

**Maximizing Wildlife Benefits Through Hardwood Timber Harvest Scheduling**

by

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(ABSTRACT)

A computerized system for planning timber harvest to maximize habitat quality over time for a specified group of wildlife species was developed for upland oak forests of the Eastern United States. This system, called WILDWOOD for WILdlife/WOOD optimization system, is designed to run on a microcomputer. It utilizes a widely available database management system called PCFile III, Version 4, a forest growth and yield simulator adapted from work by Dale (1972), and a program developed by the author. The system utilizes 43 species-specific habitat value models developed by the author and others. Timber harvests in approximately one ha blocks (patch clearcut) are specified for each year to result in a maximum yearly average wildlife benefit figure. Wildlife benefits are defined as the product of a wildlife species value provided by the user, a forest-size-class-specific habitat value index, and the area of the cutting unit.

WILDWOOD was demonstrated on a 106 ha tract of upland oak forest on Havens Wildlife Management Area of the Virginia Commission of Game and Inland Fisheries. Six different objective functions were investigated and several model tests were conducted. Implications for the application of the WILDWOOD system were discussed, and it was concluded that, although the objectives of the study were met, the current WILDWOOD system should be modified to include smooth wildlife habitat succession models, at least a 150-year planning horizon, and capabilities for addressing cutting unit size, shape, and juxtaposition. Other possibilities for future revisions include modifying HEP (U.S. Fish and Wildlife Service) for use with WILDWOOD, and linking a geographic information system to WILDWOOD.

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# Introduction

In recent years, the profession of wildlife management has been characterized by dramatic, inescapable change. Pressure from a demanding public has increased not only the traditional, game-oriented management problems, but also, wildlife managers have been given the responsibility for a wide range of non-game species. Just the number of species for which conspicuous responsibility has been assigned has increased by a factor of over 20.

The complexity of the current management problem is tremendous. Over the course of a year, the average wildlife professional may be required to comment on development plans that will affect wildlife habitat, provide mitigation plans for approved projects, provide detailed information on species and habitat loss after a toxic waste spill, plan harvests for various game species, plan habitat improvements for both game and non-game species, and keep track of all the federally listed species known to occur in an area of concern. Intuitively, no one person can be an expert on all the species in question. To meet current demands, wildlifers are either making decisions based only on their own experience or they are spending a good portion of each year compiling and assimilating information.

A need exists for systems that will help the wildlifer cope with complexity (Hayne 1969, Fraser 1985). These systems should be quickly and easily learned, otherwise wildlifers will not be willing

to invest sufficient time to become adept with the process. These systems should (1) be widely available, (2) use the minimum amount of equipment possible, and (3) they should be robust, because no amount of preplanning will take into account all possible future applications. Finally, these systems should provide a closed, easily accessible feedback loop to encourage an ever improving, dynamic system, not one that decays over time (Grayson 1973, Giles 1979). In short, we need to fill in "the missing middle" between data collection and management action (Fraser 1985). A working management system takes into account all the inputs, processes, and outputs within the context of the problem and then provides a feedback mechanism for constant improvement of the system (Giles and Scott 1969).

Computerized planning and resource analysis systems do not have a particularly good record against this list of criteria. Although most systems are theoretically sound, some even brilliant, few if any have made serious inroads into the everyday activities of the wildlife profession. They fail at a number of points, the most serious of which are their ease of use and availability. The recent popularity of microcomputers with the inevitable but somewhat lagging development of good software has improved the chances that these two sticking points can be overcome.

Similar conditions in computerized management tools can be found in many natural resource disciplines. Forestry is one of the most technically advanced disciplines in the field of computerized planning aides. For many years, the forestry profession has embraced the operations research techniques developed during World War II (Dantzig 1963, Dargavel and Bethune 1972, Field 1984, Gregory 1958, Hall 1967, Hillier and Lieberman 1967, Martin and Sendak 1973). The most notable application of computerized land management planning is probably the adoption of the FORPLAN system for national forest planning. This one application has brought about an increased acceptance of operations research techniques throughout the forestry profession (Field 1984).

Forestry parallels wildlife management in that both deal with a complex, dynamic resource, and limited availability of time and money (Duerr et al. 1978, Thomas 1985), consequently, study of

techniques and methods applicable to this similar system may be productive for wildlife problems especially those that pertain to habitat management. Forest management may be considered to be a part of wildlife management, therefore many habitat management concepts and models exist already (i.e., disguised as timber management, succession, or growth and yield models).

Despite the widespread availability of computerized planning tools for foresters, several glaring needs are apparent. Most systems were and are still designed for large landholdings. These systems require large, expensive mainframe computers, and specialized staff. Several attempts have been made to provide microcomputerized systems for small landowners (Belcher 1982, Hepp et al. 1985, Perkey 1985), but few have been designed to provide a capability for maximizing benefits for small landowners in the upland oak ecosystem.

Given this situation with a related but more technically advanced field, it is not surprising that microcomputerized wildlife habitat optimization systems are a new concept for the wildlife profession. Many problems were identified at the beginning of this study. The first and foremost was creating a method for describing the relationship of forest succession to wildlife habitat quality for wildlife species of interest. For a given species, habitat quality changes with stand age. This is the underlying principle that drives the system described in the following pages. This principle has been described in detail for many years and is the mainstay of much ecological literature and wildlife habitat management programs in forested ecosystems. Stand age is directly related to almost all the habitat parameters that are used to describe the requirements of forest dwelling species (e.g., basal area, mean diameter-breast-height, canopy closure, forb density, shrub density, species composition, ambient temperature, depth of organic matter, snag density, etc.) so it is not surprising that stand age is often considered to be the one most important control variable for forest wildlife systems.

The opportunity exists for wildlifers to modify forest harvest scheduling systems to optimize habitat for wildlife species rather than monetary return from timber harvests. The following is a report on the development and first applications of such a system.



## Objectives and Scope

The main objective of this study was **to create a timber harvest scheduling system for the upland hardwood ecosystem of western Virginia that would plan wood cutting to optimize wildlife habitat over time for a set of wildlife species.** Numerous secondary objectives were also identified.

### *Objectives*

1. **Create a forest management system for small woodland owners who are primarily concerned with wildlife management, but who are not averse to timber cutting.**

Many owners of small woodlands are interested in other than economic values of their land (Giles 1981, Giles 1978, Moss and Fraser 1985). Wildlife observation and hunting are highly valued activities by many people (Giles 1978). Few forest management aides, especially harvest scheduling aides, currently exist for this class of forest landowner even though many acres of land fall into the small nonindustrial landowning classification (Hamner 1975, Hendricks and Harrison 1985, Rauscher et al. 1986). Many of these holdings are currently unmanaged, con-

sequently an opportunity exists for the wildlife profession to bring large acreages into a wildlife management program if the technique is inexpensive and easy for the landowner to use.

2. **Demonstrate that this system can be run on a microcomputer, to allow for maximum impact on the wildlife resource.**

Microcomputers are becoming a pervasive part of current society (Naisbett 1984, Koshland 1985). Although mainframe computers are powerful, accessing difficulties and high costs discourage their use. Microcomputer hardware and software have been vastly improved in the past 5 years so that now many school children have at least rudimentary training in their operation. This trend appears to be accelerating both in the general population and the natural resources professions. In addition, most wildlife personnel in this country do not have access to a mainframe computer, but they do have access to microcomputers.

3. **Demonstrate an application of Biota Of Virginia (BOVA), a computerized fish and wildlife information system (CFWIS).**

CFWIS's are essentially computerized libraries of fish and wildlife information that can be manipulated in any way that journal articles or books can be manipulated but at a tremendously faster rate. These systems are growing in popularity and currently are being maintained or implemented by 11 state fish and wildlife agencies. BOVA consists of approximately 175 elements (types of information) for 978 fish and wildlife species. One element of information is a modified version of the U.S. Forest Service's forest size classification scheme. Each wildlife species is coded for known association with a given forest size class. These stand size classes imply a classification system for stand age although the two do not have a linear relationship.

4. **Demonstrate that computerized timber harvest prescriptions can be presented in a manner helpful to wildlife managers.**

Output and instructions for the user must be explicit. No ambiguities should exist in terms of the generated plan of timber harvesting, or the predicted results from that plan. At the same time, emphasis should be put on the management plan as a guide to and not a constraint on the managers' actions. No system can take into account all the vagaries of natural systems. Computer-generated plans should only provide a framework within which the manager can work, releasing the manager from repetitive tasks that would not or could not be completed without technical assistance.

**5. Investigate the practicality of the resulting system in terms of time and effort required.**

Ease of use is a prime concern. To investigate this question, a demonstration was completed on an area within Havens Wildlife Management Area near Salem, Virginia. The number of crew hours required to complete a medium size harvest plan should give potential users an idea of the efficacy of this system as opposed to more traditional methods.

## *Scope*

A number of ancillary issues surfaced during the preplanning phase of this project, and their explanation may help the reader better understand the objectives of this work. First, the components of the system developed were not to be original contributions by the author. The task was seen as largely synthetic. Each component is documented from the forestry, wildlife, or operations research professional literature. The desire was to present a system that integrates these components and provides a means for addressing the harvest scheduling problem. If better components can be found (e.g., a better forest simulator, better data for a given species, etc.), then those new components, by design, can easily be incorporated into the system. Poor results from the system developed may not be the fault of the system itself but a failing in one of the components. The answers

are only as good as the data inputs, and algorithms. The data are the best currently available in wildlife management, so unsatisfactory results may only indicate a need for further research into some aspect of the biology of the component systems (either forest or wildlife species).

The numbers generated in the ensuing harvest plans are intended as planning tools or guides. They are not linearly related to population density since population density is difficult to measure and sometimes a poor indicator of habitat quality (Van Horne 1983, Best and Stauffer 1986). Similarly, the wood volume figures are probably no better than most forest growth and yield simulators that may vary by as much as 30-40 percent (Avery and Burkhart 1983). Finally, although the most tangible product of this research would be a piece of software, the thesis is intended to relate an entire analytical method and a system of concepts, not just document a program for a personal computer.

# Literature Review

The nature of this project required the review of literature from forestry (primarily modeling) and wildlife (both habitat preference and computer applications to habitat management). Due to the extensive nature of this literature search, work cited below is documented in the **Literature Cited** and other related literature is contained in the **Other Pertinent Literature** section at the end of this document. Also, this subject does not lend itself to precise classification of systems either by objectives, outputs, processes or anything else the author could devise. Many systems overlap and can be used in a variety of contexts. Forest management programs can easily be used to predict wildlife habitat management changes and many succession-based wildlife habitat management programs can be used to predict forest structure. The following literature review is organized according to objectives of the systems. Sections on multiple-use and geographic information systems are included to address systems that cross disciplinary boundaries.

# *Computerized Forest Management*

Operations research techniques have become an accepted part of forest management (Hall 1967, Dargavel and Bethune 1972, Martin and Sendak 1973, Duerr et al. 1978, Clutter 1983, Field 1984). Computerized forest management can be divided into five categories as it relates to forestry: forest simulation, non-linear optimization, linear optimization, multiple-use systems, and geographic information systems.

## **Forest Simulation**

Forest simulation is a subset within operations research. This technique has a number of proponents (Bartos et al. 1983; Belcher 1982, Belcher et al. 1982, Boyce 1980, Ek 1974, Shugart and West 1980) and is probably the most widely implemented management science technique in natural resources management. In practice, forest simulators are often used as optimizers through trial and error. Asking "what if" questions is analogous to one iteration of an optimization algorithm. The user is often looking for an input to get a predetermined output just as a binary search or linear programming algorithm would. For an overview of forest modeling see Shugart and West's (1980) work on the history and applications of forest succession models. Shugart and West described the various sorts of tree and forest models (spatial-nonspatial, gap-forest-tree, monospecific-multispecific, or even-mixed age) and how each may be applied to forest management.

Forest simulation models can work at almost any scale. FORET (Dale 1985) and JABOWA (Botkin et al. 1972, Christensen and Davis 1986) are regional forest growth and succession models. Reed (1981) described a system called SUCSYM designed to analyze watershed characteristics as a function of management practices. Johnson and Swank (1973), Marks and Bormann (1972), Swank and Waide (1980), Waide and Swank (1975), and Bartos et al. (1983) all described ecosystem

level models designed to analyze nutrient flux. Cooper (1976) found that these sorts of models were best implemented at the beginning of the planning process, or they had little impact on existing management actions.

Stand level models are by far the most numerous. These are the types of models that are most often used by forest planners and field personnel interested in projecting the growth and yield of a given stand of trees to some point in the future. One of the more widely used microcomputer based forest growth and yield programs in use today is TWIGS which was described by Belcher (1982). This program has its roots in STEMS (Brand 1981, Belcher 1982) a mainframe growth and yield simulator. TWIGS is capable of predicting growth and yield for individual stands based on differing management actions like harvesting, and thinning, and Shifley et al. (1986) described a linkage mechanism between a northern gray squirrel (*Sciurus carolinensis*) habitat suitability model and TWIGS for analysis of squirrel habitat under different timber management options. Other examples of stand level models in the upland oak forest type include work reported by Mielke et al. (1978), Hilt (1985), Perkey (1985), and Harrison et al. (1986). Examples in other forest types would include Ek's (1974) work in northern hardwood ecosystems, and Bartos' et al. (1983) work in aspen forests of the Intermountain West. Simulation models are important as a basis for operations research models, but forest simulation is such a large field that a complete discussion would be inappropriate for this document.

## **Non-linear Optimization**

Recently, techniques have been developed to optimize allowable cut or rotation age to maximize profits. This involves a mathematical search technique called binary search. The most notable examples of binary search programs are ECHO, an economic/forestry model (Schmidt and Tedder 1981) and the present net worth option of TREES (Tedder 1981). In short, binary search models take the average of a high predicted annual cut and a low predicted annual cut and then decides

whether the average value is too high or too low. If the average value is too high, then the program swaps the old high value with the average value, effectively cutting the search area in half (hence the name binary search). Similarly if the average value is too low, the program swaps the old low value with the average value. The model continues to do this until it converges on a point close enough to the optimum cutting level to achieve a maximum amount of benefits (as defined by the programmer). For a discussion of this algorithm, see Johnson and Scheurman (1977). Another example of this technique was presented by Adams and Ek (1974) on the optimization of uneven-aged hardwood forests in Wisconsin. These authors attempted to maximize value growth over time by manipulating the diameter distribution of the stand. Numerous non-linear algorithms exist for various applications (Dykstra 1984, Jones et al. 1986).

## **Linear Forest Management Optimization Systems**

Linear programming and binary search are two very different ways of achieving the same goal. Linear programming is more flexible than binary search; it can address many management alternatives, and handles constraints easily. Binary search is easy to program, runs on small computers, and simulates biological systems well. Both can mimic the other through clever programming. The basic drawback to linear programming is its large memory requirements and its required linear format for objective functions. The failing of binary search is its inability to involve more than one decision variable in the optimization routine. For a discussion of the pros and cons of these two techniques, see Johnson and Tedder (1983).

Linear programming has been the most popular form of operations research model used in forestry (Hall 1967) since operations research was developed in the 1940's (Hillier and Lieberman 1967). The United States Forest Service has committed large amounts of manpower and other resources to their linear programming package currently known as DE FORPLAN, and the acceptance of operations research techniques has followed this commitment both within the Forest Service (Field



1984) and throughout forest industry (Dargavel and Bethune 1972). DE FORPLAN is an extensive linear programming package (with some very involved report writing capabilities) that can optimize product mixes (wood, wildlife, recreation, and others) for any national forest (Johnson and Tedder 1982). For an explanation of the linear programming algorithm, see Dykstra (1984).

Numerous examples of linear programming systems applications appear in the literature. Five examples of forestry applications were described by Broido et al. (1965). These examples included fire cost minimization, insect control, multiple-use, forest management, and forest sampling using both simulation and linear programming. An early example of linear programming use on a forest property was described by Kidd et al. (1966). In this example the authors used linear programming to plan forest harvests given budgetary, manpower, and allowable cut constraints. They concluded that linear programming was the only feasible way to optimize the hundreds of inputs and processes involved in forest planning. Other examples of primarily economic interest include work by Johnson (1976), Greber (1983), Rudra (1977), and Field (1973) in designing management plans that increase the net present worth of the forest enterprise.

## Multiple-Use Systems

In these programs wildlife issues are generally addressed in a cursory manner and are treated as constraints to the model rather than objectives. This is common in all the forestry/wildlife/multiple-use literature.

Several exceptions do exist, however. The most notable example is DYNAST-OB which stands for Dynamically Analytic Silviculture Technique - Optimal Benefits (Boyce 1977, Boyce 1978, Boyce 1980, Boyce 1983, Benson and Landenslayer 1986). In this example the authors described a multiple-use model that uses production functions, albeit not true economic production functions (Giles and Scott 1969), and resource weighting to generate an optimal forest plan. Ten species of

wildlife as well as forestry and other management goals are weighted by the user to determine their relative importance to the objective function. Each of the production functions is linked to a forest succession model that predicts changes in forest structure (Landenslayer and Benson 1986). Simulations are done by the investigator until an optimal mix of habitat types and forestry practices is reached.

Holthausen (1986) compared DYNAST to FORPLAN and found that, for the forest management problem tested, although both systems arrived at approximately the same answer, DYNAST was considerably faster and less expensive to run.

A multiple-use simulation program described by Smith et al. (1981) and Smith (1986) called FORHAB predicts species richness as a function of cutting regime of the forest. The program uses percent available habitat to describe relative value of a particular tract of land.

PROGNOSIS-COVER, a succession model linked to wildlife habitat models, can be used to predict canopy cover, understory cover, and height of various canopy levels (Moeur 1986). These predictions can then generate a quantitative measure of habitat quality changes for various forest-dwelling wildlife species.

Two examples of ungulate management using linear programming to optimize a mix of forest cutting and ungulate management (in an economic sense) include Jones and Schuster (1985) and Davis (1967). Both of these papers describe attempts to find an optimum timber cutting level to maximize returns from both timber and ungulate harvests.

Hunter (1979) tried to set up a modular ecosystem model that took into account all the ecological factors in management of a watershed. This effort used a modular design that allowed the user to specify different levels of inputs or required outputs in terms of forestry operations.

CAPS, which stands for Computer Aided Prescription System, is a forest/management system used by the Virginia Commission of Game and Inland Fisheries that was originally designed to integrate

the forestry and wildlife objectives of the landowner by using a geographic information system and a computerized fish and wildlife information system. The user enters the objectives for management for an area that is already in the system, and then CAPS produces a management analysis in report form (Giles 1984). This system is limited by the percent of the state that is already entered into the system.

An example of a multiple-use program that can treat wildlife equally with timber is WRAP, an interactive small-forest management program created by the Tennessee Valley Authority (Hamner 1975). WRAP also produces a management prescription given the landowner's objectives for management by using production functions similar to DYNAST-OB and a simulator that predicts the value of different habitats after a certain management action. These programs integrate forestry and wildlife production relationships to produce a usable management plan that produces both outputs.

The last but certainly not the least important system is called TIMPRO/FORMAN which stands for The TIMber yield, investment analysis, and wildlife management PROjection tool and the FORest MANagement activities scheduling system respectively (Williamson 1983, Hendricks 1985, Hendricks and Harrison 1985, Hepp et al. 1985). These two programs are utilized together; TIMPRO is the data entry, tabulation, and forest growth and yield program while FORMAN is the optimization routine. TIMPRO/FORMAN is designed to optimize forestry and wildlife objectives based on the weighted objectives of the landowner. It utilizes many techniques that will be employed in the proposed study but only includes three wildlife species. Although it is a rather complex program, it is designed to run on a standard microcomputer.

## Geographic Information Systems

Geographic Information Systems (GIS) or less complicated computerized mapping systems are gaining wide-spread acceptance in the forest management arena (Devine and Field 1986), especially in microcomputer GIS applications (Cooney and Tucker 1986). GIS can be used in conjunction with any of the forest management systems described here or entirely new systems can be built to take advantage of the spatial nature of a GIS (Brookfield 1986). Berry and Mansbach (1981) described the use of a GIS for forest cover type mapping and manipulation and, Tomlin and Tomlin (1982) used a GIS based system to schedule timber harvests.

One of the early applications of a GIS to wildlife habitat analysis was the POWER system developed by Jones (1976). POWER was a cellular, mainframe GIS developed for land use planning, particularly powerline corridor location. Through the use of indices of habitat quality based on environmental factors stored in the system, maps of high quality habitat for wildlife species could be generated.

ECOSYM, as described by Davis and Delain (1986), is really a hybrid simulator. It calculates Habitat Suitability Indices (Schamberger and Farmer 1978) values for each cell in the geo-referenced database from simulated changes in forest structure. Maps can be generated of current and future distribution of wildlife habitat for a given species in a given year.

The lone example of a microcomputer GIS in use for wildlife habitat analysis is CHAMPS (Rauscher 1986, Rauscher et al. 1986). This system was designed to aid foresters in Minnesota to evaluate, project, and map wildlife habitat and commercial forest land.

Although few examples of geographic information systems designed for wildlife habitat analysis are represented in the literature, interest is growing rapidly in this area. Many state fish and wildlife

agencies are currently developing or investigating GIS, and the trend appears to favor more exciting developments in this area with the advent of microcomputer GIS software.

## ***Computerized Wildlife Habitat Management***

Interest in computerized habitat management is growing rapidly (Christensen and Davis 1986, Grant 1986) as is indicated by two recent national meetings: National Workshop on Computer Uses in Fish and Wildlife Programs in 1983, and National Workshop on Microcomputer Applications in Fish and Wildlife Programs 1985. Few management applications have been developed and even fewer of these have been reported in the literature. Management applications that have been described are usually a part of a multiple-use system probably because the excessive commitment of personnel and funds makes a single-use system uneconomical.

Habitat management systems can be divided into either database, simulation, or index approaches. There is a subtle distinction between systems that are termed here as "multiple-use" versus "wildlife specific". The criteria are based on the objectives of the system in question. Multiple-use systems are primarily those systems that treat wildlife as a constraint or an aside to the main purpose, maximizing timber or economic yield. The division is in some ways arbitrary but important nonetheless for the user.

### **The Database Approach**

Fish and wildlife information systems can be used to predict future animal assemblages based on documented habitat associations and predicted changes in habitat types. Basically, a large database of wildlife information is gathered and keyed to habitat variables. When the user queries the data-

base, he or she retrieves the number of species associated with a given habitat (the "before" condition) and then retrieves the species that will be associated with the projected habitats after a proposed management action has taken place (the "after" condition). In this way, a list of affected species can be generated. This technique is probably the simplest and most defensible from a theoretical standpoint because each piece of data used in the analysis is (generally) documented in the published literature. The advantages to this method are that changes in the knowledge base of the system can instantly be loaded without major changes to the entire system. These systems are straightforward conceptually and training for them is usually simpler than other more complicated systems. Cost is a major disadvantage to this approach. Data collection and entry are labor intensive tasks that are positively correlated with the quality of the resulting system.

Examples of wildlife/habitat management databases include Computerized Fish and Wildlife Information Systems (CFWIS) (Patton 1978, Urich and Graham 1984, Cushwa and Kopf 1984, Cushwa 1985, Waldon et al. 1985), Wildlife and Fish Habitat Relationships Programs (WFHR) (Nelson and Salwasser 1982, Thomas 1982), and SpecList (Svoboda 1985).

RUN WILD, one of the earliest CFWIS (Patton 1978), was an attempt to address the problem of burgeoning literature and data collection effort on Western wildlife species. Too much information was being published for the field biologists to read and assimilate. Information on distribution, status, food habits, cover requirements, key habitat, and management practices were digitized and keyed to a species and species group (birds, mammals, reptiles, or amphibians). Reports could be generated based on habitat requirements or species lists could be generated for an area.

Modern CFWIS consist of an extensive body of fish and wildlife information organized by as many as 190 elements of information according to work by Mason et al. (1979). Each element corresponds to a particular type of information such as status, food habits, environmental associations, life history, management practices, or references. As many as 1040 species are included in a CFWIS, all of which are instantly accessible. Habitat management simulations can be accomplished by retrieving all the species likely to occur on an area of interest based on the habitat types

on the area and the habitat associations documented for the species in the CFWIS. Then all the species that are known to be associated with the projected habitat after a proposed management action or disturbance can be removed from the list leaving only those species that will potentially be excluded by the management action. In this way, a list of potential problem species can be generated and beneficial management actions or mitigation techniques retrieved for the manager.

