  62  80 107 125 134 125  98  53
```

Standpak output from EARLY and PPM88:

From growth module (Models EARLY and PPM88):

```
             ----------------------------------------
            |              S T A N D  G R O W T H      |
            |    Stand Treatment and Growth Simulation |
            |                Version 5.02              |
            |          Forest Research Institute       |
            |                 New Zealand              |
             ----------------------------------------

University of Canterbury                          Fri Jan 13 14:29:35 1995
CNI1                                                              #028-37CA
===========================================================================

  Growth Model        : 23 EARLY  Run Name         : CNI1
  Basal area fn.      : High      Crown fn.        : Pumice Plateau
  Basal area adj.     : -20.0%    DOS adj.         : 0.0 0.0 0.0 0.0 0.0 cm
  Height Model        : 34        Site Index       : 35.0 m
  Stand Volume fn.    : 29        Start Date       : 1997 JUL (4.0)
  Monthly Growth fn. :  1         Mean Top Height  : 5.4 m

  Growth Model        : 22 PPM88  Run Name         : CNI1
  GF rating           :  7
  Height Model        : 34        Site Index       : 35.0 m
  Stand Volume fn.    : 29        Start Date       : 1997 JUL (4.0)
  Monthly Growth fn. :  1         Mean Top Height  : 5.4 m
```

```
                         STANDING YIELD
                         --------------

 Age       MeanTopHt       BasalArea       Stocking
 yrs           m             m²/ha         stems/ha
 4.0          5.4            7.85            838
>> PRUNED (Date) 838 stems/ha to leave 3.5 m. of crown
 4.0          5.4            7.85            838
>> THINNED stand (least prnd) to waste leaving 500 stems/ha
 4.0          5.4            5.20            500
 4.9          7.4            8.92            500
>> PRUNED (Ht ) 500 stems/ha to leave 3.5 m. of crown
 4.9          7.4            8.92            500
 5.0          7.4            9.09            500
 6.0          9.4           12.39            500
 6.3         10.0           13.56            500
>> PRUNED (Ht ) 300 stems/ha to 6.2 m.
 6.3         10.0           13.56            500
>> THINNED stand (least prnd) to waste leaving 300 stems/ha
 6.3         10.0            8.50            300
10.0         17.4           17.94            300
>> SWITCHED to later model set from G23 H34 V29 M1

 Age       MeanTopHt       BasalArea       Stocking
 yrs           m             m²/ha         stems/ha
10.0         17.4           17.94            300
20.0         34.4           46.42            295
21.0         35.8           48.44            294
22.0         37.2           50.36            293
23.0         38.4           52.19            293
24.0         39.7           53.92            292
25.0         40.8           55.58            291
26.0         42.0           57.15            290
27.0         43.0           58.66            289
28.0         44.1           60.09            288
29.0         45.0           61.47            287
30.0         46.0           62.78            286
31.0         46.9           64.04            286
```

From the log grade module (volumes of grades at a range of clearfelling ages):

```
Clearfell   PR1,    PR2,    PR3,   S1S2,   S3L3,   L1L2,   PULP,   Total,  Waste,
 Age,
 20.0,      0.1,    17.6,  129.7,   35.6,  147.7,   45.8,  104.1,  480.5,   6.7
 21.0,      0.4,    42.9,  116.2,   43.4,  157.9,   55.7,  105.6,  521.9,   7.3
 22.0,      1.1,    54.8,  114.0,   55.6,  149.2,   74.5,  113.7,  562.9,   7.9
 23.0,      2.2,    66.3,  111.0,   64.1,  159.4,   88.4,  111.2,  602.6,   8.6
 24.0,      4.1,    77.1,  107.5,   81.3,  153.2,  103.4,  116.0,  642.5,   9.2
 25.0,      6.7,    86.8,  103.7,   95.8,  146.6,  127.9,  113.3,  680.8,   9.8
 26.0,     17.7,    87.8,   99.7,  102.5,  155.2,  141.4,  114.1,  718.5,  10.4
 27.0,     23.5,    93.4,   96.1,  111.8,  151.5,  163.1,  115.7,  755.2,  11.0
 28.0,     29.9,    97.9,   92.3,  117.3,  164.5,  177.5,  112.0,  791.5,  11.6
 29.0,     36.8,   101.4,   88.7,  123.6,  165.7,  194.8,  114.9,  825.9,  12.1
 30.0,     44.0,   104.1,   85.3,  132.3,  156.7,  216.2,  121.5,  859.9,  12.7
 31.0,     51.5,   106.0,   82.0,  140.3,  160.8,  234.3,  117.9,  892.9,  13.2
```