WFHR are similar systems that store less information, but can manipulate the information contained in the database in different ways. WFHR consist of environmental and habitat information organized in a matrix format after Thomas et al. (1979). WFHR also include habitat quality ratings for each habitat association. This allows the user to obtain information on the importance of different habitat types as well as simple habitat associations (Sheppard et al. 1982). CFWIS do not currently have this capability. SpecList is included as an example of a small scale WFHR database. Database applications may not necessarily be large and complicated with literally everything on fish and wildlife in the state to be useful. Information on 350+ species are stored in a matrix of habitat types. Potential species on a given area can be listed by searching the database on 35 different habitat/land use types. This information is extremely useful for planning purposes or the preparation of environmental impact statements.

## The Simulation Approach

Mathematical modeling and simulation of wildlife habitat and populations has been practiced since before the landmark textbook by Watt (1968). Bunnell (1973) reviewed the applications of mathematical simulation in wildlife management and found only a handful that dealt exclusively with wildlife. Cooperrider and Behrend (1980) simulated the production of browse for white-tailed deer (*Odocoileus virginiana*) as a result of changes in overstory basal area and different timber harvesting practices. Bobek (1980) simulated the effects of management strategies on roe-deer (*Cervus elaphus*) herds in Europe taking into account harvest strategies, available forage as a function of

stand type, and fiscal capability of the manager. He found that the model predicted that a 6-fold increase was possible in one national forest in Poland.

Giles and Snyder (1970) advocated the development of an elk (*Cervus canadensis*) forage optimization system. Biomass vs. succession curves were modified to represent elk forage vs. succession. Maximizing the area under the sum of the curves (one for each forest stand), and timing cuts to minimize deviations from a goal level would result in a powerful management system. It could be used to manipulate elk numbers, assuming food was the only controlling factor or all other controlling factors remained constant over the planning horizon. It was developed and used by the U.S. Forest Service in the Pacific Northwest Region.

## **The Index Approach**

The US Fish and Wildlife Service's Habitat Evaluation Procedures (HEP) recently have been converted to a microcomputer program (USFWS 1980, Stackowiak 1985). This system is a wildlife management tool that multiplies a Habitat Suitability Index model for given species by the number of acres in each habitat type based on graphical models of habitat suitability over a habitat variable (Schamberger and Farmer 1978). In this way different areas can be compared to determine which is better suited for the wildlife species of concern, or different management practices can be evaluated by doing before and after analyses (Schamberger and Krohn 1982, Urich and Graham 1983, Doering and Armijo 1986). It is a static evaluation, however, and there is no way for the program to optimize the acres in each habitat type for a given mix of wildlife species. More than 200 habitat suitability models are available from various sources (Roberts et al. 1984, O'Neil 1985), and many more will probably be available as of this writing. This is probably the most widely used computerized habitat management technique (other than linear multiple-use models).



A similar approach also developed by the U.S. Fish and Wildlife Service that incorporates probability levels within the habitat quality ratings is called the "Pattern Recognition" methodology (PATREC) (Kling 1980, Evans 1983, Wilson 1983, Gaudette 1986, Kirkman et al. 1986). The user develops a model for a given species by determining the probability of an area having a high or low suitability rating given various values for important habitat variables. After all the habitat probabilities are combined, a final probability that the area will be a high value area is generated. The advantages to this method over HEP analysis are the probability figures and the ease with which a model can be built using expert opinion. Time is not explicitly addressed by the PATREC models.

To recap, database systems are large, expensive, easily defensible systems that are easily modified to reflect changes in the system or new information. Database systems, however neither generally handle habitat ratings very well, nor do they attempt to include a time element in their simulation capabilities. Simulation capabilities in database systems are generally crude or non-existent. Simulation based systems handle the time element well, but are relatively inflexible. Index systems deal with relative habitat quality and, in the case of PATREC models, can even provide probability levels that a given area will have a high or low rating. Index models do not deal with the dynamics of habitat, and they are more difficult to modify than some of the other models if changes become necessary in the system. None of these systems attempt to optimize habitat. They just evaluate the habitats based on input provided to the respective system. Also, all these systems are difficult to validate (Farmer et al. 1982, Lancia et al. 1982).

## *Faunal Succession*

Management of wildlife species by means of timber cutting is a well documented, widely accepted technique. Leopold (1933) gave forestry a prominent position in the fledgling science of wildlife management by including it in his "cow, plow, fire, and axe" slogan of habitat management. He

implied that management of successional stage through grazing, row crops, prescribed burning, or forestry is an efficient method for wildlife management. Although there are other methods now available to manage succession, agriculture, burning, and forestry are still prominent methods of habitat manipulation because they are often justified on economic grounds other than wildlife management (Halls 1975).

A number of authors have suggested using modified forestry practices as a means of increasing wildlife species richness or increasing the populations of one particular species. A notable example of this is the extensive work done by Thomas et al. (1976, 1979) describing a method for wildlife management using species groups (guilds) organized by habitat requirements and forest cutting as the management tool in the Blue Mountains of Oregon.

Shaw and Ripley (1965), Shaw (1967, 1977), and Roach (1974) among others advocated planning timber harvests specifically for the benefit of wildlife species as opposed to planning timber harvests for wood production and treating wildlife habitat as a constraint. They recognized the managerial power that active forest harvest planning efforts could exert over the habitat quality of selected species. This is a subtle distinction. Many authors have called for the inclusion of wildlife requirements in forest harvest planning, and many have documented the effects of timber harvesting on wildlife, but few have actually made the transition to cutting trees intentionally to manage a piece of land for animal species. This is surprising given that seral management is a cornerstone of habitat management.

One possible exception to this observation would be the literature on maintained forest openings. Larson (1966, 1967) found that maintained openings were not economically efficient for their stated purpose, providing forage for big game species. The reason for this was the cost involved in liming, disking, mowing, etc. to keep the opening in grass cover. He stated that maintained forest openings could only be justified if public relations benefits were included in the analysis.

Numerous examples of correlations between plant succession and the species composition of the faunal community can be found in the literature. For convenience, these works have been split into Birds, Mammals, and Others in the following discussion.

## Birds

The most extensive work in plant succession relationships to wildlife species composition, or faunal succession (Johnston and Odum 1956), has been done with regards to passerine birds. Some of the first scientific studies of bird density as it relates to succession were done by Odum (1950) and Johnston and Odum (1956). They found that many species of breeding male birds chose distinct seral stages. A few species like the cardinal (*Cardinalis cardinalis*) were found in all seral stages; some generalists were identified. They also found that some species like the mockingbird (*Mimus polyglottus*) were not found at any of the census plots although they were observed in the general vicinity of the study area. This was cited as an example of a forest edge effect where some species required habitat consisting of two or more widely varying habitat types.

Hamilton and Noble (1975) did an extensive literature review of this subject. They found extensive evidence for faunal succession (passerine birds only) as a result of successional changes in habitat type and complexity. The authors advocated management of forest ecosystems for maximum habitat variety and complexity if the objective is maximum species diversity.

Conner and Adkisson (1975) also worked on correlating bird species presence/absence according to seral stage in the central Appalachian hardwood region of western Virginia. They found correlations for 39 species over 6 seral stages and concluded that competent clearcutting operations could increase the diversity of breeding birds in this area.

Shugart and James (1973) demonstrated that ecological succession occurs within the bird community of hardwood forests in Arkansas. The authors divided the successional stages of a forest into

10 seres and then found correlations between sere and breeding male observation for 60 species of birds.

Although most of the work on faunal succession has been done with singing males of neotropical migrants, there is evidence that other species groups of birds are also influenced by seral stage, and that passerines select for seral stage in the winter as well as the spring and summer. McGarigal and Fraser (1983) found a correlation between stand age and 2 species of owls. Titus and Mosher (1981) found that basal area/acre and dbh were important discriminating variables for nest-tree selection in woodland hawks. Both variables are closely related to sere. Conner et al. (1975) found stand age to be a controlling factor in woodpecker (Picidae) habitat selection. Winter habitat selection by passerines was investigated by Conner et al. (1979) for 20 species of passerine birds and similar results were found.

## **Mammals**

Although changes in mammalian species composition with forest age is not as well documented, successional relationships appear to be important. White-tailed deer prefer forest stands of different ages at certain times of the year (Shaw and Ripley 1965, Halls 1973). Kirkland (1977) found that clearcutting hardwood forests in West Virginia resulted in an increase in abundance and diversity of small mammals until the forest returned to a mature forest size class. In other areas of the country, Ream and Gruell (1980) summarized the literature on small mammal succession in western forests and found that a definite successional pattern occurred mostly as a result of logging residue and microhabitat relationships. Atkeson and Johnson (1977) found that small mammal succession occurred even in relatively young (<15 years) pine stands in the Georgia piedmont. They hypothesized that changes in ground cover were responsible. These works indicate that plant succession has a major effect on the habitat quality for some mammalian species.

## Other Species Groups

The faunal succession pattern is a common factor linking habitat work for many different species groups. Blymer and McGinnes (1977) found a weak relationship between salamander abundance and diversity and forest stand age as did McKinstry and Cunningham (1980). Boyce (1985) described an application of DYNAST where forest arthropods were managed through careful forest management. Similarly, Johanson (1981) found considerable variation in the frequency of insects in different orders in various aged loblolly pine (*Pinus taeda*) stands. I anticipate that other forest dwelling species would display similar preferences for certain ages of forest stands, but more research needs to be conducted in this area.

The literature reveals a great opportunity for an integrated management system. Several different types of forest models (i.e. simulation, non-linear optimization, and linear optimization) are in wide use to predict growth and yield, analyze cash flow, plan harvests, or investigate impacts. Wildlife habitat models are being developed and utilized to do the same types of activities for different objectives. The abundance of many wildlife species can be correlated strongly with stand age and tree size. Therefore, an opportunity exists for using forestry-type planning models for wildlife objectives using faunal succession as the linking mechanism.

## Methods

The main objective of this project was to create a timber harvest scheduling system for the upland hardwood ecosystem of western Virginia that would plan wood cutting to optimize wildlife habitat over time for a set of wildlife species. Secondary objectives included:

1. Design the system to run on a microcomputer to allow for maximum impact on the wildlife resource.
2. Demonstrate an application of BOVA (Biota of Virginia), a computerized fish and wildlife information system.
3. Demonstrate that computerized timber harvest prescriptions can be presented in a manner helpful to wildlife managers.
4. Investigate the practicality of the resulting system in terms of time and effort required.

The steps identified in meeting these objectives are outlined below.

## *Steps to Meet Objectives*

1. Develop a robust model of wildlife habitat value as it relates to mean stand dbh where mean stand dbh is a surrogate variable for stand age.
2. Create or find a microcomputer program(s) that would do the following:
  - Store forest cutting unit attributes and species specific habitat attributes and values in a manner conducive to easy addition, deletion, and modification.
  - Mathematically simulate upland oak forest growth in western Virginia, i.e., predict mean dbh of a cutting unit over time as well as other descriptors over time (e.g., wood volume, trees/acre, basal area/acre).
  - Allow the user to quantify the value of each wildlife species on a scale of 0-99 and then based on wildlife habitat models (habitat value vs. mean cutting unit dbh), predict the benefits derived over time from each cutting unit.
  - Utilize easily obtainable cutting unit data, preferably data normally collected in conjunction with existing forest management surveys.
  - Conduct iterative searches over a range of potential cutting levels (acres/year) to find the cutting level that maximizes a prespecified objective function.
  - Present the resulting harvest schedule in a readable, easily understood manner.
3. Demonstrate the system on a 80-160 ha area of Havens Wildlife Management Area using several objective functions. Include a summary of time and effort required to institute the management system on this area.

4. Use a map display system to display some results.

## ***Mathematically Portraying the Forest/Wildlife System***

In the current climate of reduced budgets and manpower, good sense demands that new management systems strive towards parsimony. Minimally, the combined system must address the dynamics of the forest and its subsequent effects on wildlife habitat quality. The problem was split into two parts: (1) wildlife models that describe the changes in habitat quality for a given species as they relate to mean dbh of the forest stand and (2) a forest growth and yield model that describes the dynamics of succession for a particular stand. For the wildlife models, simple graphical representations were developed for each species of interest plotting habitat quality against forest size class (mean dbh class). For the forest succession model, an existing growth and yield model was adapted to project iteratively changes in mean dbh over time.

### **Data Storage and Manipulation**

WILDWOOD uses a readily available microcomputer data base management system called PCFile for data storage and manipulation. It may be freely copied and distributed<sup>1</sup>. PCFile is a very simple, easily understood, hierarchical data base manager that has the capability to retrieve, sort, search, modify, delete, or write reports from the data stored by it. The user is required to learn a minimal amount of the true capabilities of this software to actually run WILDWOOD. Documentation and database dictionaries may be found in the user's manual.

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<sup>1</sup> Some restrictions do apply. See the user's manual appendix for more information.



## Wildlife Models

Modeling of wildlife habitat relationships has been approached in a number of different ways (e.g., CFWIS, HEP, WFHR, and PATREC). All of the methods currently in use have their own idiosyncracies and shortcomings such as excessive cost of development and complexity. These problems reduce the application of computerized wildlife habitat modeling when these methods could improve the analytical ability of the wildlife profession.

Numerous studies have demonstrated the correlation between animal species and habitat parameters (Hamilton and Noble 1975, Robbins 1978). Almost all of the parameters are related to or controlled by succession. Succession is a primary factor in the forest/wildlife system. The minimum variables for describing wildlife habitat changes over time are simply x and y coordinates. The x being time from last harvest (successional stage), and the y being some measure of habitat quality. In the upland oak ecosystem of western Virginia, stand age is a poor indicator of successional stage due to the effects of fire, timber harvest, grazing, and generally poor site quality. In WILDWOOD, mean dbh of the cutting unit is used as a surrogate variable for successional stage. Mean dbh is split into 5 forest size classes patterned loosely after the U.S. Forest Service's Forest Size Class Rating System. These are SEEDLING (live trees  $\leq 2.5$  cm dbh), SAPLING (live trees  $> 2.5$  cm and  $\leq 12.7$  cm dbh), POLE (live trees  $> 12.7$  cm and  $\leq 25.4$  cm dbh), MATURE (live trees  $> 25.4$  cm and  $\leq 43.1$  cm dbh), and OVERMATURE (live trees  $> 43.1$  cm dbh). The reason for choosing this classification scheme over other classification schemes is that it is simple, easily understood by the user, and currently in widespread use by a leader in the forestry profession (the U.S. Forest Service) as well as BOVA (Virginia's computerized fish and wildlife information system).

One problem with this approach is that smooth mathematical functions are not generally available for the relationship between habitat quality and mean dbh of the forest stand, but discrete data points are widely available through a number of sources. To take advantage of these information

sources, models were built in a stepwise manner (a histogram). Habitat quality was converted to an index value from 0 to 1.0 for each forest size class (similar to HEP) as determined by a number of different sources.

Table 1. Wildlife habitat value by forest size class for 42 wildlife species in WILDWOOD.

Forest size classes S = seedling Sa = sapling P = pole M = mature O = overmature

Species Common Name	S	Sa	P	M	O	Model Citations	Model Type
American goldfinch ( <i>Carduelis tristis</i> )	1.0	0.5	0.0	0.0	0.0	Conner and Adkisson 1975 Conner, Via, and Prather 1979	literature
Appalachian Bewick's wren ( <i>Thryomanes bewickii</i> )	1.0	1.0	0.0	0.0	0.0	Legrand and Hamel 1980	BOVA
barred owl ( <i>Strix varia</i> )	0.0	0.0	0.0	0.5	1.0	McGarigal and Fraser 1983	literature
black bear ( <i>Ursus americanus</i> )	0.0	0.1	0.2	0.9	1.0	Garner 1986	literature
black-and-white warbler ( <i>Mniotilta varia</i> )	0.0	0.0	0.2	0.8	1.0	Conner, Via, and Prather 1979 Johnston and Odum 1956 Shugart and James 1973 Titterington, Crawford and Burgason 1979	literature
blue jay ( <i>Cyanocitta cristata</i> )	0.0	0.1	1.0	0.5	0.5	Conner, Via and Prather 1979	literature
blue-gray gnatcatcher ( <i>Polioptila caerulea</i> )	0.0	0.0	1.0	0.5	0.5	Conner and Adkisson 1975 Conner, Via and Adkisson 1979	literature
broadhead skink ( <i>Eumeces laticeps</i> )	0.0	0.0	0.0	1.0	1.0	Barbour 1971	BOVA

Methods	Table 1. (continued)							
	common yellowthroat ( <i>Geothlypis trichas</i> )	0.1	1.0	0.1	0.0	0.0	Johnston and Odum 1956 Titterington, Crawford and Burgason 1979	literature
	deer mouse ( <i>Peromyscus maniculatus</i> )	0.7	0.3	0.6	1.0	1.0	Kirkland 1977	literature
	downy woodpecker ( <i>Picoides pubescens</i> )	1.0	0.1	0.1	1.0	1.0	Conner and Crawford 1974 Conner and Adkisson 1975 Conner, Via and Prather 1979 Johnston and Odum 1956	literature
	Eastern bluebird ( <i>Sialia sialis</i> )	1.0	0.2	0.0	0.0	0.0	Conner and Adkisson 1975	literature
	Eastern gray fox ( <i>Urocyon cinereoargenteus</i> )	0.2	1.0	0.5	0.5	0.5	Cushwa 1986	expert
	Eastern hognose snake ( <i>Heterodon platyrhinos</i> )	1.0	1.0	1.0	0.0	0.0	Wright and Wright 1975	BOVA
	Eastern wood pewee ( <i>Contopus virens</i> )	0.0	0.3	0.0	1.0	1.0	Conner and Adkisson 1975 Johnston and Odum 1956	literature
	Eastern wood rat ( <i>Neotoma floridana</i> )	0.0	0.0	1.0	1.0	1.0	Burt and Gossensheider 1964 Goertz 1970	BOVA
	Eastern woolly cottontail ( <i>Sylvilagus floridanus</i> )	1.0	0.5	0.0	0.0	0.0	Chapman, Hockman and Ojeda 1980	literature
31	field sparrow ( <i>Spizella pusilla</i> )	0.2	1.0	0.1	0.0	0.0	Conner and Adkisson 1975 Conner, Via, and Adkisson 1979 Johnston and Odum 1956 Shugart and James 1973	literature
	gray catbird ( <i>Dumetella carolinensis</i> )	0.0	1.0	0.1	0.5	0.5	Conner and Adkisson 1975 Conner, Via and Prather 1979	literature

Table 1. (continued)

indigo bunting ( <i>Passerina cyanea</i> )	1.0	0.5	0.0	0.0	0.0	Conner and Adkisson 1975 Conner, Via, and Prather 1979	literature
least shrew ( <i>Cryptotus parva</i> )	1.0	0.0	0.0	0.0	0.0	Hamilton 1944	BOVA
meadow vole ( <i>Microtus pennsylvanicus</i> )	1.0	0.5	0.0	0.0	0.0	Kirkland 1977	literature
Northern bobwhite ( <i>Colinus virginianus</i> )	0.5	1.0	0.2	0.0	0.0	Shugart and James 1973	literature
Northern gray squirrel ( <i>Sciurus carolinensis</i> )	0.0	0.0	0.1	1.0	1.0	Allen 1982	literature
ovenbird ( <i>Seiurus aurocapillus</i> )	0.0	0.0	1.0	0.8	0.8	Conner and Adkisson 1975 Conner, Via and Prather 1979 Titterington, Crawford and Burgason 1979	literature
pileated woodpecker ( <i>Dryocopus pileatus</i> )	0.0	0.2	0.2	0.5	1.0	Schroeder 1982	HSI
pine vole ( <i>Microtus pinetorum</i> )	1.0	0.1	0.1	0.1	0.1	Smolen 1981	literature
prairie warbler ( <i>Dendroica discolor</i> )	0.0	1.0	0.0	0.0	0.0	Conner and Adkisson 1975 Conner, Via and Prather 1979 Johnston and Odum 1956	literature
raccoon ( <i>Procyon lotor</i> )	0.1	0.5	0.0	1.0	1.0	Lotze and Anderson 1979	literature
red fox ( <i>Vulpes vulpes</i> )	1.0	0.5	0.2	0.2	0.2	Cushwa 1986	expert
redback salamander ( <i>Plethodon cinereus</i> )	0.0	0.0	0.5	1.0	1.0	Blymer and McGinnes 1977	literature

Table 1. (continued)

ruby-throated hummingbird ( <i>Archilochus colubris</i> )	0.0	1.0	0.0	0.0	0.0	Bent 1940 Todd 1940	BOVA
ruffed grouse ( <i>Bonasa umbellus</i> )	0.1	1.0	0.3	0.1	0.1	Servello 1986	expert
scarlet tanager ( <i>Piranga olivacea</i> )	0.0	0.1	1.0	0.9	0.9	Conner and Adkisson 1975	literature
Southern flying squirrel ( <i>Glaucomys volans</i> )	0.0	0.0	0.0	1.0	1.0	DeGraaf, Witman, and Rudis 1981 MacClintock 1970 Sonenshine et al. 1979	BOVA
veery ( <i>Catharus fuscescens</i> )	0.0	1.0	0.1	0.5	1.0	Sousa 1982	HSI
Wehrle's salamander ( <i>Plethodon wehrlei</i> )	0.0	0.0	0.0	1.0	1.0	Conant 1975 Bishop 1947	BOVA
white-tailed deer ( <i>Odocoileus virginianus</i> )	1.0	0.5	0.1	0.5	1.0	Stauffer 1986 Kopf 1986	expert
wild turkey - adult ( <i>Meleagris gallopavo</i> )	0.1	0.1	0.4	1.0	1.0	Schroeder 1985	HSI
wild turkey - poult ( <i>Meleagris gallopavo</i> )	1.0	0.9	0.1	0.1	0.1	Schroeder 1985	HSI
yellow warbler ( <i>Dendroica petechia</i> )	0.0	1.0	0.0	0.0	0.0	Schroeder 1982	HSI
yellow-billed cuckoo ( <i>Coccyzus americanus</i> )	0.0	0.0	0.0	1.0	1.0	Conner, Via and Prather 1979	literature
yellow-breasted chat ( <i>Icteria virens</i> )	0.1	1.0	0.1	0.0	0.0	Conner and Adkisson 1975 Conner, Via and Prather 1979	literature

Out of the 200 species that were likely to occur on the demonstration area, 42 species were chosen for inclusion in the system. These models were generated from BOVA (8), from habitat suitability models (4), the literature (26), and expert opinion (4). A fifth method, field observation, was not undertaken for this study (see Table 1 on page 30). Although field observation models have the most potential for accuracy on a given site, the added expense of doing additional field work was not deemed necessary given the demonstration-oriented objectives of this study.

### ***BOVA Models***

BOVA stores data on wildlife species in a binary manner for each species for each forest size class according to the sources used for that species. Because BOVA is computerized, information on a given species is easy to retrieve; large numbers of these sorts of models could be developed in this manner. However, no attempt is made, by design, to include habitat quality information associated with forest size class in BOVA. Consequently, habitat quality can only be inferred as 1.0 (associated with that size class) or 0 (not associated with that size class) with no values in-between. If a wildlife species is only associated with 1 or 2 forest size classes then this lack of discrimination or qualitative difference does not cause a serious problem. If the species is associated with 3 or more size classes (as with most species), then using BOVA-inspired wildlife models produces conditions in which no discrimination can be made by the system as to how to cut and how ages in the "best" future forest should be distributed. This defeats the purpose of the system by removing the analytical value of the wildlife habitat quality models. Models for 8 species were generated in this manner.

### ***HSI Models***

HSI models generally include several graphical models for a given species. For forest-dwelling species, mean dbh of the stand, basal area per acre, canopy height, or number of stems greater than

some dbh are often key determinants for the habitat suitability indices. Models for 4 species were generated by using existing habitat suitability index models.

### ***Literature Based Models***

Numerous studies of faunal succession have been conducted. Work by Conner et al. (1975) with birds, and Kirkland (1977) with small mammals are good examples. These studies often give a frequency of animal captures or detection by successional stage or stand age. Work such as this can easily be translated into a habitat quality index by forest size class model by mathematically scaling the sightings to a 0-1.0 scale for each size class, 1.0 being assigned the greatest abundance or abundance index. Models for neotropical migrants, especially, are generally valid for spring and summer only. Models for 26 species were generated in this manner.

### ***Expert Opinion Models***

Although many species have been investigated in relation to faunal succession, years will pass before all the species to be managed will be studied. Experts are often called in when a question arises on a species, and experts should be able to create a first approximation model without going to the expense of a full scale study. This method is useful when no other documentation or scientific evidence exists for a species. Models for 4 species were generated in this manner as examples of this method. Documentation from other sources was not sought for these species.

### ***Field Observation Models***

In a case where a higher precision is required (e.g., endangered species, site specific species habitat selection, etc.) the user could institute studies to ascertain the model values for a particular site.



This could be accomplished through standard population density estimation techniques by selecting forested study areas with varying mean dbh.

## Valuation of Species

Orwell (1946: p.148) said in his classic *Animal Farm*,

All animals are created equal, but some animals are more equal than others.

Being human, wildlife managers and landowners cannot help but value some wildlife species more than others. For example, game species and endangered species are valued highly while pest species have a lesser value. To take this aspect of wildlife planning into account, wildlife species values (0-99) were attached to each species model after work by Churchman and Ackoff (1954). The method used follows closely work by Smith et al. (1953). These authors explained that decision criteria can be reduced to an "efficiency" term which is the probability that an outcome will occur as planned and a "value" which is the relative worth of that outcome. The product of the two results is an "expected value". In WILDWOOD, the value corresponds to a ranking placed on each wildlife species in relation to each other. The efficiency is the size-class-specific habitat rating placed in each species-forest size class model that may be defined as the probability that a given forest size class in the area of interest will provide excellent habitat for the species associated with that model. Churchman and Ackoff (1954) expanded greatly on work by Smith et al. (1953) in terms of mathematically justifying the weighting procedure used.

In practice, the user is told to choose a list of species for the analysis, then place a 99 value on the most highly valued species in the list. The user is then instructed to value all the other species in relation to the most highly valued species. A value of 0 excludes that species from all analysis. In this manner, all the available species (ones with models in the system) can be included in an analysis or any subset can be analyzed. Subset lists can be weighted within themselves or within the larger list.

## Manipulating Wildlife Models

Straight addition is used to combine weighted species lists into a cumulative species model. This cumulative benefit model is the crux of the system. Mathematically, this model is a summation by forest size class of all the weighted species habitat index values.

$$\sum_{s=1}^N (\text{habitat rating}_{ks} * \text{human value}_s)_k$$

where:

s = wildlife species

N = maximum number of species

k = forest size class

The cumulative benefit model is the basis for the objective functions for all the different management optimization activities of the system. The units generated by the cumulative benefit model are referred to in the rest of this document as benefit units. Benefit units from the cumulative benefit model are summed over time and space to optimize the habitat quality over an area. They are the product of two indices (habitat quality index X human value index), and therefore, are unitless. The purpose of using a unitless measure is to provide a quantitative measure for manipulation by a digital computer. The units themselves are an abstraction and cannot be related directly to animal populations. They can provide a relative measure of the value of a given stand at a given age to the humans using the system.

## Forest Simulation

Mathematically projecting the growth and yield of forest stands is nothing new in the forestry profession. Although projecting future growth from past growth is risky at best, the general structure of the forest stand is predictable from a wildlife perspective. The forest simulation program adapted for WILDWOOD system is GROAK an oak growth simulator originally written by Dale (1972) and adapted for a personal computer by Perkey (1985). This is a simple simulator that predicts basal area growth, in-growth, mortality, mean dbh, and several different volume figures. The equations themselves (Table 2 on page 40) are based on non-linear regression equations from Dale (1972). Supplementary values for stump sprout density default values were obtained from McGee and Hooper (1970, 1975). The simulator takes the values for site index (base age 50 for oaks), trees/acre, basal area/acre, and stand age for one stand and then predicts future stand structure after one year. It then repeats this operation up to and including the number of years specified by the user. GROAK is just one of many simulators that could have been adapted for use by WILDWOOD. In fact, if other simulators become available, they can be incorporated into WILDWOOD as an option.

GROAK has several good aspects to it, however. First of all, and most importantly, it is in current use by forestry professionals in West Virginia in very similar ecosystems to those found in western Virginia. Secondly, it is quite compact, consisting of less than 25 lines of programming code. Lastly, documentation in the form of a user's manual already exists.

The forest simulator is connected to the rest of the program through the cumulative benefit model. As mean dbh of the cutting unit (an area of forest that will be cut all at one time) is predicted for a given year, the benefit units for that stand in that year are recorded and added to the total figure. For example, if the program predicts that cutting unit 2201, a 10 acre stand, will have a mean dbh of 16.5 cm (a pole stand) in year 9, and the benefit value for pole stands from the cumulative benefit model is 125.5 units, then 125.5 units will be recorded for that cutting unit in that year and 125.5

times the area of cutting unit 2201, or 1255 units, will be added to the total forest wide benefit figure. Some variation on maximizing this forest-wide benefit figure is the objective of the system.

## Mathematical Forest Planning

Long-term forest management plans need to address spatial, temporal and volumetric aspects of forest cutting. When, where, and how much to cut, are the questions that need to be answered in terms of fairly precise recommendations to managers or those for whom they work. The spatial aspect of harvest planning is accomplished by WILDWOOD through a sorting algorithm. The user specifies an attribute to determine the sequence with which the units are cut. The user can prioritize the cutting unit sequence in one of the following ways:

1. Cut oldest units first.
2. Cut best working class units first.
3. Cut highest site index units first.
4. Cut in the order that the cutting units are stored in the database.

Option one represents the way most forests are cut normally, that is, the bigger, older stands are harvested ahead of younger, smaller stands. Option two is based on a one digit code ranking of 0-4 where 0=unworkable and 4=easily workable. The third option is more ecologically based. The cutting units with the highest site index (base age 50 for upland oaks) should be able to support the highest rate of timber cutting; consequently, cutting in that order should provide the highest biological return/unit effort. This hypothesis was not tested for this study but is left for the users' experimentation and comparison to other options. The fourth option was included to allow any other sequence of cutting units the user may wish to develop. The user can edit the cutting unit database and sequence the cutting units in any way imaginable simply by ranking the units in a database element called CUT ORDER and then sorting the database on that element. The re-

Table 2. Equations for the forest cutting unit simulator.

$$MDBH_i = \sqrt{(183.3464944 * BA_{i-1} / TPA_{i-1})}$$

$$BA_i = BA_{i-1} + ((-BA_{i-1} / (AGE_i)^8) * \ln(BA_{i-1}) + 3.68521 * (BA_{i-1} / (AGE_i)^{75}) + 0.011383 * SI * (BA_{i-1} / (AGE_i)^{1.05}))$$

IF  $AGE_i \geq 50$

$$INGROWTH_i = .009264291 + .00000113 * \sqrt{(AGE_i)} - 0.015674 * \ln(BA_{i-1}) - 0.076175 * MDBH / (AGE_i)^8 + (0.0010186 * TPA_{i-1} / (AGE_i)^8) - (.00000083 * TPA_{i-1} * SI)$$

$$MORTALITY_i = -0.15021 - 1.181 / (AGE_i)^{1.05} + 0.029721 * \ln(SI) + 0.007847 * \ln(TPA_{i-1}) + 0.11115 / MDBH$$

IF  $AGE_i < 50$

$$INGROWTH_i = .09264291 + .00000113 * \sqrt{(AGE_i)} - 0.015674 * \ln(BA_{i-1}) - 0.076175 * MDBH / (AGE_i)^8 + .0010186 * TPA_{i-1} / (AGE_i)^8 - .00000083 * TPA_{i-1} * SI - (.00001391 * \sqrt{(90 - SI)} * (50 - AGE_i)^3 / (900 - \sqrt{(TPA_{i-1})}))$$

$$MORTALITY_i = -0.15021 - 1.181 / (AGE_i)^{1.05} + 0.029721 * \ln(SI) + 0.007847 * \ln(TPA_{i-1}) + 0.11115 / MDBH + ((.00370714 * (90 - SI) / (90 - AGE_i)) * (TPA_{i-1})^3 / .00000001)$$

$$TPA_i = TPA_{i-1} + (INGROWTH * TPA_{i-1}) - (MORTALITY * TPA_{i-1})$$

AGE = age of cutting unit

BA = basal area/acre of cutting unit in ft<sup>2</sup>

i = year from year 0

INGROWTH = number of trees/acre entering smallest diameter class

MDBH = mean cutting unit diameter-breast-height

MORTALITY = number of stems/acre leaving cutting unit

SI = site index base age 50 for upland oaks

TPA = trees/acre

sulting forest cutting plan is optimal only within the constraints of the cutting priority chosen, i.e., the program optimizes annual cut given a predetermined cutting priority but does not attempt to optimize cutting priority.

The program sorts the cutting unit records (all the data for a given cutting unit) based on the element chosen (i.e., option one sorts initial cutting unit age), and from then on, all simulated cuts will be done in that order. For example, a forest with 5 cutting units of age 35, 5, 45, 100, and 80 years might be cut in decreasing stand age order. That means that the 100-year-old stand would be cut first, the 80-year-old stand second, and the 5-year-old stand last. Stand age is a common criterion for systematically cutting stands to convert an unmanaged forest into a regulated one. The other criteria, site index and working class, may be used in special situations where site quality or economics are important variables in the total plan.

Temporal planning is classically accomplished through the adoption of an annual cut figure as a basis for long term management. A common method for doing this sort of planning is to divide the area by the rotation age of the trees. This will result in a managed forest, in terms of sustainable yield, after one rotation, if the rotation age is correct and the area is of uniform site quality. The implied objective to this sort of approach is maximum sustainable yield of wood products or maximum present net value, either of which are worthwhile goals but hardly meaningful to the wildlife resource.

The other option is to determine the rotation age and growth rate (the mean or periodic annual increment) for each individual stand and then determine a maximum sustainable yield based on the current and projected wood volume. This is termed volume control and may take one to several rotations to institute. However, it does acknowledge variation in site quality and stocking levels. Despite the arguments for one method over another, the goal of the analysis is to determine the precise amount of area to cut of each characteristic in a given year.

WILDWOOD uses a hybrid method of area control. It utilizes the benefit units from the cumulative benefit model in the objective function rather than wood volume or net present value. For example, if the objective function is simply to maximize the benefit units, WILDWOOD searches for an annual cut area that gives the maximum possible total benefit figure for the forest, given the priority ranking specified and the cumulative benefit model specified. This annual cut figure also gives a de facto temporal plan for each stand. For example, if the forest contains 3 stands, a 5-year-old, 10-acre stand; an 80-year-old, 5-acre stand; and a 100-year-old, 2-acre stand; and the annual cut is 2 acres then (assuming they are placed in sequence of oldest first) the 100-year-old stand will be cut in the first year, the 80-year-old stand will be cut in year 2, and the 5-year-old stand will be cut in year 4. To adhere to the 2 acre/year limit, another stand could not be cut until year 10. This is a trivial example, granted, yet the complexity of the problem becomes immense when many cutting units are involved. The resulting WILDWOOD-generated harvest plan addresses spatial planning by telling the user which cutting units to harvest and summarizing their size. It also addresses temporal planning by using the optimal cut/year figure to determine the year in which each cutting unit should be harvested. The system does not attempt to tell the user the optimal size or shape of the cutting units. These are important variables, however, and should be studied further to improve the system.

## **The Maximization Algorithm**

The algorithm used in WILDWOOD is a highly constrained non-linear search algorithm that finds the annual cut/year that will maximize the wildlife benefits as defined by the objective function. This objective function is normally defined by the cumulative benefit model, however one other variation will be discussed later.

Search algorithms (primarily binary) are well established as a basis for forest planning systems (Schmidt and Tedder 1981, Tedder 1981, Johnson and Tedder 1983). In short, a search involves

trying different levels of inputs over a feasible range of values until a maximum level of output is achieved. The search algorithm utilized in WILDWOOD iteratively modifies the annual cutting level (which modifies the year of cut for each cutting unit) and projects the wildlife benefits until a maximal level of benefits are converged upon. At that point the optimum annual cutting limit is recorded, a forest plan is generated, cords of wood removed under that cutting regime are recorded, and wildlife benefits under that cutting regime are recorded.

Both a Fibonacci search and a binary search were tested for use in WILDWOOD. A Fibonacci search is similar to a binary search algorithm in that it iteratively tests different cut/year figures to find an optimum level to reach a maximum amount of benefits based on the designated objective function. The difference between the Fibonacci and the binary search is the way in which the search area is divided. A binary divides the search area in half at every iteration. The Fibonacci divides the search area based on a ratio of a special series of numbers called a Fibonacci series (Cohen et al. 1973, Bazaraa and Shetty 1979, Schwefel 1981). These two algorithms were tested for speed and similarity of convergence points before any of the demonstration scenarios were run. The process steps are:

1. **Defining an objective function.** Several functions are available in WILDWOOD. A typical one is average yearly accumulated wildlife benefits.

$$\text{Maximize } (\sum_{i=1}^H \text{TOTYEARLYBEN}_i)/H$$

where: TOTYEARLYBEN = sum of the wildlife benefits over all cutting units for year i.

H = the number of years in the analysis.

i = year.



This test variable is then maximized by the repetition of the following steps.

2. **Defining a search area.** The lower boundary of the search area is set at 0 acres/year (i.e., no harvest) and an upper boundary is set at one-third the sum of the workable acres in all cutting units. The one-third boundary is set based on the empirical knowledge that most upland oak stands require at least 3 years to go from seedling to sapling stages. Constraining the model to cut a maximum of one-third of the cuttable forest per year means that no cutting unit should be projected for cutting less than 3 years after being cut the first time. Realistically, if the program recommends cutting one third of the forest per year, the manager should realize that to cut as many acres as possible (given other silvicultural, economic, and social constraints) is recommended.
3. **Determine initial annual cut values.** In a binary search, the initial value would be determined by splitting the area into halves (hence the name binary) and then splitting the two halves into two to get the initial annual cut values.
4. **Project the value of the test variable (outputs) given the initial values for annual cut (input).** Using the succession model, each cutting unit is mathematically "grown" for a specified number of years. The succession model embodies the unit-specific wildlife benefits likely produced over the planning horizon. The value of the test variable is recorded for each iteration using both the low initial cut per year and the high initial cut per year.
5. **Compare the results from the low and high initial values for an hypothetical cut in each year.** Since WILDWOOD is a maximization system, the cut per year yielding the highest average yearly benefit figure is the one of interest.
6. **If the high initial value for cut per year yields a greater average yearly benefit figure than the low initial value for cut per year, then replace the lower boundary of the search area with the midpoint of the search area. If the low initial value for cut per year yields more total benefits**

than the high initial value for cut per year, then replace the upper boundary with the midpoint of the search area. These replacements reduce the search area after each iteration.

7. Repeat until the convergence criterion is met (go to step 3). The convergence criterion for WILDWOOD is defined as the condition in which the most recent low estimate subtracted from the most recent high estimate is less than 0.1 acres.

The two search algorithms (Fibonacci and binary) were tested against each other for speed and repeatability of results by running WILDWOOD on a small subset of the Havens dataset (42 cutting units, 14 cuttable under site index and working class constraints) with both algorithms and recording time required, annual cut converged upon, and total benefits generated by the program.

## *Constraints and Assumptions of the System*

Several assumptions are inherent in the search algorithm. The algorithm requires that the function being analyzed is smooth and unimodal to converge properly. Local maxima can result in a sub-optimum answer. To avoid this pitfall, multiple runs were made under three different cumulative benefit model possibilities: a bimodal model with larger values in the smaller forest size classes, a bimodal model with larger values in the larger forest size classes, a unimodal model skewed to the lower forest size class, and a unimodal model skewed to the largest forest size class. Another problem with search algorithms in general is the inverse relationship between computer run times and error rates. The optimum cut per year figure will only be within plus or minus the 0.1 acre tolerance level of the true optimum. If the tolerance level is very small, the optimum answer generated by the program will be very close to the true optimum (to as many decimal places as the computer can accommodate). But the time required to reach convergence increases geometrically with increasing error rate requirements. There is a tradeoff between error rate and run time which

requires a compromise. The error rate specified in WILDWOOD is one that seems to work satisfactorily given the numerous runs conducted during system testing.

The main assumption of the larger system is that habitat value for species in the system changes with succession (functionally the mean dbh) in a definable and predictable pattern over the planning horizon. Given the voluminous evidence provided by the literature and other sources, this assumption appears to hold at least well enough to provide insight for habitat management activities.

Another assumption is that wildlife, as a resource, has value to people and that value can be expressed (at least grossly and in relative ways) in a numerical fashion such as on a scale of 0-99 and other ratio expressions. Economic forest management is not addressed by the system because other systems are available to meet this demand, and because of limitations in the available resources for this project.

Another assumption is that the cutting unit descriptors required by the system are representative of the entire cutting unit, i.e., the cutting unit is homogenous. Finally, it is assumed that the user knows the proper size and shape of cut to be performed and that all workable cutting units are equally accessible. Patch clearcuts, 0.1 - 2.0 ha in size (sometimes erroneously called group selection) are recommended for western Virginia, but the system will handle whatever the user provides.

The last assumption is that cutting units all respond in the same way to cutting. It was necessary that a beginning value be assigned to cutting units that had been cut. A basal area of 2 square feet and a trees/acre of 1000 were assumed for these values regardless of site index or previous stand conditions. After multiple tests of the forest growth simulator, these default values were found to produce cutting units with attributes similar to existing cutting units. These values were also found to agree with McGee and Hooper (1970,1975) on upland oak stands in the southern Appalachians. Because the first rotation is the most important from a management standpoint,

no further testing was conducted to revise these default values that only affect the analysis after the first rotation.

Constraints on the WILDWOOD system are as follows -

1. Cutting units with a workability class of 0 cannot be cut, but are included in the analysis. This constraint has important consequences for the program and wildlife management in general. Leaving large acreages uncut due to poor access, steep slopes, or other problems means that two areas of equal size may be cut at a drastically different rate depending on the amount of reserved land on each tract. In a case where a high percentage of the area is reserved and the objective function weights early to middle succession species heavily, the cuttable area is likely to be harvested very fast and frequently due to the influence of the reserved stands. This will be discussed further in the **Results** and **Discussion** sections.
2. An entire cutting unit is cut at one point in time within one year. No partial cutting, thinning, etc. is allowed. This simplifies the problem, but opens the subject of model efficacy vs. model complexity. More options such as allowing different silvicultural options would provide a more realistic picture of forest management, but would also make the system unwieldy at best and, at worst, unfathomable. The marginal return of adding another option to a system of this sort is always of great concern to the creator, and in this case has been left to future students to investigate.
3. Cutting units with a site index of less than 60 cannot be cut as these areas are too prone to environmental degradation (U.S. Forest Service 1986), and return on investments is likely negative.
4. No more than a third of the forest may be cut in any one year. See *Defining a Search Area* under **The Maximization Algorithm**.

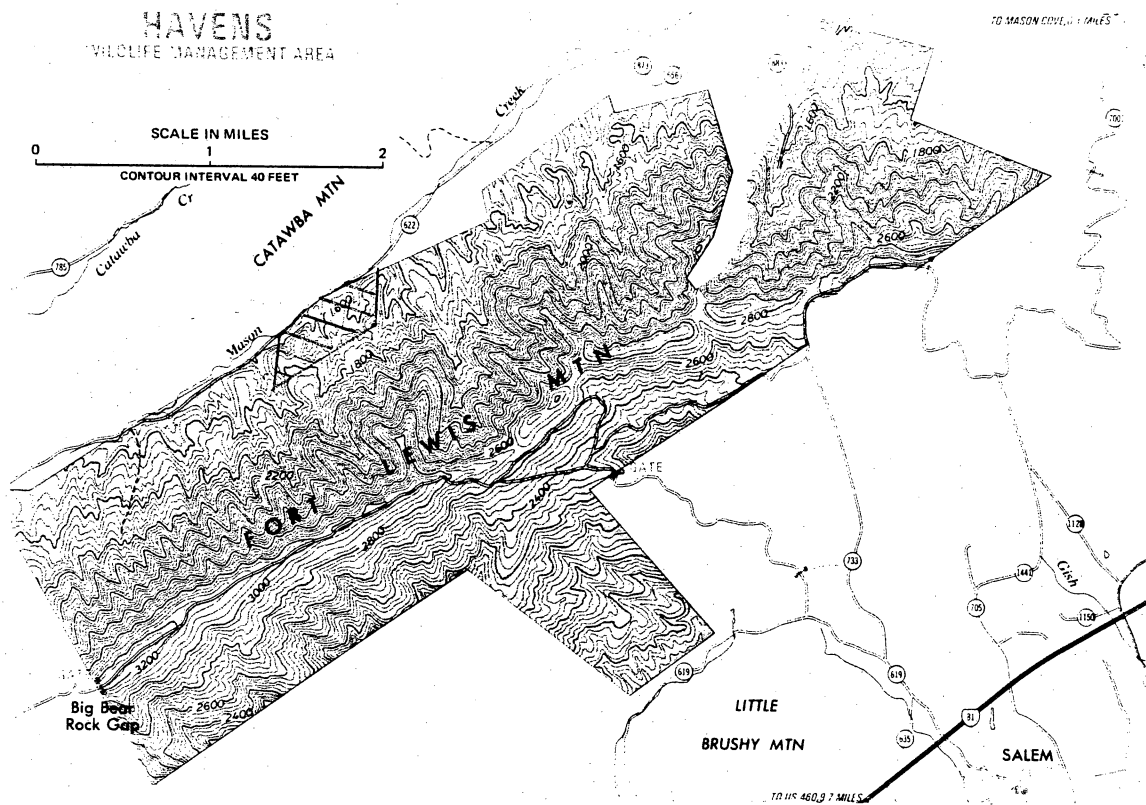


Figure 1. A map of Havens Wildlife Management Area with the demonstration area delineated.

The nature of this project was very methods oriented. A premium was placed on developing a practical management system that could be used with minimum expense, start-up time, and data collection and processing. Early on, the decision was made to strive for a robust system that could be refined and modified by other students of forest management eventually arriving at a field tested, professional level tool for forest-wildlife managers. To achieve this, many possibilities for making the system more realistic were bypassed in an effort to lay a solid framework for the future. Comments on possibilities for future revisions are discussed further in the **Conclusion** of this document.

## *The Demonstration*

To investigate the efficacy of WILDWOOD as a planning tool, a 106 ha portion of Havens Wildlife Management Area near Salem, Virginia was delineated as a demonstration and teaching area (Figure 1 on page 48). Information was gathered from 106 plots each representing a one ha cutting unit. The objective of the demonstration was to explore the possibilities of using the system on a typical area and to demonstrate that WILDWOOD can be applied to small landholdings. Since the required data were not available from outside sources for Havens, the author conducted a minimal cruise gathering the data needed for demonstration purposes. After the data were collected, 7 different runs were made with WILDWOOD using different objective functions. A sensitivity analysis was then conducted to determine which of the many variables included in the system had the most effect on the final outcome (the cut/year).

## **Havens Wildlife Management Area Description**

The demonstration area is located on Havens Wildlife Management Area, a 2,546 ha tract of land owned by the Virginia Commission of Game and Inland Fisheries. An area of 106 ha was delineated

on the northwestern slope of the main ridge (Fort Lewis Mountain). Havens is located in the Ridge and Valley province of the Appalachian Highlands. The soil consists of Gilpin fine sandy loam with only small intermittent streams present. Elevations range from 457 m to 914 m, and temperature varies from a mean low of 1.1 °C in January to a mean high of 21.1 °C degrees in July. The average annual rainfall is 109 cm. The aspect of the demonstration area varies from northeast to west (White and Randolph 1984).

The Havens area has been logged extensively in the past, and periodic burning has had an effect on the vegetation. Currently, the entire area is forested. Dominant timber types are hemlock, scarlet oak, chestnut oak, pitch pine, white oak-red oak-hickory, yellow poplar, yellow poplar-white oak-northern red oak, and yellow poplar-hemlock (SAF 1954). All types of silvicultural manipulation can and have been practiced in the Appalachian region, and these silvicultural manipulations have an important impact on the wildlife of the region (Barrett 1980).

## Data Collection

In October of 1986, a minimal forest survey was conducted on the demonstration area. A random-systematic survey design was implemented utilizing a plotless technique (Avery and Burkhardt 1983). Basal area/acre was taken with a 10 basal area factor prism and the dbh of the "in" trees was taken as well. Only trees 2.6" dbh and larger were recorded. The mathematics for converting these data to basal area/acre and trees/acre are as follows:

$$TPA_p = \sum_{i=1}^T [10/((DBH_i)^2 * 0.00545]$$

where:

T = total number of "in" trees in a basal area prism plot  
(BAF = 10)

p = plot number  
i = "in" tree number for plot p  
DBH = diameter-breast-height for tree i in plot p

Also, tree species group was recorded because the forest simulator used by WILDWOOD is only valid for pure even-aged, upland oak stands. Mixed age and type stands are included in the demonstration however. Site index at the plot was recorded after the technique described by Avery and Burkhardt (1983). A dominant or codominant tree was cored with an increment borer and the annual rings counted with a dissecting microscope to determine age. Height of the site index tree was determined with a clinometer. The age of the site index tree was considered to be the age of the stand for this demonstration and was recorded as such. Using the age and height information, site index was recorded for each cutting unit using Schnur's (1937) site index curves for upland oaks. These data were collected on 106 plots over a 3-week period. The workability of each cutting unit was determined based on steepness and access from a USGS 7.5' topographic map of the area.

## Objective Functions

Several objective functions were identified as good examples of the types of things WILDWOOD is capable of doing. The list is not extensive because new variations on objective functions are almost endless. The changes most easily made are in the weights of the animal species in the system. Assigning weights only to game species or only to rare species will drastically change the cumulative benefit model; such changes have a direct bearing on the outcome. The other obvious way to change the objective function is through adding or relaxing a constraint on the model. The list of examples of objective functions are as follows:

1. Maximize average yearly benefits with only white-tailed deer.



2. Maximize average yearly benefits with only ruffed grouse.
3. Maximize average yearly benefits with only game species.
4. Maximize average yearly benefits with all species weighted.
5. Maximize average benefits with species weighted according to their efficiency as gypsy moth predators.
6. Maximize stability of wildlife benefits according to a Q index where  $Q = \text{benefits} - (\text{deviations from a specified goal})^2$ . This particular objective function puts a premium on reducing the instability of the wildlife benefit outputs from the harvest plan. It discriminates against drastic practices that would result in either a severe increase or decrease in wildlife benefits. Because of the squared deviation term, large variations are penalized at a geometric rate the farther they occur from the average level. Small deviations are penalized much less severely.

These are just a few examples of the range of objective functions that may be addressable by WILDWOOD.

To summarize, a microcomputer-based optimization system was developed to specify the timing of fixed-size timber harvests within a forest for a variety of wildlife-oriented objectives. Then, a demonstration area was delineated, and a forest survey conducted to obtain information for demonstration analyses. Analyses were made of 7 different examples using the WILDWOOD system.

## Results

### *Potential Working Area*

WILDWOOD treats cutting units in English units, consequently from this point on, all references to area will be in terms of acres not hectares.

The first and most startling result of this study was that only 31 of the 106, 2.5 acre cutting units met the criteria for cutting. That is, they had a working class not equal to 0 and a site index greater than or equal to 60. This means that no matter what the rate of cutting on the area, a majority will be allowed to revert to old-growth timber and thus to areas which will favor old-growth wildlife species.

Time expended in gathering the necessary data for the demonstration area was also of interest because it will affect the probability that wildlife managers will use the system. Data collection required 69 person-hours which is roughly 0.26 hours/ac. This includes travel time between plots but not travel time to the site. This figure is probably inflated because some sampling trips were taken by a crew of as many as 7 individuals (far too many for efficient work), some sampling was

done by one person (more are needed for safety and efficiency), and the final samples were taken by a crew of two (the desirable size).

Projected costs for future applications based on a labor cost of \$10/hr would include 1 hour/species model (50 models = \$500), .2 hours/ acre for data collection (100 acres = \$200), travel and miscellaneous costs (\$100), and 1 hour of data entry (\$10). The total for a 100 acre tract using 50 species models is \$810. The bulk of this estimate is time spent in developing species models. Subsequent analyses using the same 50 species models would cost less than half as much. Also, information from BOVA or species experts would speed up the model development process, reducing this cost. These estimates do not include hardware and software costs, printer paper, time spent in interpretation of results, or other equipment costs (increment corer, compass, etc.).

## *System Tests*

Two optimization algorithms were tested for speed and repeatability of results. The main assumption, that the benefit output function is smooth and unimodal, was also tested.

### **Algorithm Test**

A simple comparison was made between the Fibonacci search algorithm and the binary search algorithm by running both with the same test data set under the same objective function. The test dataset was a subset of the Havens dataset that contained 42 cutting units, 14 of which were considered workable given the constraints set on the program (site index greater than or equal to 60 and working class not equal to zero). The binary search algorithm proved to be 24% faster on the test dataset (133 minutes vs. 175 minutes). The difference between the two answers was approxi-

mately 0.01 acre. Given these results, the binary search was used in successive system tests and demonstrations.

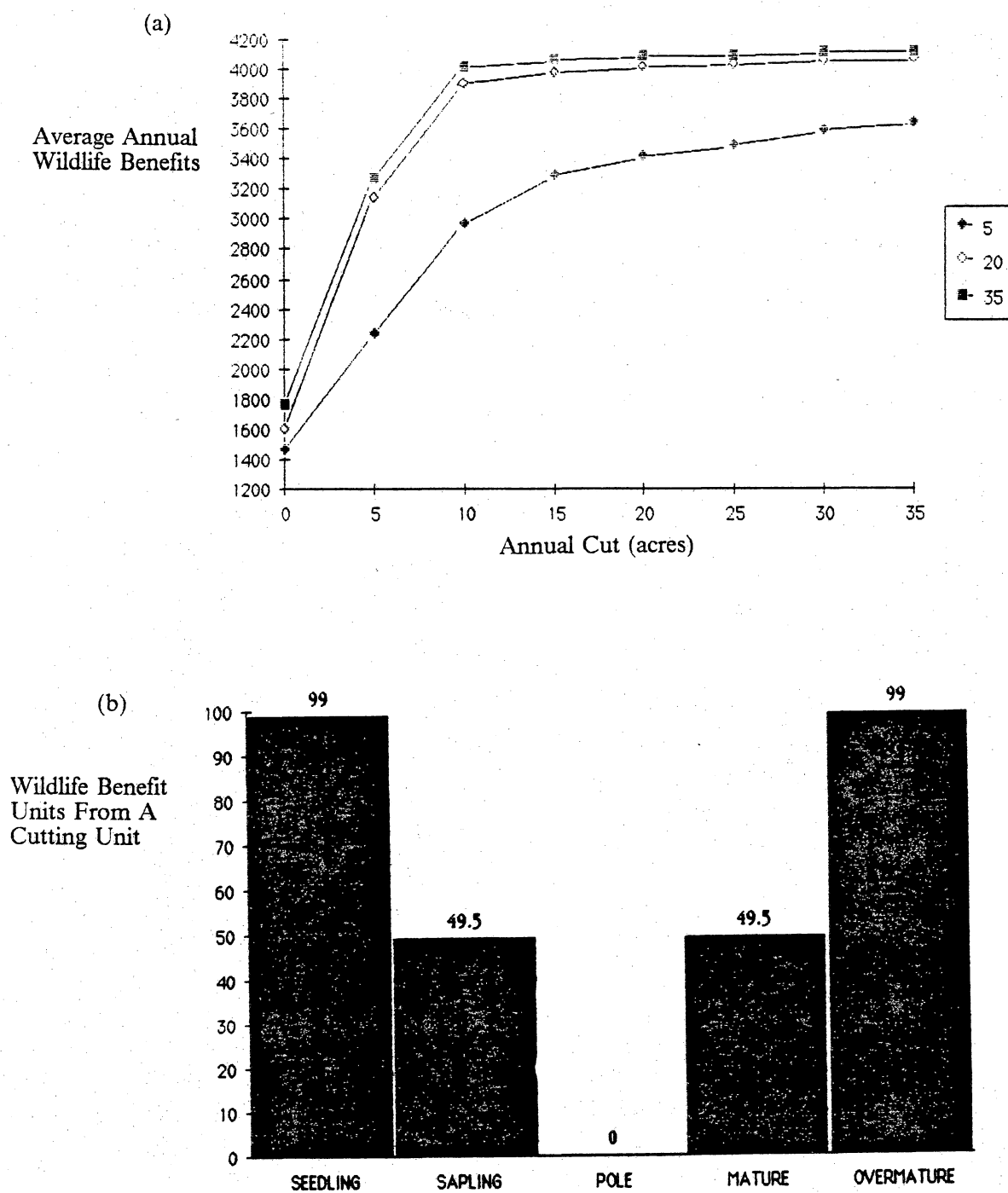
## Test for Unimodality and Smoothness

Another simple empirical test was devised for verifying this assumption. The system was constrained to simulate hypothetical annual cutting levels from from 0 to 1/3 the total acreage of the test dataset and record the resulting benefits. These numbers were then graphed.

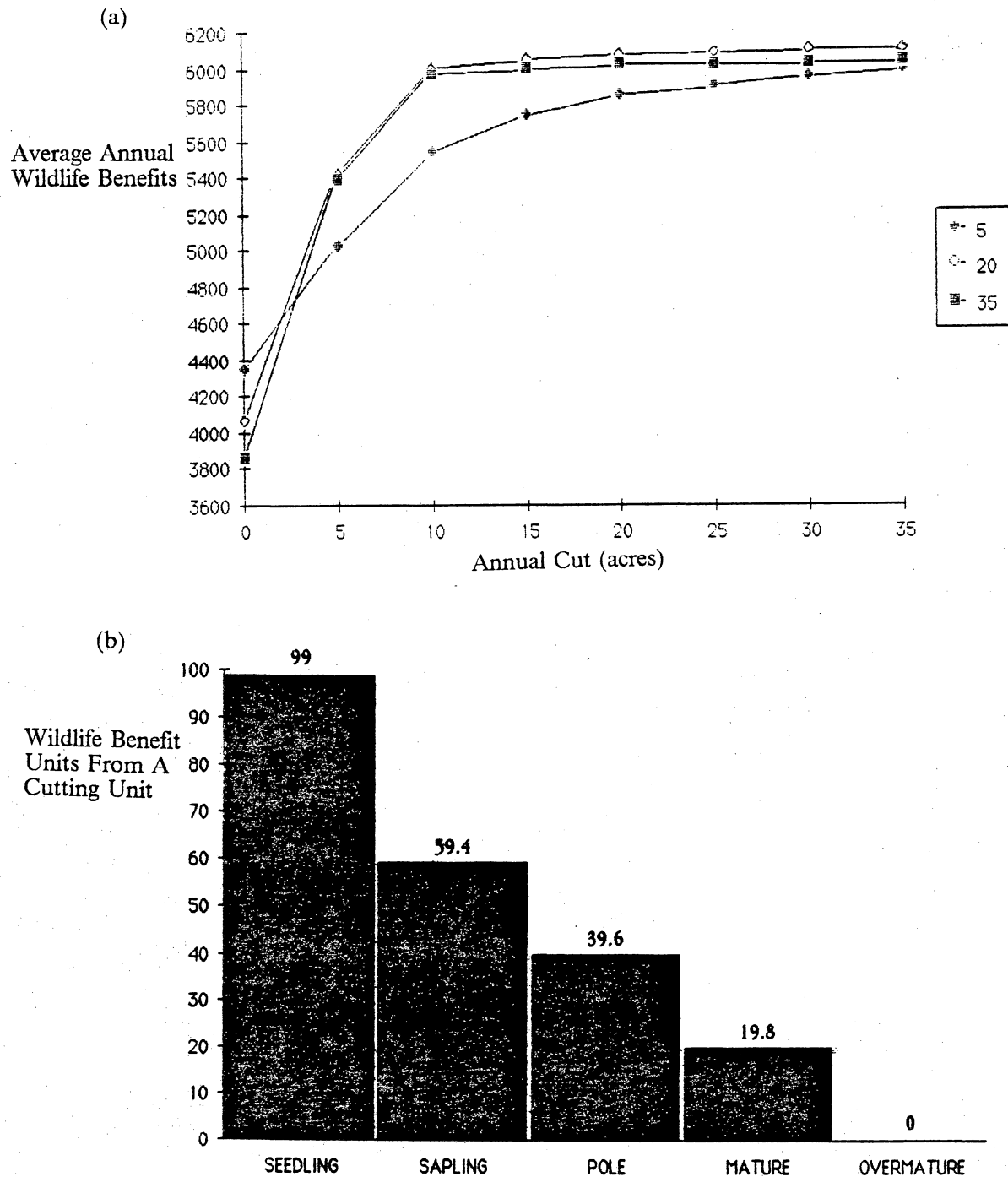
Three hypothetical possibilities of the cumulative benefit curve were investigated. Figure 2 on page 56 shows a cumulative benefit model that is severely bimodal. The graph shows analyses for 5, 20, and 35-year planning horizons all of which show the smooth, unimodal shape required. Similar results were obtained using a highly skewed cumulative benefit model in Figure 3 on page 57 and a unimodal cumulative benefit model in Figure 4 on page 58. A slight bimodal tendency was detected by using the cumulative benefit model in Figure 5 on page 59.

Given the slight bimodality of Figure 5 on page 59, a modification was made to the search algorithm. A test for bimodality was devised by sequentially generating benefit levels for 5 different annual cutting limits and then recording the direction that the curve travels from one point to another as a +1 or -1. Then, by sequentially adding one point with the point "in front" of it, a list of numbers is generated. Every 0 in the list represents a change in direction. A unimodal function should have only one change in direction (one 0 in the list) and a bimodal function will have more than one change in direction (more than one 0 in the list). In this way a bimodal function is detected if more than one 0 is present in the final list. This method is currently employed in the WILDWOOD system. The examples were tested graphically for bimodality.

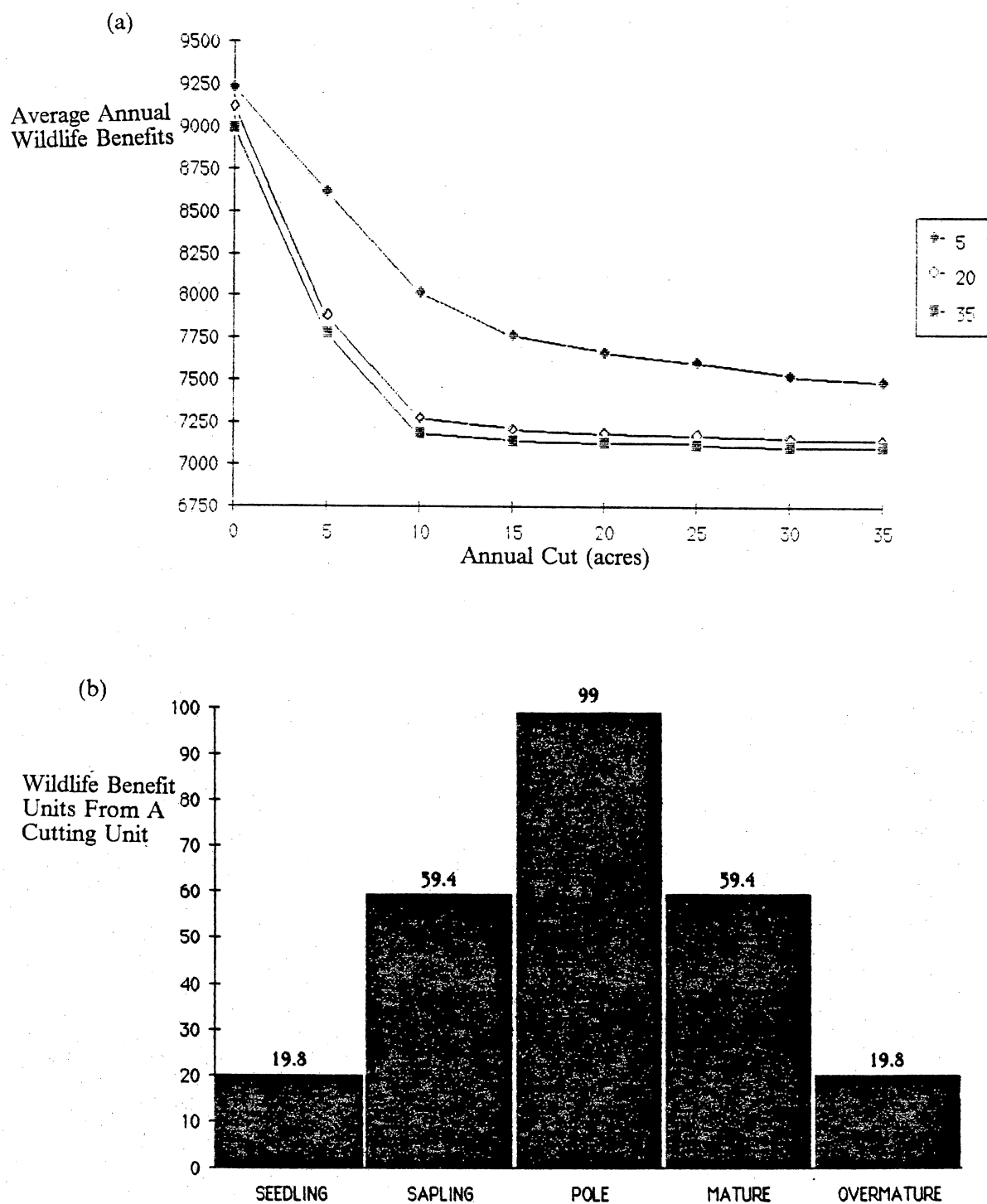
Other interesting results were obtained from this analyses as well. First, it becomes apparent that the current condition of the forest has great impact on the shape of the benefit graphs. An example



**Figure 2. Test for unimodality and smoothness:** Total wildlife benefits (a) with 3 planning horizons (5, 20, and 35 years) resulting from a bimodal cumulative benefit model (b).



**Figure 3. Test for unimodality and smoothness:** Total wildlife benefits (a) with 3 planning horizons (5, 20, and 35 years) resulting from a unimodal cumulative benefit model (b).



**Figure 4. Test for unimodality and smoothness:** Total wildlife benefits (a) with 3 planning horizons (5, 20, and 35 years) resulting from a symmetric unimodal cumulative benefit model (b).

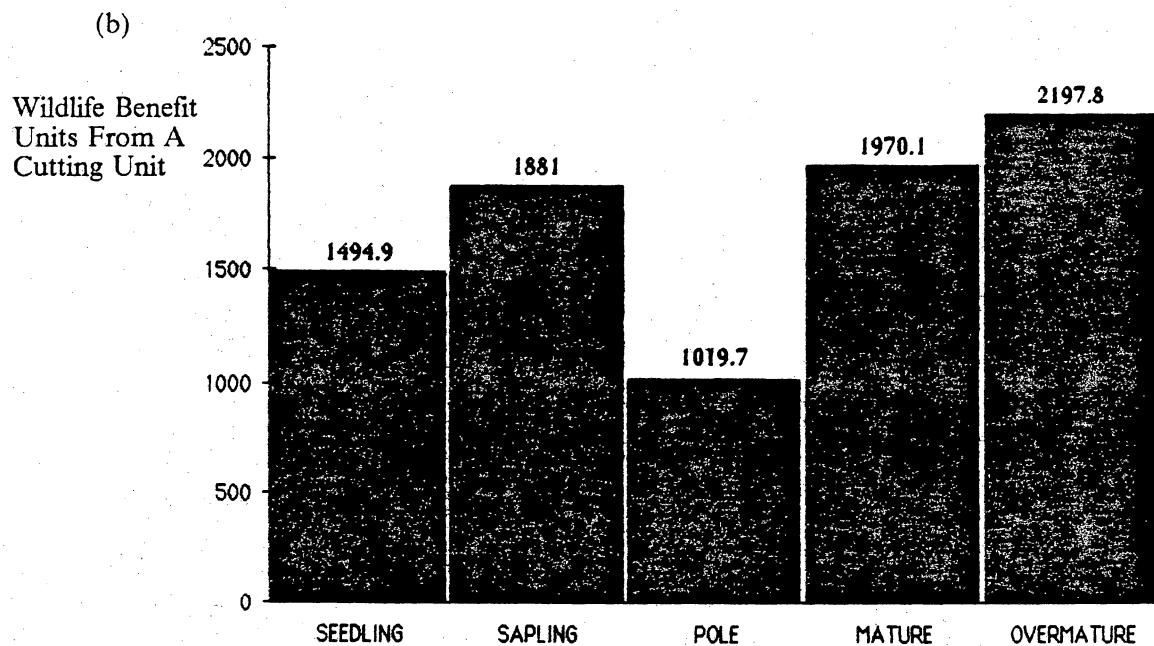
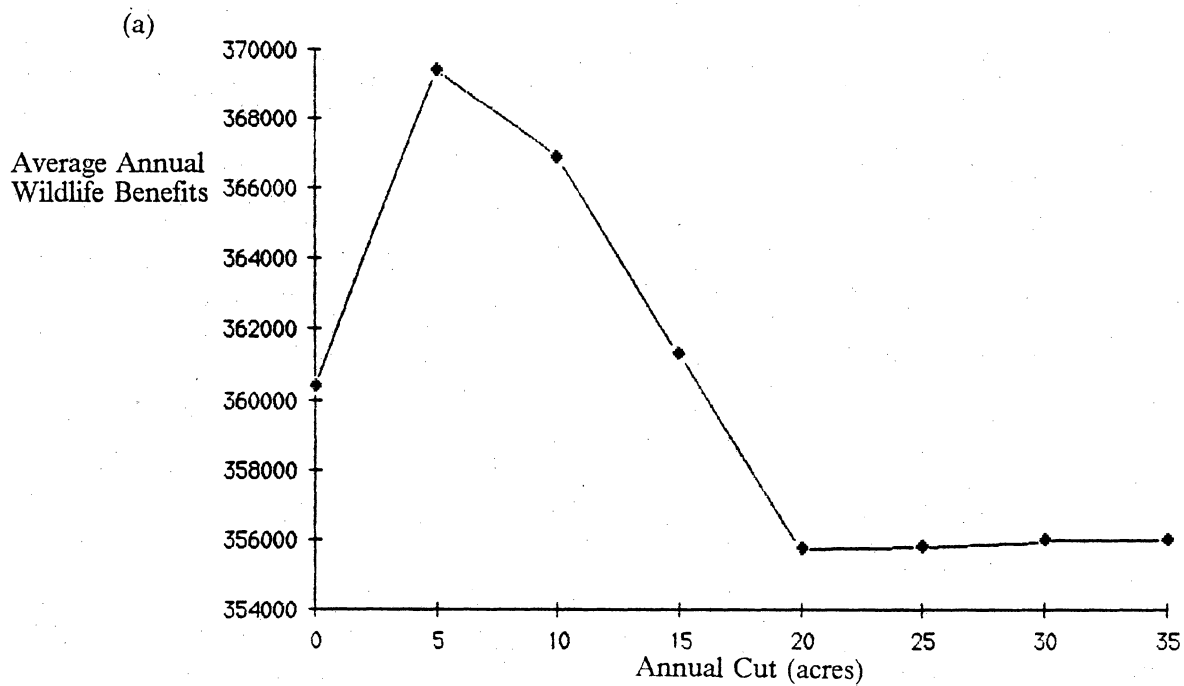


Figure 5. Test for unimodality and smoothness: Total wildlife benefits (a) resulting from a non-symmetric bimodal cumulative benefit model (b).

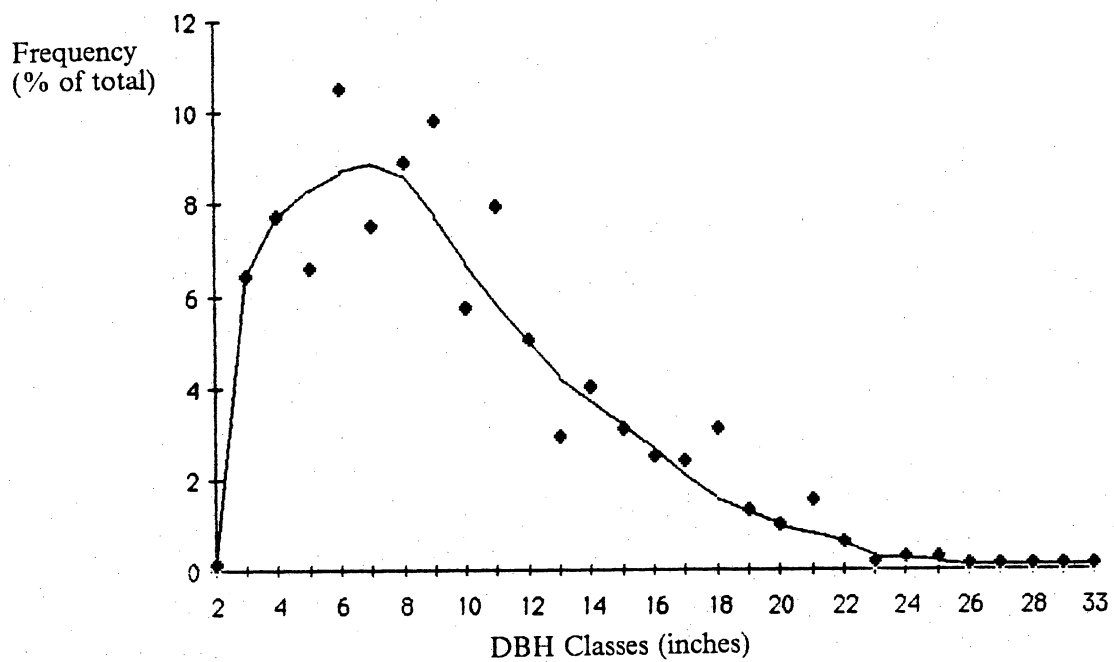


is Figure 4 on page 58. This graph shows a declining benefit curve with increased cutting even though the old-growth forest size class is the lowest ranking size class. It is hypothesized that because the demonstration area is primarily a pole-mature forest (see Figure 6 on page 61), cutting moves stands into the seedling size class which also has a low ranking, reducing the benefits output. Also, since so many stands are uncuttable (28 of 42) in this test dataset, what would happen if no cutting occurred? The answer is that at some point in the future, the forest moves so far into the low ranking size class (old-growth) that cutting once again becomes profitable from a wildlife benefits point-of-view. This quirk of the system is probably related to the 35-year limitation on planning horizons. Presumably if the analysis was run for 100 years, the curve would be a different shape in this special case.

## *Results of the WILDWOOD Analyses*

The WILDWOOD demonstrations are designed to investigate the flexibility and range of application of the system. The results will be presented in summary, but due to the size of the total WILDWOOD generated report, the entire cutting plan and data summary will not be presented here. A sample of the tabular output is displayed in Table 3 on page 62 and a sample of the run summary is displayed in Table 4 on page 64.

Cutting units for these examples were first sorted using priority option 1. Harvesting sequence was based on cutting unit age (harvesting oldest first). Although other cutting priorities are available within the WILDWOOD system, they were not demonstrated, but were left for users and future students to investigate. Similarly, 35 years (the maximum) was chosen as the planning horizon for the examples. Presenting examples that vary all the different options of the WILDWOOD system



**Figure 6. Frequency of trees of various diameters on the Havens demonstration area (n=875).**

**Table 3. Representative data summary for one cutting unit (unit 0114)**

: For the demonstration area, 106 such forms were produced for each analysis. Asterisks denote harvest years (age=0).

**Report for cutting unit 0114**

Year	Age	MDBH	BA	Benefits/Acre	Benefits	Cords/Acre	Acres
1987	57	7.4	110	1020	2549	36.6	2.5
1988	58	7.5	111	1020	2549	37.2	2.5
1989	59	7.6	111	1020	2549	37.7	2.5
1990	60	7.7	112	1020	2549	38.2	2.5
1991	61	7.9	112	1020	2549	38.6	2.5
1992	0	0.6	2	1495	3737	0.0	2.5 *
1993	1	0.6	2	1495	3737	0.0	2.5
1994	2	0.6	2	1495	3737	0.0	2.5
1995	3	0.6	2	1495	3737	0.0	2.5
1996	4	0.9	5	1495	3737	0.0	2.5
1997	5	1.2	8	1881	4702	0.0	2.5
1998	6	1.6	13	1881	4702	0.0	2.5
1999	7	1.9	19	1881	4702	0.0	2.5
2000	8	2.1	25	1881	4702	0.0	2.5
2001	9	2.4	31	1881	4702	0.0	2.5
2002	10	2.6	37	1881	4702	0.1	2.5
2003	11	2.8	42	1881	4702	0.2	2.5
2004	12	2.9	47	1881	4702	0.4	2.5
2005	13	3.1	52	1881	4702	0.8	2.5
2006	14	3.2	56	1881	4702	1.1	2.5
2007	15	3.3	60	1881	4702	1.6	2.5
2008	0	0.6	2	1495	3737	0.0	2.5 *
2009	1	0.6	2	1495	3737	0.0	2.5
2010	2	0.6	2	1495	3737	0.0	2.5
2011	3	0.6	2	1495	3737	0.0	2.5
2012	4	0.9	5	1495	3737	0.0	2.5
2013	5	1.2	8	1881	4702	0.0	2.5
2014	6	1.6	13	1881	4702	0.0	2.5
2015	7	1.9	19	1881	4702	0.0	2.5
2016	8	2.1	25	1881	4702	0.0	2.5
2017	9	2.4	31	1881	4702	0.0	2.5
2018	10	2.6	37	1881	4702	0.1	2.5
2019	11	2.8	42	1881	4702	0.2	2.5
2020	12	2.9	47	1881	4702	0.4	2.5
2021	13	3.1	52	1881	4702	0.8	2.5
2022	14	3.2	56	1881	4702	1.1	2.5

would require hundreds of runs and many hundreds of pages to summarize. Consequently, only a small number of the more useful items are discussed here.

## **Management Plans**

The following objective functions were used to test WILDWOOD:

1. **White-tailed Deer Scenario**
2. **Ruffed Grouse Scenario**
3. **Game Species Scenario**
4. **All Species Scenario**
5. **Gypsy Moth (*Porthetria dispar*) Predators Scenario**
6. **Stability Scenario**

Each management plan scenario was selected and specified to demonstrate a particular aspect of the WILDWOOD system. Unlimited possibilities exist for creating new management objectives. These eight are designed to give the reader some idea of the efficacy of the WILDWOOD system.

### **White-tailed Deer Scenario**

This is an example of single species management of an economically important game species. For this example, the white-tailed deer was ranked at 99 and all other species were ranked at 0, effectively removing them from the analysis. The white-tailed deer is considered by many to be an early succession species that is favored by forest harvesting. The white-tailed deer model was created by the "expert opinion" of two researchers knowledgeable in the biology of the species and habitat

**Table 4. Representative WILDWOOD Plan Summary. One Summary was produced for each analysis.**

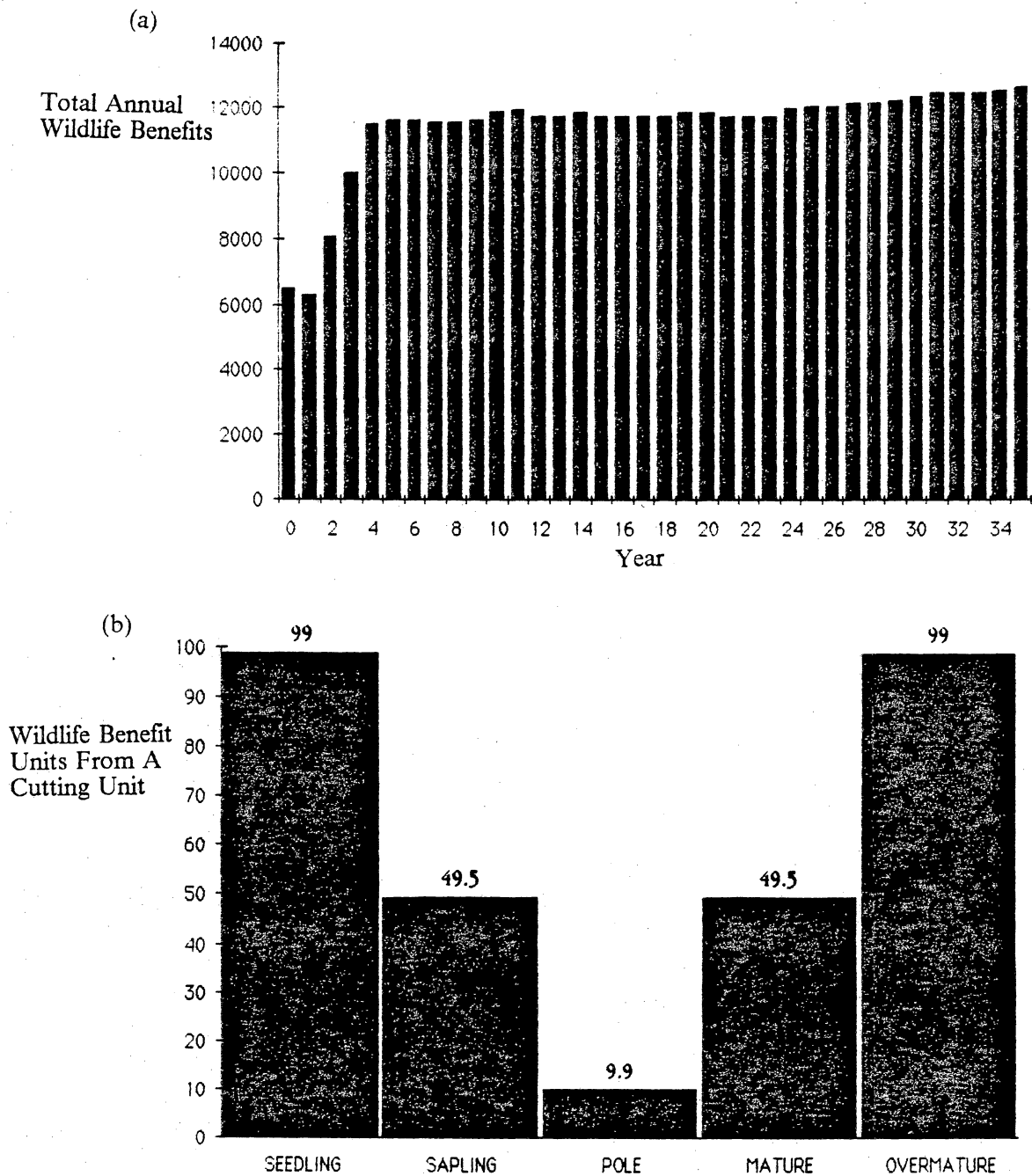
<hr/> <hr/>	
The mean annual benefit figure for this run	: 5767
The yearly cutting level (acres) to achieve this	: 2.00
Q	: -1.52
The number of cords projected to be cut	: 37
<hr/> <hr/>	

modeling in general (Kopf 1986, Stauffer 1986) and indicates a bimodal relationship in which old-growth (presumably in a gap-phase successional state) is of equal value with seedling stage forests. For food value, old-growth upland oak forests provide high quality hard mast and cover when some trees begin to fall out of the canopy creating small thickets of seedlings and brush. Seedling stage forests provide browse and low growing grasses and forbs plus cover. Intuitively, WILDWOOD could have recommended no cutting and arrived at a forest in a perfect state in regards to deer habitat (according to the model). WILDWOOD did not recommend a 0 annual cut because the majority of the forest is currently in the pole and mature size classes. Cutting these stands moves them into the seedling size class which has a much higher habitat quality rating. Consequently, cutting raises habitat quality in the short run (less than 35 years). It is hypothesized that allowing WILDWOOD to run 150 years or more (an impossibility due to hardware/software constraints at this writing) would result in a 0 annual cut recommendation.

The benefits for this scenario range from 6,509 to 12,721 an increase of 48.8% with an average value of 11,657 (Figure 7 on page 66). The annual cut recommended is 25.8 acres/year. This is the maximum allowed by WILDWOOD for this dataset because the cutting level is constrained to a maximum of one-third the cuttable acreage on the area. The rotation age resulting from this recommendation is 2-3 years which may be translated into maintaining brushy openings for this species. The number of cords harvested under this cutting plan is 659 for the 35-year planning horizon which is much lower than in other scenarios. It is to be expected, however, because once a cutting unit is harvested, it is not allowed to grow harvestable cords for the rest of the planning horizon.

## Ruffed Grouse Scenario

This is another example of a single species management objective. In this scenario the ruffed grouse was valued at 99 and all other species were given a value of 0. The ruffed grouse is a highly valued



**Figure 7. White-tailed Deer scenario results:** Total annual wildlife benefits from the white-tailed deer from all stands (a) and the cumulative wildlife benefit model used in the white-tailed deer scenario (b).

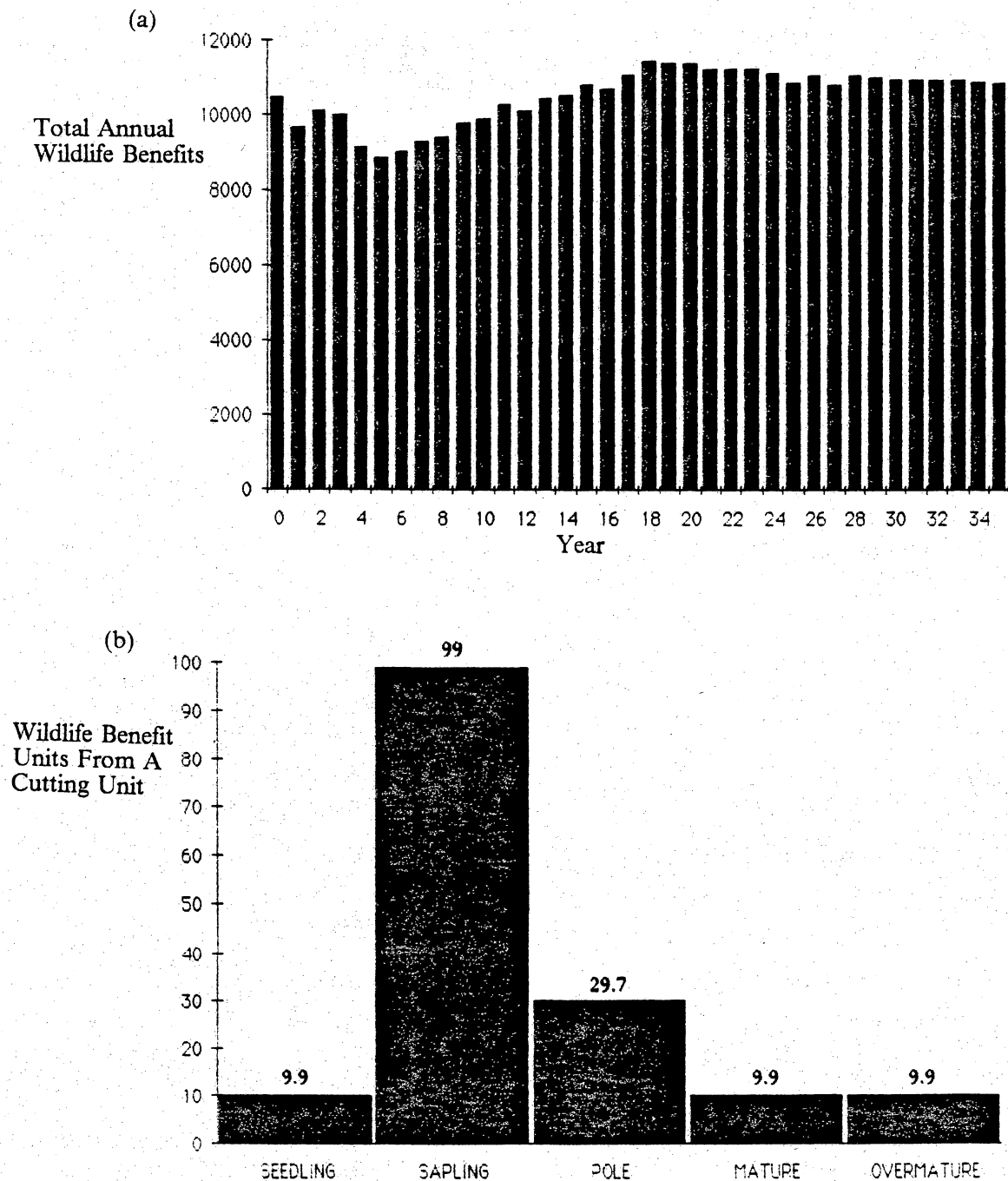
game bird in western Virginia that is affected by timber harvest practices (Johnsgard 1973). The cumulative benefit curve (Figure 8 on page 69) is unimodal, peaking in the sapling forest size class which would indicate that at least some cutting will be advisable given that the Havens demonstration area is primarily a pole-mature forest.

The analysis yielded a cutting recommendation of 3.8 acres/year which translates into a rotation age of 18-19 years. The plan calls for harvesting 1073 cords of wood over the 35-year planning horizon, more than any of the other scenarios. The yearly benefit level ranges from 10,469 to 10,840 an increase of 3.4%, the smallest increase of any of the scenarios. The average yearly benefit level was 10,523.

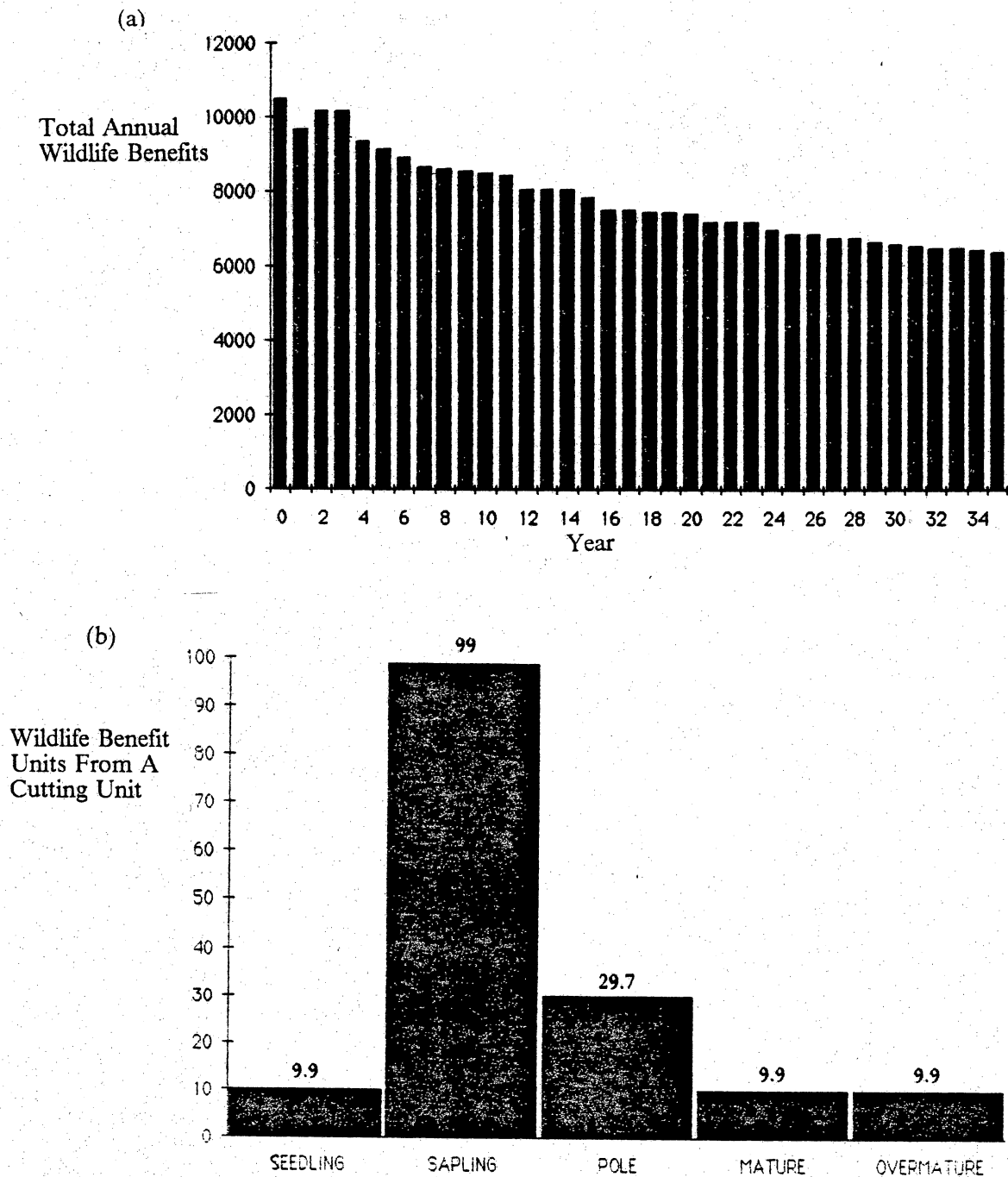
This small increase is probably related again to the current state of the forest. Many unworkable cutting units are pole size. These cutting units are growing into mature stands over the 35-year planning horizon which is a much lower-valued forest size class. This unavoidable loss of grouse habitat is offsetting the gains made by forest harvesting in the workable stands so the recommendation is that 3.8 acres/year need to be cut just to maintain current ruffed grouse habitat quality. Presumably, a case could occur under different circumstances that would result in a loss of overall habitat value, but the loss would be smaller if the WILDWOOD recommendations are taken.

To test this hypothesis, another simulation run was made with WILDWOOD to display the projected results of managing the Havens demonstration area under a no harvest option. The results are displayed in Figure 9 on page 70. In this analysis with the cutting level arbitrarily forced to 0 acres/year, average benefits are 7,723/year, a 26.6% decrease from the WILDWOOD recommendation of 3.8 acres/year. Wildlife benefits range from 10,469 at present to 6,360 after 35 years, a decrease of 64.6%.





**Figure 8. Ruffed grouse scenario results:** Total annual wildlife benefits from the ruffed grouse from all stands (a) and the cumulative wildlife benefit curve used in the ruffed grouse scenario (b).



**Figure 9.** Ruffed grouse scenario results with cut forced to 0 acres/year: Total annual wildlife benefits from the ruffed grouse from all stands (a) and the cumulative wildlife benefit curve used in the ruffed grouse scenario with the annual cut forced to zero (b).

## Game Species Scenario

This is an example of a more complex management problem that may be faced by a hunting preserve or hunt club. All the game species in the database were included with the exception of the black bear and the wild turkey - poult. The black bear was not included because of its rare nature and because few if any private landowners could actively manage habitat over a large enough area to affect black bear populations. The wild turkey - poult was not included because it does not represent a huntable entity. Also poult habitat is generally important at a time of the year other than hunting season. The list of species and their values for the analysis are listed below:

1. white-tailed deer	99
2. wild turkey - adult	99
3. Northern bobwhite	5
4. ruffed grouse	5
5. Northern gray squirrel	1
6. Eastern woolly cottontail	1
7. raccoon	1
8. red fox	1
9. Eastern gray fox	1

Again WILDWOOD converged at 25.8 acres/year as an annual cut, the same as in the white-tailed deer scenario. As before, the white-tailed deer will be provided good habitat under a maximum annual cut (25.8) or a minimum annual cut (0), but the program converges to 25.8 acres/year because of the truncated planning horizon. The wild turkey on the other hand should have thrown the balance towards no cutting because old-growth is weighted highly and seedling stage forests are rated poorly. When combined with the other lower valued species which are basically all (with the exception of the Northern gray squirrel) early succession species, the result is another bimodal cumulative benefit model (Figure 10 on page 72). As in the white-tailed deer scenario, WILDWOOD

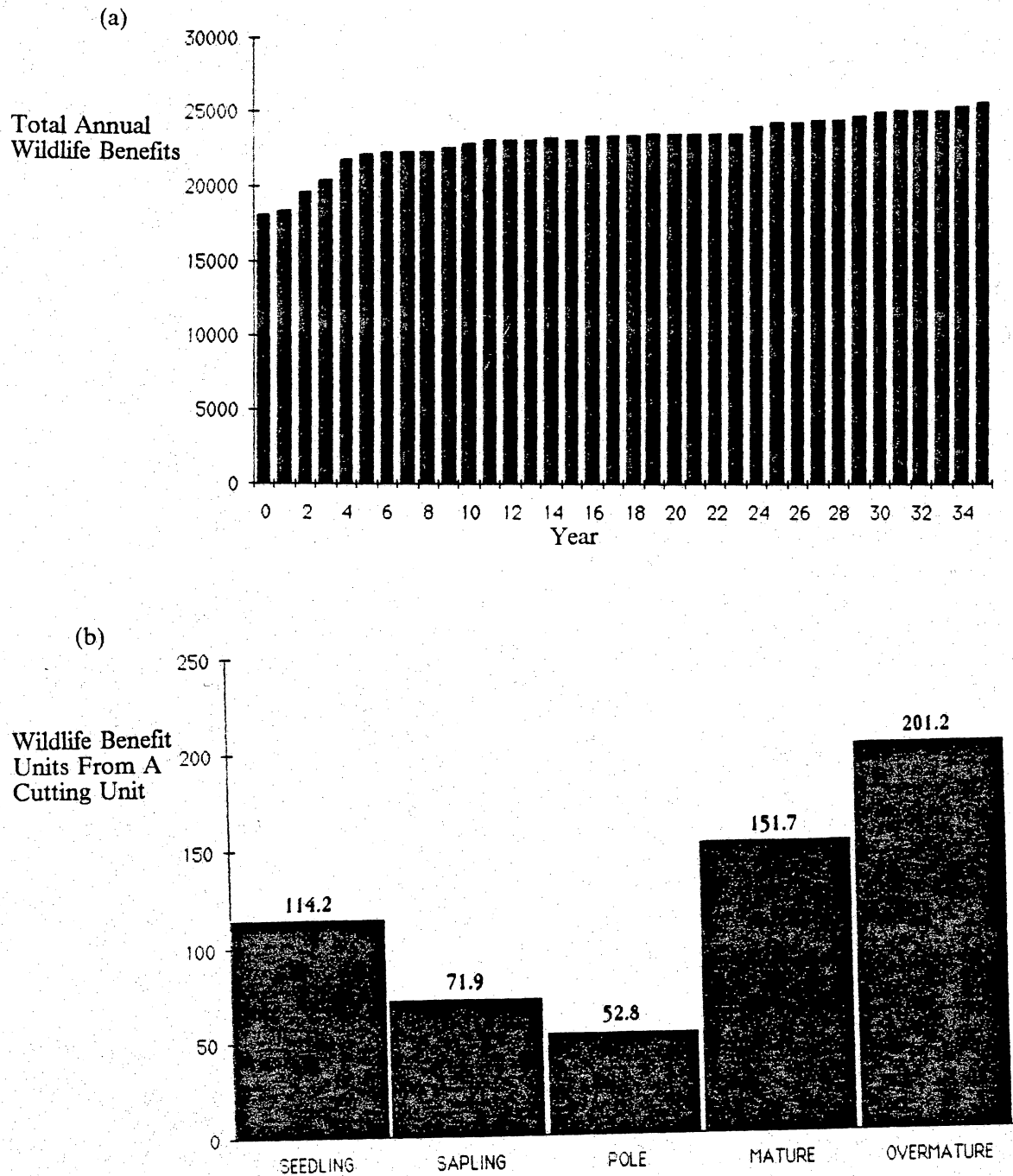
converges towards the more intense cutting regime because many cutting units on the area are slow-growing pole stands. Cutting these stands as quickly as possible moves them into the seedling stage which is a higher rated condition in the cumulative benefit model which results in a higher mean annual benefit level, the goal of the system. If most of the cutting units on the Havens demonstration area were mature or old-growth, or the analysis had been run for a longer period of time, presumably the program would have recommended a cutting level of 0 acres/year.

The benefits from this cutting level (25.8 acres/year) ranged from 18,109 to 25,598 an increase of 29.3% with a mean annual benefit level of 23,277 (Figure 10 on page 72). Again, 659 cords would be harvested at an annual cutting level of 25.8 acres/year, and the rotation age is approximately 2-3 years.

## **All-Species Scenario**

In this scenario, all 42 species in the SPECIES database were ranked equally at 99 for the first part of the analysis, and then another analysis was done with various weights on the 42 species. The species and weights are listed in Table 5 on page 73.

The first part of this analysis represents the sort of management problem that might confront a government agency dedicated to managing for diversity (species richness) of wildlife or an agency that, by policy or legal mandate, does not officially rank or place a value on wildlife species. The reality of the situation is more closely portrayed by the second part of the analysis. The tendency is to place different values on species based on visibility, economic importance, or rarity. The results from the first part of this scenario are displayed in Figure 11 on page 76. The cumulative benefit model is bimodal and highest at the old-growth end. There is a 53% difference from the highest (old-growth) to the lowest (pole) value. WILDWOOD calls for 5.05 acres/year to be harvested which will result in 1008 cords being cut over the 35-year planning horizon. The rotation



**Figure 10.** Game species scenario results: Total annual wildlife benefits from game species from all stands (a) and the cumulative wildlife benefit curve used in the game species scenario (b).

**Table 5. List of species and values used in the All Species Scenario.**

white-tailed deer	99	wild turkey - adult	80
wild turkey - poult	80	black bear	50
Eastern gray fox	25	Eastern woolly cottontail	10
Northern bobwhite	10	raccoon	10
red fox	10	Appalachian Bewick's Wren	5
barred owl	5	ruffed grouse	5
pileated woodpecker	2	American goldfinch	1
black-and-white warbler	1	blue jay	1
blue-gray gnatcatcher	1	broadhead skink	1
common yellowthroat	1	deer mouse	1
downy woodpecker	1	Eastern bluebird	1
Eastern hognose snake	1	Eastern wood pewee	1
Eastern wood rat	1	field sparrow	1
gray catbird	1	indigo bunting	1
least shrew	1	meadow vole	1
Northern gray squirrel	1	ovenbird	1
pine vole	1	prairie warbler	1
redback salamander	1	ruby-throated hummingbird	1
scarlet tanager	1	Southern flying squirrel	1
veery	1	Wehrle's salamander	1
yellow warbler	1	yellow-billed cuckoo	1
yellow-breasted chat	1		

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age predicted for the Havens demonstration area would be 14-15 years for the workable cutting units. Benefits are predicted to range from 340,213 to 393,648 a positive increase of 13.6%.

The reader will note that the total resulting benefits from this analysis are much higher than the previous scenario. This is because roughly 10 fold more species were included in the analysis and all at the highest possible value. This raises the question of comparability between analyses and may be one of the most serious shortcomings of the system as it currently exists. A similar problem would become apparent if areas of different sizes (numbers and sizes of cutting units) were compared. There is no way at present to account for comparisons between different size areas (except by expressing average benefit units per acre in the management unit) or comparisons between different species lists on the same area.

Results from the second part of the analysis are presented in Figure 12 on page 77. The cumulative benefit model for this scenario is quite bimodal with the highest values in the seedling (232.6) and the old-growth (284.4) forest size classes. Due to the predominantly pole to mature condition of the existing forest, the system predicted that an annual cutting limit of 25.8 acres/year (the maximum) would yield the most wildlife benefits over the 35 year planning horizon. Wildlife benefits ranged from 33,694 in year 0 to 43,960 in year 2016, a 23.4% increase. This annual cutting limit would produce 659 cords of wood.

The difference between part 1 and part 2 of this scenario may quantitatively explain the difference between public groups that hope to limit forest cutting by certain government agencies and the agency wildlife planners that recommend a high level of cutting. Both groups are discussing the same list of species, but the groups place an entirely different set of values on the individual species on the list. The results of these analyses are intuitively correct. An objective of maximum species diversity (equal weighting) requires a small amount of cutting to meet the requirements of early succession wildlife species. An objective function that values early succession species highly, results in a large annual cut that quickly moves the forest into the highly valued, seedling size class. Intuitively, a no-cutting option should eventually result in the optimum plan but since the planning

horizon is only 35 years, the system converges towards the higher cutting limit to move low producing pole and mature cutting units into a more productive (over the 35 years) size class.

## Gypsy Moth Predators Scenario

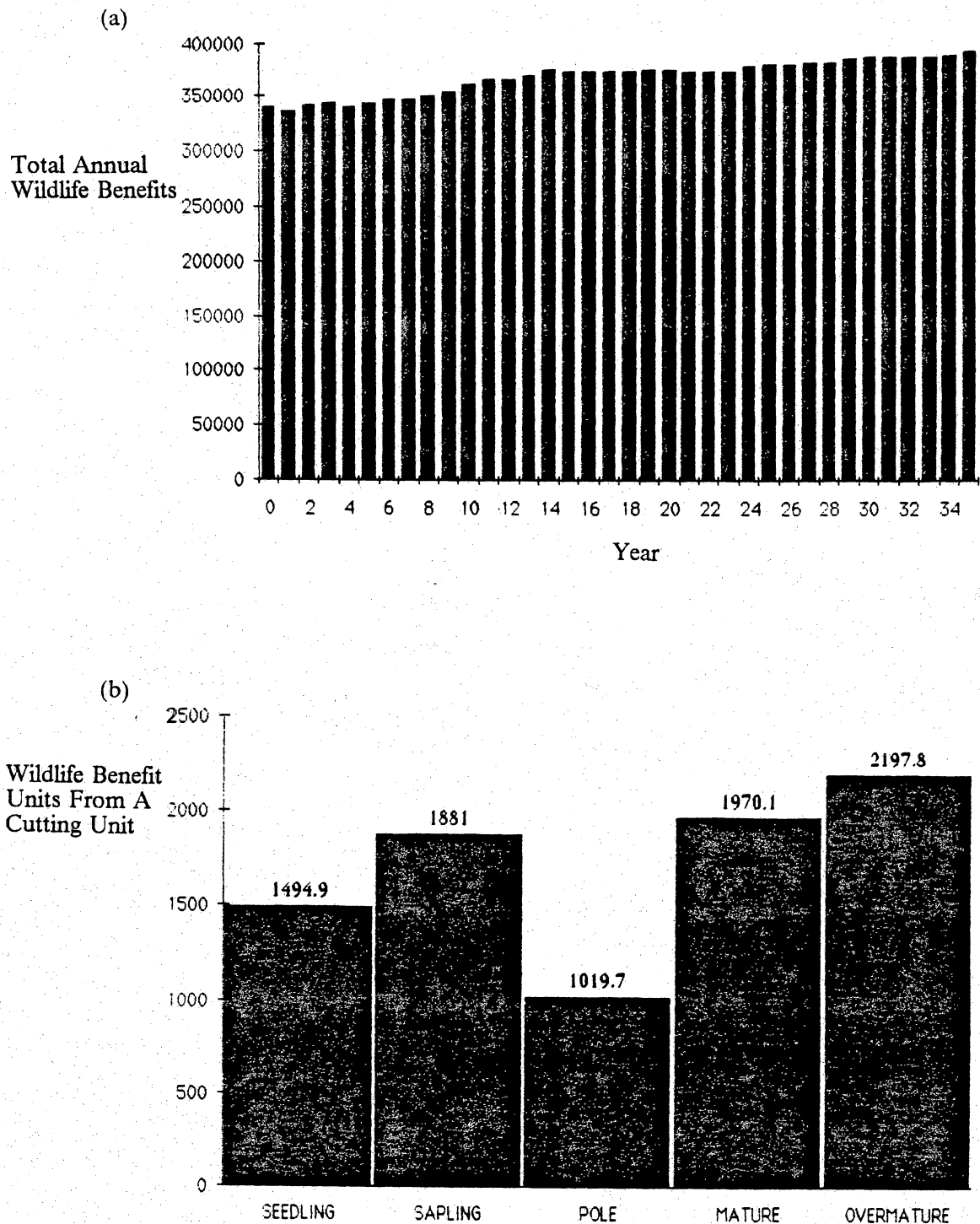
This scenario was stimulated by a paper by Smith (1985) describing the relative predation among forest animals on gypsy moth adults and larvae. Four of the 43 species in the species database were found to prey extensively on the gypsy moth, an important pest species of the northeastern United States and one apparently increasing in Virginia. These species are:

1. Yellow-billed cuckoo	99
2. Blue jay	51
3. Gray catbird	20
4. Downy woodpecker	8

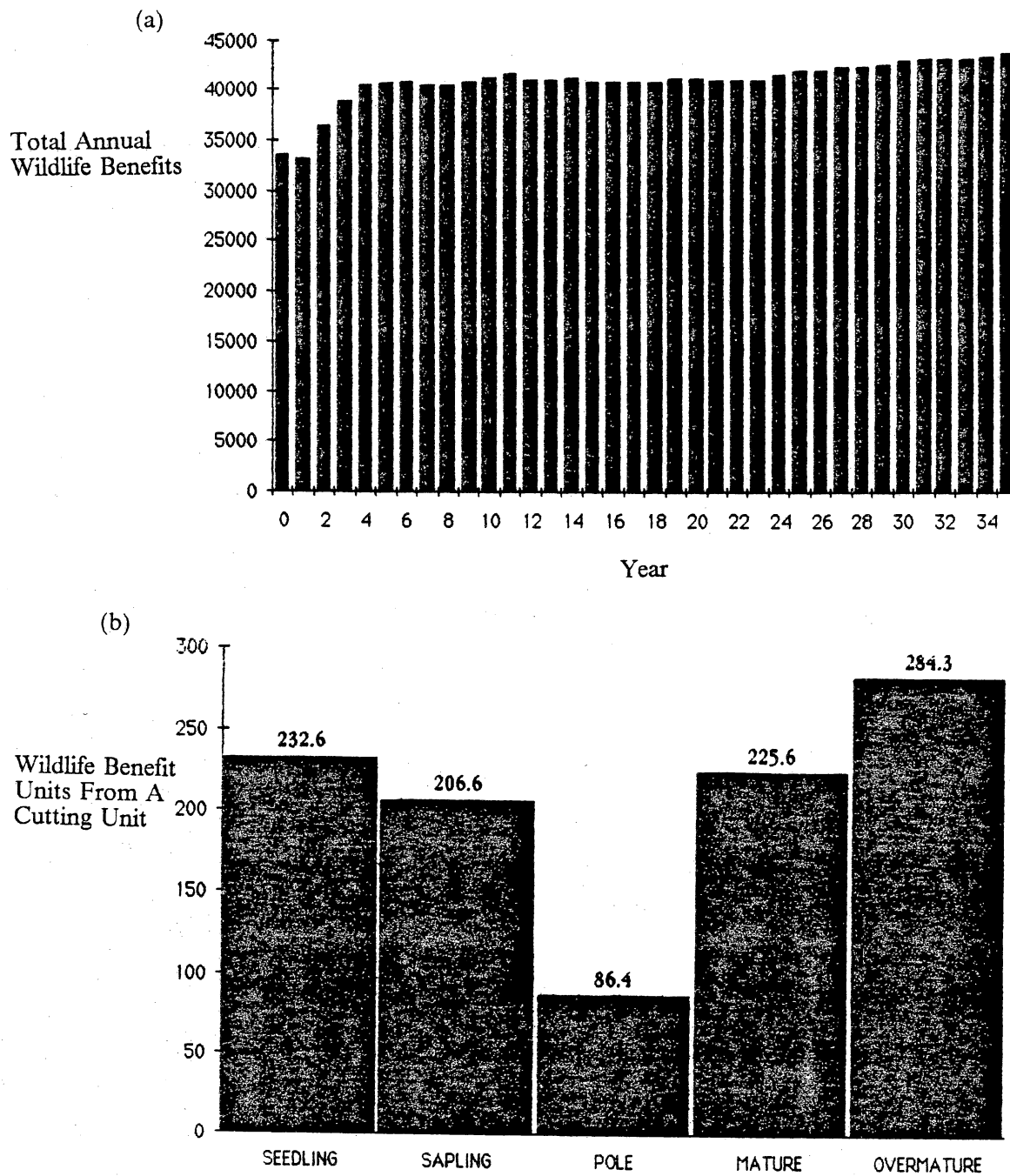
The weighted value assigned to these species was the reported frequency of gypsy moth adult or larvae found in the food habits (crop item identification) study done by Smith (1985). The weighting could be further refined with information on the birds hunting efficiency, time in the area, or population density. For this example, only the raw data were used.

The purpose of including this application of WILDWOOD is two-fold. WILDWOOD is a systems approach (Von Bertalanffy 1973) to forest wildlife management. This means that the WILDWOOD system is designed to describe robustly, interactions between forest wildlife and forest structure. Many different applications are possible with WILDWOOD, and the approach may be useful to every aspect of wildlife habitat management. Single species management, guild management, rare and endangered species management, featured species management, indicator species management, game management, non-game management, furbearer management, etc. can all be





**Figure 11.** All species scenario results with species values = 99: Total annual wildlife benefits from all species from all stands (a) and the cumulative wildlife benefit curve used in the all species scenario (b) with all species values = 99.



**Figure 12.** All species scenario results with various species values: Total annual wildlife benefits from all species from all stands (a) and the cumulative wildlife benefit curve used in the all species scenario (b) with various species values.

addressed with only slight, interactive modifications of the WILDWOOD system. In this scenario, a part of a guild (those species preying on gypsy moths) is managed for a specific economic objective, i.e., reduction of a forest pest.

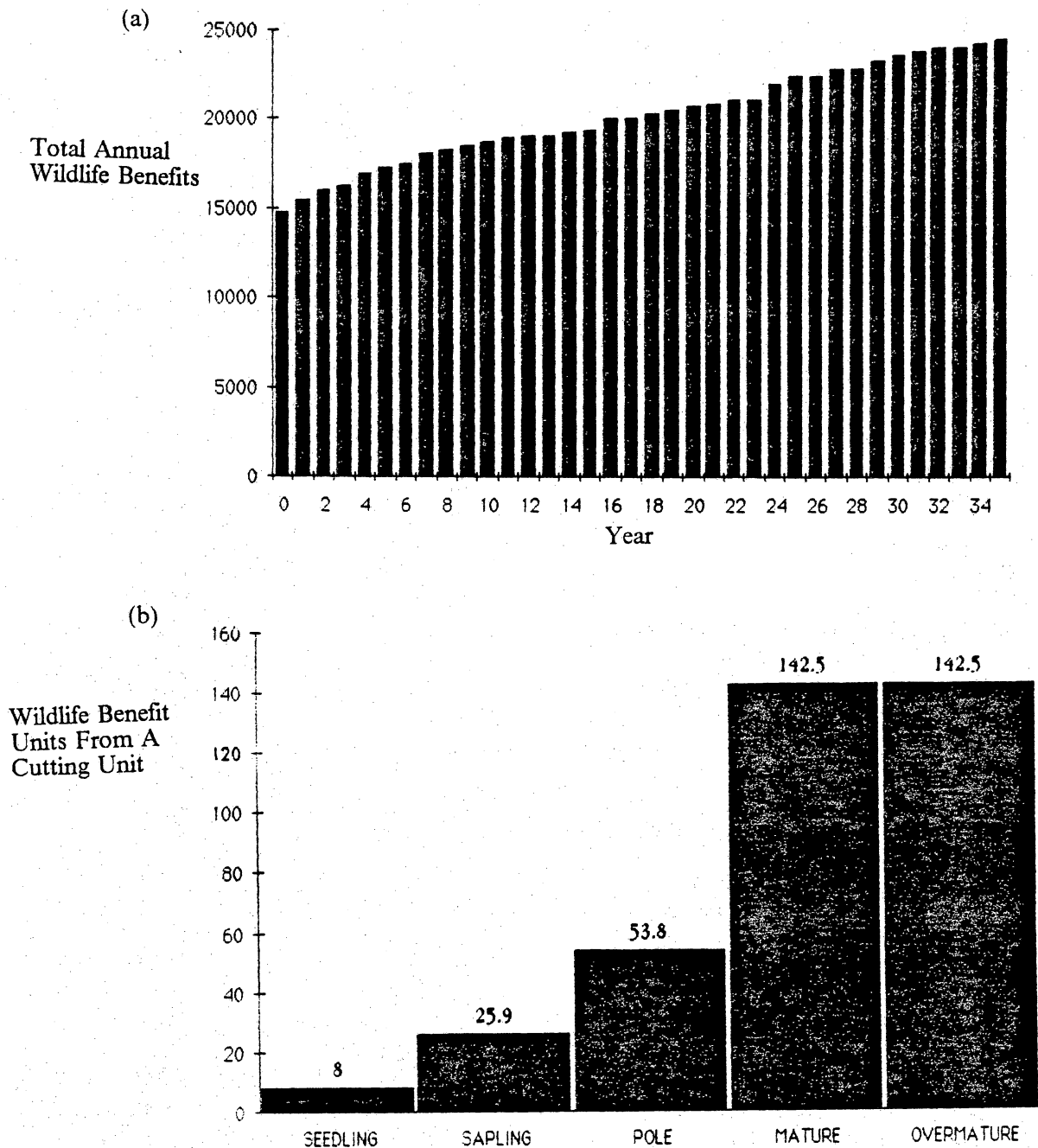
The management information generated by WILDWOOD for this objective function is summarized in Figure 13 on page 79. The cumulative benefit model for this objective is weighted more heavily towards the old-growth forest size class (8.0 units vs. 142.5 units, an increase of over 17 times). Intuitively, a management plan this heavily weighted towards old-growth forest should recommend no cutting, and WILDWOOD does not recommend cutting under this objective function. The successional histogram does show a gradual increase in the value of the forest for these species over time as more cutting units enter the old-growth forest size class. Yearly benefit units are projected to increase from 14,691 at present to 24,552 in year 2016 an increase of 40%. The average benefit level over the 35-year planning horizon is 20,350.

It is debatable whether allowing the forest to grow on into the old growth category would be the best management strategy given the gypsy moth's ability to defoliate large acreages in a few years. About all that can be concluded from this analysis is that forest cutting will not improve habitat quality for avian gypsy moth predators.

## Stability Scenario

In some management situations, stability may be more desirable than a raw maximization of available wildlife benefits. Public agencies are often times judged on last year's performance rather than a 35 year average. So a policy of controlled growth of habitat quality may be advantageous.

A stability objective for WILDWOOD was to maximize  $Q$  where  $Q =$  the sum of the expression over all years:



**Figure 13. Gypsy moth predator scenario results:** Total annual wildlife benefits from gypsy moth predators from all stands (a) and the cumulative wildlife benefit curve used in the gypsy moth predators scenario (b).

(total benefits for each year - (the deviations from a specified goal)<sup>2</sup>)

This objective function does not completely restrict the program from maximizing wildlife benefits. It does penalize a given annual cutting limit for causing yearly benefits to fluctuate from a specified goal. The results from this demonstration are displayed in Figure 14 on page 82. The field sparrow was chosen as the only species in this scenario (valued at 99, all others 0); consequently, the cumulative benefit model in Figure 14 on page 82 is the same shape as the field sparrow model. This analysis was completed in two parts: one run with a very high goal benefit level and one run with a goal level that falls within the range of yearly benefit values.

The resulting plan with the high benefit goal predicted a rotation age for the workable cutting units of 16-17 years. The range of benefits (6,707 to 7,549) was quite narrow, only an 11.1% difference. The annual cut recommended was only 4.4 acres/year. The average benefit over the 35 year planning horizon was 7,262, and 1,017 cords of wood are predicted to be removed under this cutting level. The goal level chosen for this part of the analysis was 35,000. Because this goal level was so high, the program, in actuality, was using the same objective as the other scenarios, i.e., plan for maximum benefits regardless of year-to-year variation. This can be graphically shown as in Figure 16 on page 84. If the goal is always higher than the yearly benefit level, the program is penalizing a given annual cutting limit for not pushing the wildlife benefits to a maximum (because the goal is unattainably high). This analysis provides an interesting basis for the next portion of the analysis.

This analysis was redone with a goal of 7000 total benefits/year for the 35 year planning horizon (Figure 15 on page 83). Lowering the goal from 35,000 to 7,000 resulted in a much smaller variation between years; the difference between year 0 and year 35 was only 2.3% (6,707 - 6,558). The average yearly benefits over the planning horizon was 6,765 total benefits/year as opposed to 7,262 total benefits/year from the previous analysis. The annual cutting limit to achieve this is 8.1 acres/year, roughly twice the annual cutting limit of the previous analysis. This results in a rotation age of 8-9 years on cuttable units. The smaller variation achieved by this plan was the stated objective of the analysis, however, the cost of implementing this more stable plan is a reduction in

wildlife benefits (-6.8%) and cords (839 vs 1017) and presumably a higher cost to the manager due to increasing the management intensity (cutting every 8-9 years vs 16-17 years). The manager must decide whether the advantages of a stable wildlife benefit supply (including public opinion benefits) outweigh the foregone benefits and extra costs of that more stable plan.

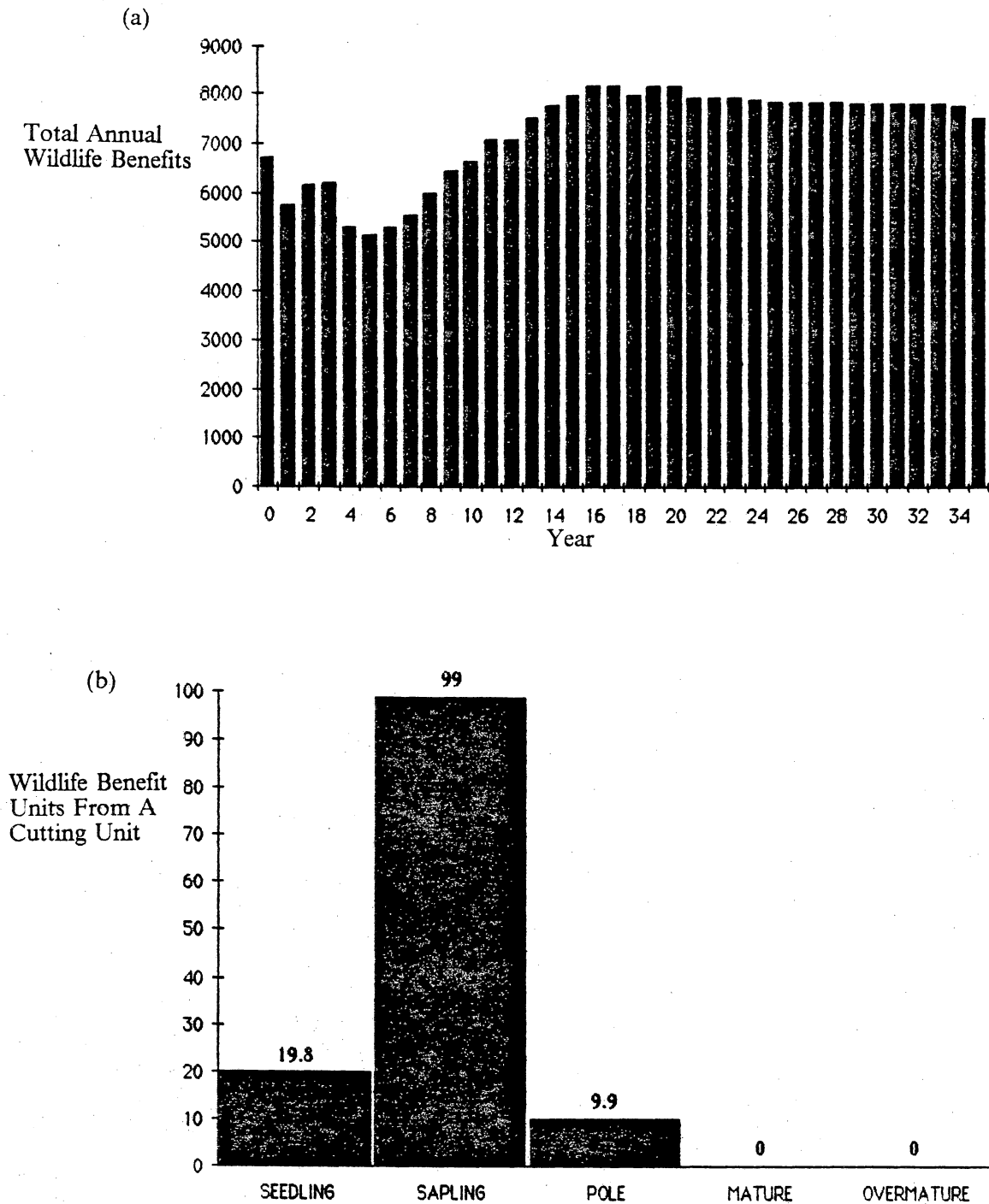
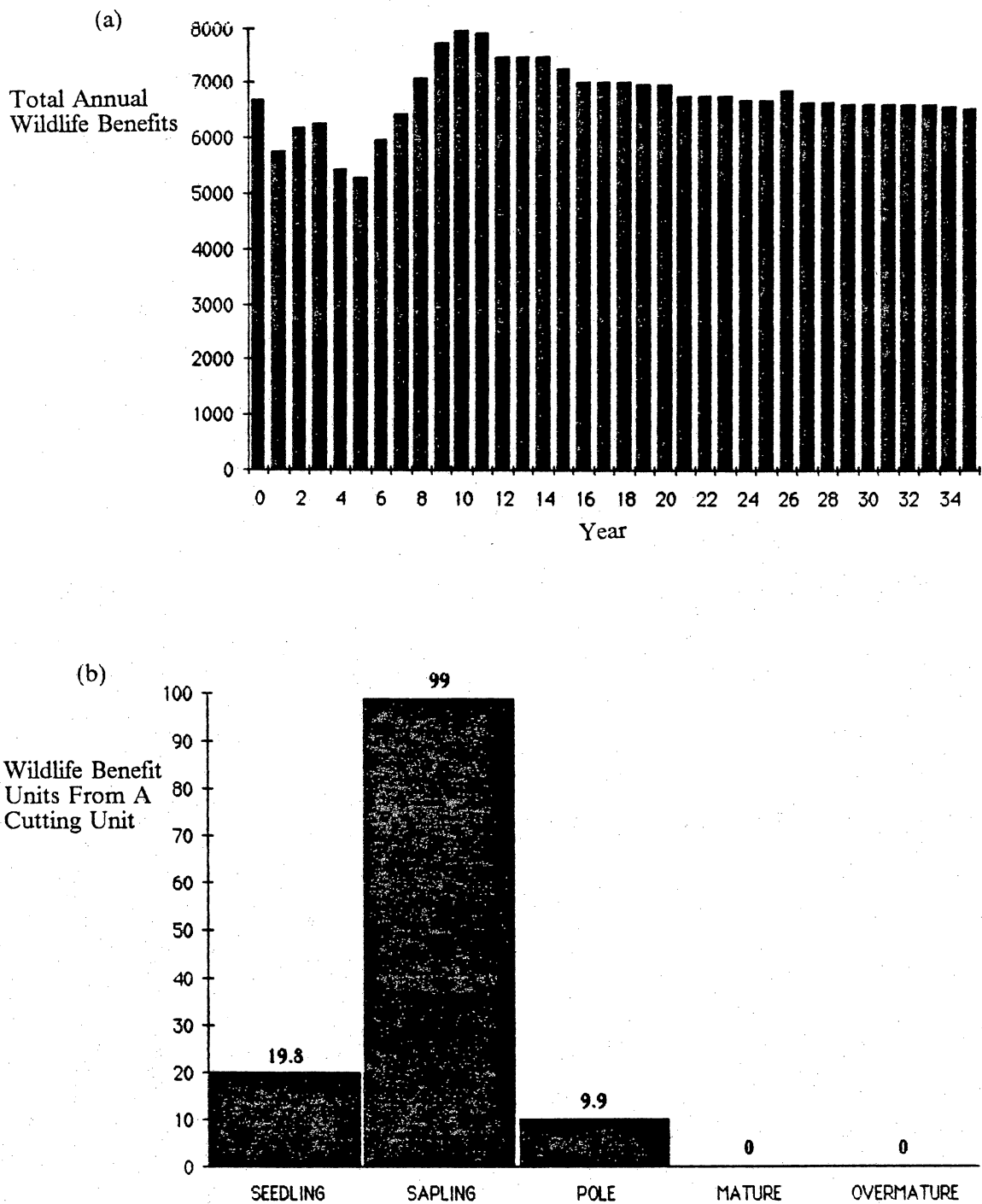
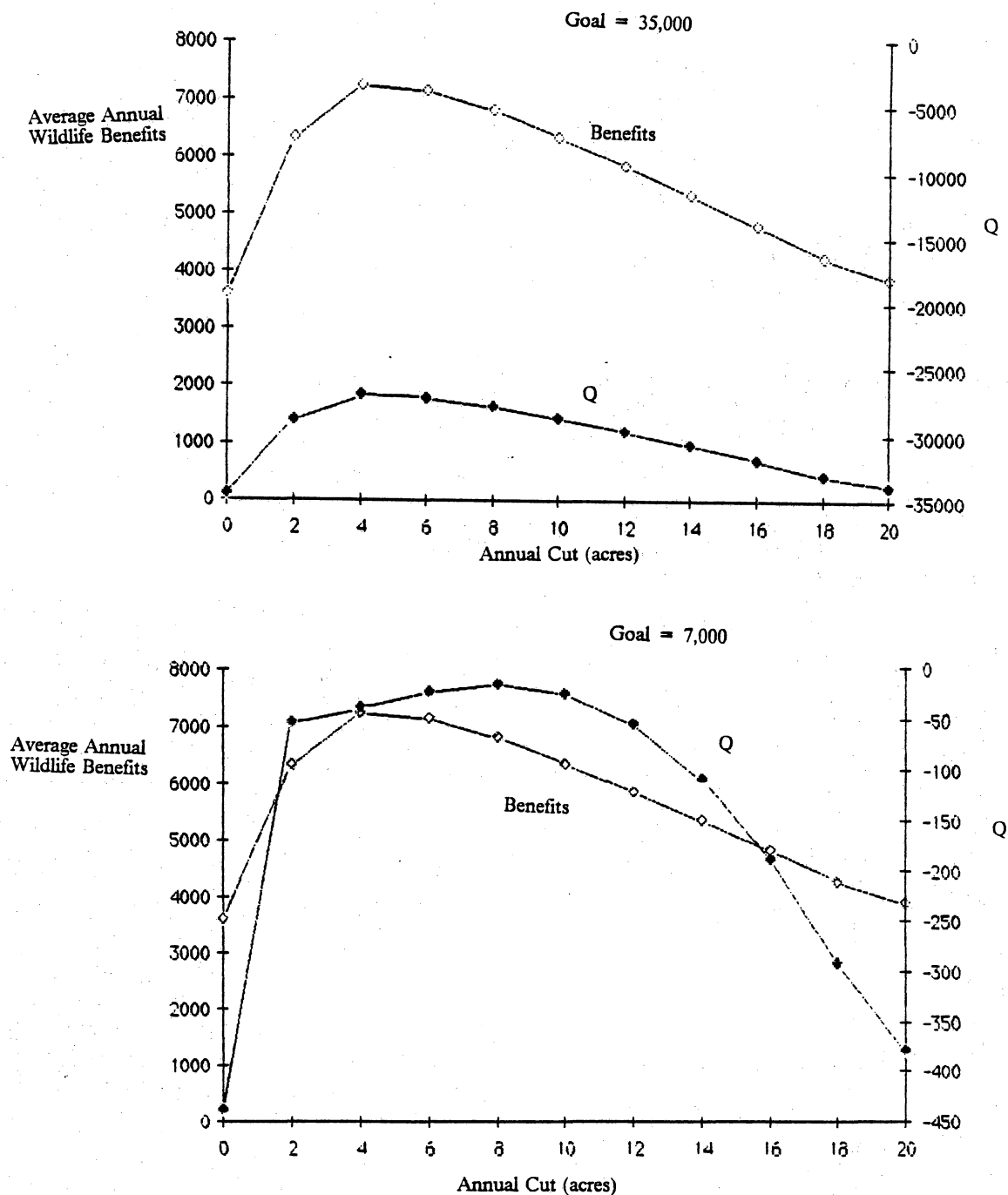


Figure 14. Stability scenario results with the goal = 35,000 benefit units/year: Total annual wildlife benefits from the field sparrow from all stands (a) and the cumulative wildlife benefit curve used in the stability scenario (b) where the goal = 35,000 wildlife benefits/year.



**Figure 15.** Stability scenario results with the goal = 7,000 benefit units/year: Total annual wildlife benefits from the field sparrow from all stands (a) and the cumulative wildlife benefit curve used in the stability scenario (b) where the goal = 7,000 wildlife benefits/year.





**Figure 16.** Comparison of objective functions used in the stability scenario: Mean yearly benefits and the Q index vs. annual cut when the goal = 35,000 wildlife benefits/year (a) and when the goal = 7,000 wildlife benefits/year (b).

## Discussion

The results of this study will be discussed from the perspectives of the objectives stated in that section. Other notable findings such as the problems with the wildlife species models, wildlife benefits, and the usefulness of the system also will be addressed.

### *Evaluation of Objectives*

The main objective was to create a timber harvest scheduling system for the upland hardwood ecosystem of western Virginia that would plan wood cutting to optimize wildlife habitat over time for a set of wildlife species. WILDWOOD simulates forest growth, yield, and harvesting and optimizes the timing of timber harvests through an annual cut/year (in acres) based on an objective function defined by the user. The objective function is a compilation of wildlife habitat value models that are defined and ranked by the user. WILDWOOD is available for distribution as a free software package to anyone who provides a blank 5 1/4 inch personal computer diskette to the author.

Secondary objectives were all addressed and met with varying degrees of success.

1. **Demonstrate that this system can be run on a microcomputer to allow for maximum impact on the wildlife resource.** - WILDWOOD is currently designed for an MS DOS microcomputer with 256 kilobytes of random access memory, two 5 1/4 inch disk drives, and graphics capability.
2. **Demonstrate an application of BOVA (Biota of Virginia), a computerized fish and wildlife information system.** - Eight wildlife species models were generated using information within the BOVA information system as well as an area-specific species list (i.e., the Havens demonstration area).
3. **Demonstrate that computerized timber harvest prescriptions can be presented in a manner helpful to wildlife managers.** - All the information reported for the scenarios was generated by WILDWOOD and presented interactively to the operator through a report generating program within WILDWOOD. This includes the histograms presented but not the line graphs; samples of the plan summary and one cutting unit summary may be found in Table 3 on page 62 and Table 4 on page 64. The actual cutting unit level harvest prescription can be printed directly, displayed on the microcomputer monitor, or stored on a diskette for later inclusion in computer generated reports. WILDWOOD tells the manager how much area to cut year, which cutting units to cut and when (year), and what yield may be expected from the recommendation in terms of cords of wood harvested and relative changes in wildlife habitat value. WILDWOOD does not address shape of the cutting unit, size of the cutting unit, or juxtaposition of cutting units. These variables are left to the manager.
4. **Investigate the practicality of the resulting system in terms of time and effort required** - The data required for WILDWOOD are the same data normally collected for a commercial forest survey. The minimum expenditure of time and effort such as was demonstrated in this study (roughly 0.65 hours/ha) should give a reasonable wildlife oriented plan. If the objective is to

collect data to provide timber volume data to a landowner, then a more intensive survey is recommended.

## *Wildlife Species Habitat Models*

Although the 5-point models (as in Figure 13 on page 79) corresponding to habitat value for a given wildlife species in a given forest size class work satisfactorily, a smoother representation of the size class/habitat value relationship probably would be more realistic. Nature abhors straight lines and sharp corners, consequently a curve-fitting algorithm should be developed to produce a smooth function based on the 5 points provided in the model. If, in the future, a higher degree of resolution can be acquired for the habitat value/forest succession relationship, more points can be added into the WILDWOOD system with ease. Higher resolution would provide the curve-fitting algorithm already mentioned a higher degree of accuracy as well.

Developing the models was relatively simple, especially if published results already existed for the species in question. Much work has been done on forest birds, less has been done on mammals, and almost nothing has been done on other forest creatures. The expert opinion models provide a quick and easy way to generate a first approximation model, and may be the best way to generate a localized model. This approach in no way reduces the need for biological research; it in fact emphasizes it, and states particular needs, namely faunal association with stand type, site index, and age. Nonetheless it provides a means to face the immediacy of many forest use decisions by using the best information currently available.

One technique not demonstrated is splitting models for species by habitat requirements. A wild turkey analysis may include several models, one for poult habitat, adult-winter habitat, adult summer-habitat, roosting habitat, etc. This is done by naming new faunal "species", e.g., the adult

x, the young x, then describing their specific needs. A pileated woodpecker (*Dryocopus pileatus*) analysis may include models for nesting habitat and foraging habitat. The advantage of this technique is that different habitat components can be weighted differently according to the manager's opinion of which component is limiting or most important for specific purposes.

The user could also create a negative habitat quality model, or cumulative disproduct model, for pest species. By placing the highest values in the forest size class that is least likely to encourage a forest pest species, a forest harvest schedule can be produced to minimize that forest pest (such as the gypsy moth or other wood-destroying insect).

The wildlife model concept as used in WILDWOOD is a robust technique for putting the wildlife habitat value and forest succession relationship in a form easily manipulated by a microcomputer. The models are simple to conceptualize and present in a histogram. They are also simple to edit and revise. Although more refinement is needed, this technique proved to be invaluable for this study.

## *Benefit Units as a Measure of Habitat*

The ranking technique utilized in WILDWOOD is useful for its simplicity. There are problems, however, with the scale used. Some cases may exist where the species of interest is more than 99 times as valued as the lowest species on the list (say 5000 times). This might occur when a high-valued game species is the species of interest, yet the user wishes to include many other species of a lower value. In WILDWOOD, 99 species with a value of 1 will exactly equal 1 species with a value of 99. This is not a problem with the demonstration SPECIES database, but may become worrisome in the future. Cason (1980) encountered the similar problem in adding impacts or costs in environmental impact analysis. An option needs to be included for ranking species below 1 but

greater than 0 or increasing the scale to 1000 or more to account for this. The number of species in the database of species models will determine the correct scale.

Another problem with the wildlife benefit unit technique used in WILDWOOD is the lack of comparability between areas or between analyses of the same area using different species lists. No way currently exists to do these comparisons based on wildlife benefit units alone. A possibility for future revision may be to work with average yearly benefit units/acre as the convergence goal rather than average yearly benefit units. This would allow different areas with the same species lists that are valued in exactly the same way to be compared.

Another potential problem was discussed in the Ruffed Grouse Scenario. Sometimes the current condition of the forest is such that wildlife habitat value for the species of interest will decline despite management. Given the current state of WILDWOOD, the user cannot know to what extent management actions are improving wildlife habitat in comparison to a no cut option. Making a no-cut analysis, almost as a standard practice, may be one subject that warrants future investigation and development.

## *Usefulness of the System*

The value that the user places on a correct answer will always determine the degree of accuracy required for the analysis. Managers demand a high level of confidence for endangered species plans, and a lesser confidence in small game management plans. The system described can provide insight into the tradeoffs that are constantly occurring in forest management. It is up to the user to decide whether WILDWOOD is suitable for a given application.

WILDWOOD can quickly generate timber harvest recommendations and reports for the manager. The recommendations are simple to interpret which is an advantage, but because of their simplicity, may be followed too strictly without due consideration to other variables that have an equal, if not more profound, effect on forest wildlife. Computer-generated harvest recommendations are just recommendations. The manager must be made aware of that and encouraged to evaluate every analysis. The recommendations should be considered as guidelines, not as hard and fast rules for action. Tests of the system to date have been encouraging in terms of the creator's expectations. Demonstrations have resulted in easily interpreted management recommendations that agree with conventional theory on forest/wildlife management. Actual validation of the system was not possible, however, so harvest recommendations from WILDWOOD should be treated with skepticism and used with care. To validate WILDWOOD, data should be collected on an area of upland oak forest where strict area control of harvest will be practiced for 35 years or more and detailed records kept of the cords removed and relative changes in wildlife species populations. A study of this type is likely to be prohibitively costly and time consuming in the current economic climate.

Two other problems exist with WILDWOOD in its current state due to hardware/software limitations. The first is the 35-year maximum planning horizon. This alters some results as has already been discussed. The problems inherent in this short planning horizon call attention to government agencies that use planning horizons as short as 5 years in forest planning. A planning horizon that is too short encourages short-term gain at the expense of long-term stability, a problem in many activities, not just forest harvest scheduling. The other problem inherent in WILDWOOD is that it is unable to address juxtaposition, size, and shape of timber harvests. A first step has already been made towards dealing with this problem through the inclusion of a map display system in WILDWOOD. As hardware/software constraints are lifted in the future, these attributes of the forest/wildlife system can be addressed more fully.

## Conclusion

The current version of WILDWOOD meets the objectives identified at the beginning of this study. Many modifications can be made in the future to better represent the forest/wildlife system and improve the management capabilities of WILDWOOD.

The Habitat Evaluation Procedures (HEP) as instituted by the U.S. Fish and Wildlife Service could eventually be used as the wildlife habitat modeling component of the WILDWOOD system. This modification would make WILDWOOD more difficult for the non-professional user but would increase the realism of the total system. A modified HEP program with a WILDWOOD-like forest simulator and optimization routine would be a powerful tool in the hands of the forest/wildlife manager. Another criticism of the WILDWOOD system is its silvicultural inflexibility. WILDWOOD assumes a patch clearcut silvicultural plan. Shelterwood cuts, seed tree cuts, and thinning options could be included to give the manager a more realistic representation of forest management. Similarly, forest types other than upland oak forests could be included such as loblolly pine, cove hardwoods, bottomland hardwoods, or any other forest type. The most exciting possibility for a WILDWOOD modification would be linking a WILDWOOD-like system to a microcomputer geographic information system. In this way, juxtaposition, size, and shape of cuts could effectively be addressed while providing maps of the area by year, size-class, working class, etc.



The WILDWOOD system is a first step towards the creation of a truly useful management tool. The system is designed to provide a basis for future students and researchers to develop a total management system. The philosophy behind the work to date has been to link components together which will allow later modification with a minimum of reprogramming and restructuring of the system. It is the sincere wish of the author that others will now build upon this work to provide the management tools necessary for the wildlife professional of the future to wisely manage the forests of that future.

## Appendix A. BOVA Generated Species List

The following list of wildlife species was generated by the Virginia Commission of Game and Inland Fisheries computerized fish and wildlife information system (CFWIS). These are all the species potentially found on Havens Wildlife Management Area according to the literature included in Biota of Virginia (BOVA).

CATEGORY	NAME	GENUS	SPECIES
Amphibians	Frog, pickerel	Rana	palustris
	Frog, upland chorus	Pseudacris	triseriata
	Frog, wood	Rana	sylvatica
	Newt, red-spotted	Notophthalmus	viridescens
	Peeper, northern spring	Hyla	crucifer
	Salamander, Appalachian seal	Desmognathus	monticola
	Salamander, four-toed	Hemidactylium	scutatum
	Salamander, longtail	Eurycea	longicauda
	Salamander, marbled	Ambystoma	opacum
	Salamander, northern dusky	Desmognathus	fuscus
	Salamander, northern two-lined	Eurycea	bilineata
	Salamander, ravine	Plethodon	richmondi
	Salamander, redback	Plethodon	cinereus
	Salamander, slimy	Plethodon	glutinosus
	Salamander, spotted	Ambystoma	maculatum
	Salamander, Wehrle's	Plethodon	wehrlei
	Spadefoot, eastern	Scaphiopus	holbrooki
	Toad, American	Bufo	americanus
	Toad, Fowler's	Bufo	woodhousii
	Treefrog, gray	Hyla	versicolor
	Category Total: 20		
CATEGORY	NAME	GENUS	SPECIES
Reptiles	Copperhead, northern	Agkistrodon	contortrix
	Kingsnake, eastern	Lampropeltis	getulus

Racer, northern  
black  
Rattlesnake, timber  
Skink, broadhead  
Skink, five-lined  
Snake, black rat  
Snake, corn  
Snake, eastern  
garter  
Snake, eastern  
hognose  
Snake, eastern worm  
Snake, northern  
water  
Stinkpot  
Turtle, common  
snapping  
Turtle, eastern box  
Turtle, eastern  
painted  
Turtle, midland  
painted

Category Total: 17

Coluber  
  
Crotalus  
Eumeces  
Eumeces  
Elaphe  
Elaphe  
Thamnophis  
  
Heterodon  
  
Carphophis  
Nerodia  
  
Sternotherus  
Chelydra  
  
Terrapene  
Chrysemys  
  
Chrysemys

constrictor  
  
horridus  
laticeps  
fasciatus  
obsoleta  
guttata  
sirtalis  
  
platyrhinos  
  
amoenus  
sipedon  
  
odoratus  
serpentina  
  
carolina  
picta  
  
picta

# CATEGORY

## Birds

# NAME

Bittern, American  
Bluebird, eastern  
Bobwhite, northern  
Bunting, indigo  
Cardinal, northern  
Catbird, gray  
Chat,  
yellow-breasted  
Chickadee, Carolina  
Chuck-will's-widow  
Coot, American  
Cowbird,  
brown-headed  
Creeper, brown  
Crossbill, red  
Crossbill,  
white-winged  
Crow, American  
Cuckoo,  
yellow-billed  
Dove, mourning  
Duck, American black  
Duck, wood  
Eagle, bald  
Egret, great  
Egret, snowy  
Finch, house  
Finch, purple  
Flicker, northern  
Flycatcher, acadian  
Flycatcher, alder  
Flycatcher, great  
crested  
Gnatcatcher,  
blue-gray  
Goldfinch, American  
Grackle, common  
Grebe, pied-billed  
Grosbeak, evening  
Grosbeak,  
rose-breasted  
Hawk, broad-winged  
Hawk, red-shouldered  
Hawk, red-tailed  
Hawk, rough-legged  
Hawk, sharp-shinned  
Heron, green  
Hummingbird,  
ruby-throated  
Jay, blue  
Junco, dark-eyed  
Kestrel, American  
Kingbird, eastern  
Kingfisher, belted  
Kinglet,  
golden-crowned  
Kinglet,  
ruby-crowned  
Merganser, hooded  
Mockingbird,  
northern  
Night-heron,  
yellow-crowned  
Nuthatch,  
white-breasted  
Oriole, northern  
Ovenbird  
Owl, barred

# GENUS

Botaurus  
Sialia  
Colinus  
Passerina  
Cardinalis  
Dumetella  
Icteria  
  
Parus  
Caprimulgus  
Fulica  
Molothrus  
  
Certhia  
Loxia  
Loxia  
  
Corvus  
Coccyzus  
  
Zenaida  
Anas  
Aix  
Haliaeetus  
Casmerodius  
Egretta  
Carpodacus  
Carpodacus  
Colaptes  
Empidonax  
Empidonax  
Myiarchus  
  
Poliopitila  
  
Carduelis  
Quiscalus  
Podilymbus  
Coccothraustes  
Guiraca  
  
Buteo  
Buteo  
Buteo  
Buteo  
Accipiter  
Butorides  
Archilochus  
  
Cyanocitta  
Junco  
Falco  
Tyrannus  
Ceryle  
Regulus  
  
Regulus  
  
Lophodytes  
Mimus  
  
Nyctanassa  
  
Sitta  
  
Icterus  
Seiurus  
Strix

# SPECIES

lentiginosus  
sialis  
virginianus  
cyanea  
cardinalis  
carolinensis  
virens  
  
carolinensis  
carolinensis  
americana  
ater  
  
americana  
curvirostra  
leucoptera  
  
brachyrhynchus  
americanus  
  
macroura  
rubripes  
sponsa  
leucocephalis  
albus  
thula  
mexicanus  
purpureus  
auratus  
virescens  
alorum  
crinitus  
  
caerulea  
  
tristis  
quiscula  
podiceps  
vespertinus  
caerulea  
  
platypterus  
lineatus  
jamaicensis  
lagopus  
striatus  
virescens  
colubris  
  
cristata  
hyemalis  
sparverius  
tyrannus  
alcyon  
satrapa  
  
calendula  
  
cucullatus  
polyglottos  
  
violaceus  
  
carolinensis  
  
galbula  
aurocapillus  
varia

Owl, common barn	Tyto	alba
Owl, great horned	Bubo	virginianus
Owl, long-eared	Asio	otus
Owl, northern	Aegolius	acadicus
saw-whet		
Pewee, eastern wood	Contopus	virens
Phoebe, eastern	Saydmis	phoebe
Raven, common	Corvus	corax
Redstart, American	Setophaga	ruticilla
Robin, American	Turdus	migratorius
Sandpiper, solitary	Tringa	solitaria
Sandpiper, spotted	Actitis	macularia
Sandpiper, upland	Batramia	longicauda
Screech-owl, eastern	Otus	asio
Shrike, migrant	Lanius	ludovicianus
loggerhead		
Siskin, pine	Carduelis	pinus
Snipe, common	Capella	gallinago
Sparrow, chipping	Spizella	passerina
Sparrow, field	Spizella	pusilla
Sparrow, song	Melospiza	melodia
Starling, European	Sturnus	vulgaris
Tanager, scarlet	Piranga	olivacea
Thrush, wood	Hylocichla	mustelina
Titmouse, tufted	Parus	bicolor
Towhee, rufous-sided	Pipilo	erythrophthalmus
Turkey, wild	Meleagris	gallopavo
Veery	Catharus	fuscescens
Vireo, red-eyed	Vireo	olivaceus
Vireo, solitary	Vireo	solitarius
Vireo, warbling	Vireo	gilvus
Vulture, black	Coragyps	atratus
Vulture, turkey	Cathartes	aura
Warbler,	Mniotilta	varia
black-and-white		
Warbler,	Dendroica	caerulescens
black-throated blue		
Warbler,	Dendroica	fusca
blackburnian		
Warbler, blackpoll	Dendroica	striata
Warbler, Cape May	Dendroica	tigrina
Warbler, cerulean	Dendroica	cerulea
Warbler,	Dendroica	pennsylvanica
chestnut-sided		
Warbler, hooded	Wilsonia	citrina
Warbler, magnolia	Dendroica	magnolia
Warbler, northern	Parula	americana
parula		
Warbler, palm	Dendroica	palmarum
Warbler, pine	Dendroica	pinus
Warbler, prairie	Dendroica	discolor
Warbler, worm-eating	Helmitheros	vermivorus
Warbler, yellow	Dendroica	petechia
Warbler,	Dendroica	coronata
yellow-rumped		
Warbler,	Dendroica	dominica
yellow-throated		
Waxwing, cedar	Bombycilla	cedrorum
Whip-poor-will	Caprimulgus	vociferus
Woodcock, American	Scolopax	minor
Woodpecker, downy	Picoides	pubescens
Woodpecker, pileated	Dryocopus	pileatus
Wren, Appalachian	Thryomanes	bewickii
Bewick's		
Wren, Carolina	Thryothorus	ludovicianus
Wren, house	Troglodytes	aedon
Yellowthroat, common	Geothlypis	trichas

Category Total: 112

#### CATEGORY

#### Mammals

#### NAME

Bat, big brown  
 Bat, evening  
 Bat, hoary  
 Bat, northern red  
 Bat, seminoe  
 Bat, silver-haired  
 Bear, black  
 Beaver, Canadian  
 Bobcat, rufus  
 Chipmunk, Fisher's  
 eastern  
 Cottontail, Woolly  
 eastern  
 Deer, white-tailed  
 Fox, eastern gray  
 Fox, red  
 Lemming, Stone's  
 southern bog  
 Mink, common  
 Mole, eastern  
 Mole, hairy-tailed  
 Mole, star-nosed  
 Mouse, common golden  
 Mouse, deer

#### GENUS

Eptesicus  
 Nycticeius  
 Lasiurus  
 Lasiurus  
 Lasiurus  
 Lasiurus  
 Lasiurus  
 Ursus  
 Castor  
 Felis  
 Tamias  
 Sylvilagus  
 Odocoileus  
 Urocyon  
 Vulpes  
 Synaptomys  
 Mustela  
 Scalopus  
 Parascalops  
 Condylura  
 Ochrotomys  
 Peromyscus

#### SPECIES

fuscus  
 humeralis  
 cinereus  
 borealis  
 seminolus  
 noctivagans  
 americanus  
 canadensis  
 rufus  
 striatus  
 floridanus  
 virginianus  
 cinereoargenteus  
 vulpes  
 cooperi  
 vison  
 aquaticus  
 breweri  
 cristata  
 nuttalli  
 moniculatus

Mouse, eastern  
 harvest  
 Mouse, house  
 Mouse, Lewis' golden  
 Mouse, meadow  
 jumping  
 Mouse, northern  
 white-footed  
 Mouse, woodland  
 jumping  
 Myotis, Keen's  
 Myotis, little brown  
 Myotis, small-footed  
 Opossum, Virginia  
 Raccoon  
 Rat, eastern wood  
 Rat, hispid cotton  
 Shrew, ashen masked  
 Shrew, gray  
 long-tailed  
 Shrew, Kirtland's  
 short-tailed  
 Shrew, least  
 Shrew, smoky  
 Shrew, southeastern  
 Skunk, eastern  
 spotted  
 Skunk, striped  
 Squirrel, fox  
 Squirrel, northern  
 gray  
 Squirrel, red  
 Squirrel, southern  
 flying  
 Vole, meadow  
 Vole, pine  
 Weasel, least  
 Weasel, long-tailed  
 Woodchuck

Category Total: 51

Grand Total: 200

#### Reithrodontomys

Mus  
 Ochrotomys  
 Zapus

#### Peromyscus

#### Napaeozapus

Myotis  
 Myotis  
 Myotis  
 Didelphis  
 Procyon  
 Neotoma  
 Sigmodon  
 Sorex  
 Sorex

#### Biarina

Cryptotis  
 Sorex  
 Sorex  
 Spilogale

Mephitis  
 Sciurus  
 Sciurus

Tamiasciurus  
 Glaucomys

Microtus  
 Microtus  
 Mustela  
 Mustela  
 Marmota

#### humilis

musculus  
 nuttalli  
 hudsonius

#### leucopus

#### insignis

keenii  
 lucifugus  
 subulatus  
 virginiana  
 lotor  
 floridana  
 hispidus  
 cinereus  
 dispar

#### brevicauda

parva  
 fumeus  
 longirostris  
 putorius

mephitis  
 niger  
 carolinensis

hudsonicus  
 volans

pennsylvanicus  
 pinetorum  
 nivalis  
 frenata  
 monax

## **Appendix B. User's Manual for WILDWOOD**

### **Abstract**

WILDWOOD is a personal computer based management tool designed to provide support to users who are involved in wildlife/forestry planning activities. The system utilizes a growth and yield model, habitat quality models, and a binary search algorithm to maximize wildlife benefits by choosing an optimum annual cutting level (in acres). The program permits a maximum of 100 cutting units and a maximum of 35 years in the planning horizon.

### **System Requirements**

WILDWOOD requires an MS-DOS compatible personal computer with a monochrome or color graphics screen, two disk drives or a hard disk, and 256K of RAM. A printer is optional but recommended.

## Introduction

WILDWOOD seeks to exploit computational techniques in wildlife habitat management widely used in forest management. WILDWOOD uses common forest growth and yield data to estimate wildlife species habitat value. The program can then be used to plan timber harvests based on projected changes in wildlife habitat. The first assumption of the system is that habitat value to wildlife changes in a definable way for a given animal species over the life of the forest stand. These relationships have been abundantly documented in the wildlife management literature. The second assumption is that changes in forest structure with age (succession) can be described in a definable way. Once again the literature abounds with descriptions of succession models and growth and yield models. WILDWOOD combines these two relationships into an analytical tool.

The most important contribution of the program in this version may be its educational value. WILDWOOD can analyze the wildlife value of over 100 forest cutting units and project changes in value for 35 years into the future. Playing "what if" games with different management options will (hopefully) allow the user to gain a better understanding of the relationships between faunal communities, forest cutting, and valuation of featured species objectives.

Many good and interesting applications of the program and the databases associated with it can be developed that are not mentioned in this manual. The manual is only intended to provide the user with a starting point. This program is still in the development stages. The author would appreciate notification in the event a user finds a programming error. This program is public domain. However, the data entry and manipulation software (PCFile) included on the disk is not. That software package is copyrighted by Jim Button, ButtonWare, Inc., P.O. Box 5786, Bellevue, WA 98006. Buttonware's policy on this evaluation copy is that it may be freely copied for evaluation purposes but should be purchased from Buttonware Inc. if the user finds that he or she is using it on a regular basis. Some documentation for PCFile is included on the disk. Last, WILDWOOD was designed for use in the upland oak ecosystem of western Virginia. Any application to other

ecosystems would be suspect at best, especially since validation of the model has not yet been attempted, and may never be possible due to the great costs and time required to do so based on some concepts of validation.

## How Does It Work?

The flow chart in Figure 17 on page 101 describes the basic structure of the system. It consists of two main programs accessible from DOS, PCFile which handles all the data entry, and editing, and some of the sorting, and report writing capabilities, and WILDWOOD itself which performs the simulations, histograms, optimization routine, and several specialized reports. Together they allow the user to enter descriptive data on a forest property and then to project how wood volume, and wildlife benefits will change over the planning horizon.

The first computational step to process is to create a cumulative species model that is a mathematical conglomeration of all the species in the database that are designated by the user for inclusion in the analysis (Figure 18 on page 102). In addition, each species is weighted by the user on a scale of 0 to 99 prior to the analysis as to its importance. Each species model consists of 5 habitat value index ratings (0-1.0), one each for the 5 major US Forest Service Size Classes. In WILDWOOD, mean dbh of the cutting unit is used as a surrogate variable for successional stage. Mean dbh is split into 5 forest size classes patterned loosely after the U.S. Forest Service's Forest Size Class Rating System. These are SEEDLING (live trees  $\leq 2.5$  cm dbh), SAPLING (live trees  $> 2.5$  cm and  $\leq 12.7$  cm dbh), POLE (live trees  $> 12.7$  cm and  $\leq 25.4$  cm dbh), MATURE (live trees  $> 25.4$  cm and  $\leq 43.1$  cm dbh), and OVERMATURE (live trees  $> 43.1$  cm dbh). The reason for choosing this classification scheme over other classification schemes is that it is simple, easily understood by the user, and currently in widespread use by a leader in the forestry profession (the U.S. Forest Service) as well as BOVA (Virginia's computerized fish and wildlife information system).



The program multiplies a habitat value for a particular forest size class times the user supplied value and then adds it to the cumulative model (also a 5 point model). The units for the resulting model are called wildlife habitat benefit units or simply benefit units. This cumulative benefit model is then used throughout the analysis to determine wildlife value. A simple look-up table approach is used wherein the cutting unit's mean stand dbh is determined from a set of regression equations and then the wildlife benefit units are picked from 1 of 5 possibilities in the cumulative wildlife benefit model. Benefit units are then summed over cutting units over time to generate reports and provide a criterion by which the cutting plan may be determined later.

The core of the system is a growth and yield simulator which includes as one of its variables mean dbh of the cutting unit in inches. Cutting units are mathematically grown (simulated) given the initial conditions stored in the cutting unit database. In each year of the simulation, mean dbh for each cutting unit is calculated and wildlife benefits are determined from the cumulative benefit model. Cutting simulations are done at the end of each year's growth period, and it is assumed that cuts are done instantaneously. Cutting simulations are carried out to test the effects of a given annual cutting level on habitat quality. It is assumed that one annual cutting level will produce the highest average habitat quality given the constraints of the model. This optimum cutting level is the goal of the system.

The growth and yield simulator used in WILDWOOD was constructed using regression equations from Dale (1972), (Table 6 on page 103). Credit should also go to Arlyn Perkey of the US Forest Service, Northeast Forest Experiment Station in Morgantown, WV for first converting Dale's equations to computer code in a program called GROAK (Perkey 1985).

The real power of WILDWOOD is tapped when using it in optimization mode. The key variable in the system is annual cut. The user can specify an annual cut in a simple simulation, and cutting units are harvested at that annual rate. The optimization section of WILDWOOD will search for an annual cut that maximizes total wildlife benefits over time. The user can specify whether or not

A. INPUT DATA FILES - (PCFILE.EXE)

B. PERFORM ANALYSES - (WW.COM)

1. TITLE SCREEN
2. KEYBOARD INPUT FROM USER
3. OPEN DATA FILES
4. READ SPECIES DATA FROM PCFILE DATABASE
5. CREATE CUMULATIVE BENEFIT MODEL
6. DISPLAY CUMULATIVE BENEFIT MODEL
7. READ CUTTING UNIT DATA FROM PCFILE DATABASE
8. SORT CUTTING UNIT DATA ON USER DEFINED ATTRIBUTE
9. CUT WORKABLE CUTTING UNITS UP TO CUTTING LEVEL
10. GROW REMAINING CUTTING UNITS
11. REPEAT STEPS 9 AND 10 FOR NUMBER OF YEARS IN ANALYSIS
11. CHECK OBJECTIVE FUNCTION FOR OPTIMUM LEVEL:  
GO TO 6 OR STOP
12. REPORT: SUMMARY, TABULAR, HISTOGRAM

Figure 17. Flow diagram for WILDWOOD.

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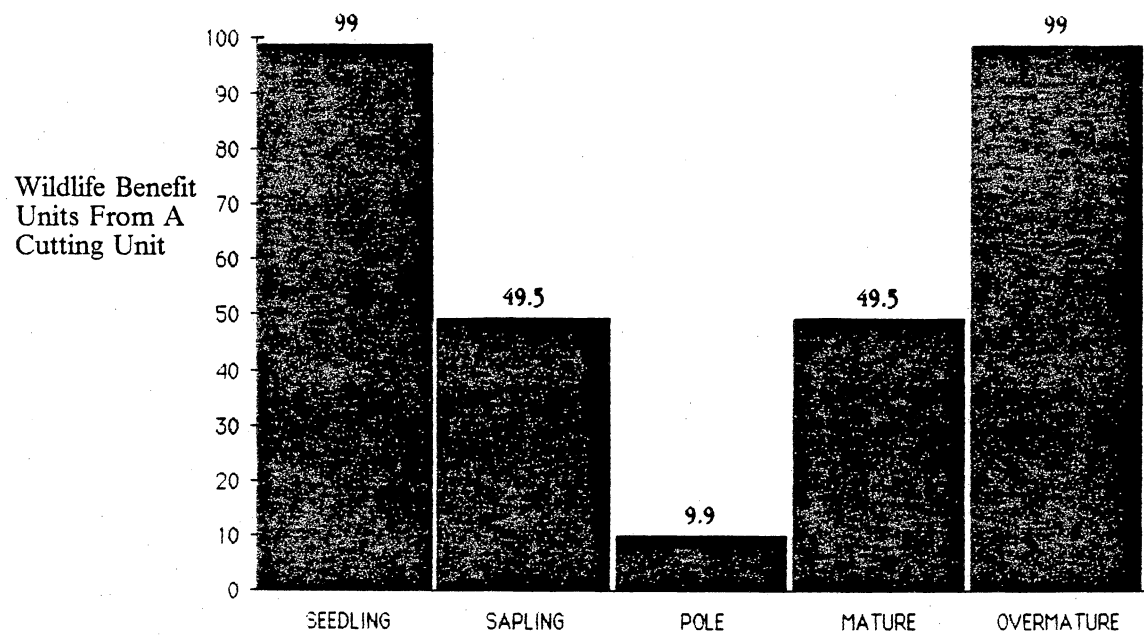


Figure 18. Histogram of habitat value over forest size class for species i.

Table 6. Equations for the forest cutting unit simulator.

$$MDBH_i = \sqrt{(183.3464944 * BA_{i-1} / TPA_{i-1})}$$

$$BA_i = BA_{i-1} + ((-BA_{i-1} / (AGE_i)^8) * \ln(BA_{i-1}) + 3.68521 * (BA_{i-1} / (AGE_i)^{.75}) + 0.011383 * SI * (BA_{i-1} / (AGE_i)^{1.05}))$$

IF  $AGE_i \geq 50$

$$INGROWTH_i = .009264291 + .00000113 * \sqrt{(AGE_i)} - 0.015674 * \ln(BA_{i-1}) - 0.076175 * MDBH / (AGE_i)^8 + (0.0010186 * TPA_{i-1} / (AGE_i)^8) - (.00000083 * TPA_{i-1} * SI)$$

$$MORTALITY_i = -0.15021 - 1.181 / (AGE_i)^{1.05} + 0.029721 * \ln(SI) + 0.007847 * \ln(TPA_{i-1}) + 0.11115 / MDBH$$

IF  $AGE_i < 50$

$$INGROWTH_i = .09264291 + .00000113 * \sqrt{(AGE_i)} - 0.015674 * \ln(BA_{i-1}) - 0.076175 * MDBH / (AGE_i)^8 + .0010186 * TPA_{i-1} / (AGE_i)^8 - .00000083 * TPA_{i-1} * SI - (.00001391 * \sqrt{(90 - SI)} * (50 - AGE_i)^3 / (900 - \sqrt{(TPA_{i-1})}))$$

$$MORTALITY_i = -0.15021 - 1.181 / (AGE_i)^{1.05} + 0.029721 * \ln(SI) + 0.007847 * \ln(TPA_{i-1}) + 0.11115 / MDBH + ((.00370714 * (90 - SI) / (90 - AGE_i)) * (TPA_{i-1})^3 / .00000001)$$

$$TPA_i = TPA_{i-1} + (INGROWTH * TPA_{i-1}) - (MORTALITY * TPA_{i-1})$$

AGE = age of cutting unit

BA = basal area/acre of cutting unit in ft<sup>2</sup>

i = year from year 0

INGROWTH = number of trees/acre entering smallest diameter class

MDBH = mean cutting unit diameter-breast-height

MORTALITY = number of stems/acre leaving cutting unit

SI = site index base age 50 for upland oaks

TPA = trees/acre

an optimization run should be attempted. At present, an optimization run takes over 3 hours with a standard IBM-PC working on the largest possible problem (100 cutting units for 35 years), and although the time is excessive compared to many software programs, it is still fast enough to permit the problem to be solved in an "overnight" mode (turn it on at 5 p.m. come back the next morning and it's done). Since the user isn't being charged for computer time in most cases, this long run-time is justified.

## Data Entry

Buttonware Inc. has included partial documentation (sufficient for use with WILDWOOD) on the diskette that may be printed by issuing the command

```
A > pcdoc
```

while the PCFile diskette is in drive A. The rest of this manual will assume that the reader is familiar with the basics of using PCFile. The PCFile user's manual is quite explicit for adding, editing, and sorting reports which are the three main functions which the users of WILDWOOD will require.

WILDWOOD reads PCFile databases that have been defined like the ones on your data disk. Each database consists of at least 3 files: the .HDR or header file that defines the database, the .DTA file which is the actual data, and the .INX file or index which allows the user to search the data from within PCFile. The user may create a new database either through the cloning facility of PCFile (see PCFile documentation) or a copy of the database may be made using the following command from DOS:

```
A > copy a:havens.* b:fn.*
```

where fn is a filename of the new database. When the copy is made, PCFile can be used to delete all the existing records so new data can be entered.

WILDWOOD requires 2 databases and a third is recommended. The first is the cutting unit database. This database, called HAVENS on the data diskette contains all the descriptive information on each cutting unit. The second database, called SPECIES on the data diskette, contains information on the wildlife species that may be included in the analysis. The last database is not directly accessed by WILDWOOD, but it is available if it is needed by the user. This database is called SPECREFS on the data diskette and contains information on the citations used in the species database.

**The Cutting Unit Database:** While in PCFile, enter the HAVENS database, hit F1, and look at the list of elements on the left hand side of the input screen. The elements and instructions for each are listed below.

1. CUT UNIT - This is a 4-character identifier used for the cutting unit. Any combination of letters or numbers may be used, but if sorting is to be done on this field, the field must be zero-filled (no spaces).
2. ADD UPDATE - This is a data control field that allows the user to keep track of the date the unit was added or last edited.
3. ACRES - The area of the cutting unit in acres.
4. SI - The site index, base age 50, for upland oaks. Should be  $\leq 90$  and  $\geq 55$ .
5. TYPE - A one character code for timber type. This is an optional element.
6. AGE - Age in years of the cutting unit.
7. BA - Basal area/acre for the cutting unit in square feet. Must be  $< 130$  sq. ft./acre.
8. TPA - Trees/acre for the cutting unit. Should not exceed 1200.
9. ASPECT - Code for land slope aspect. This is an optional element.
10. WORK CLASS - A code for workability of the site based on slope, distance from road, and distance from stream. The codes are 0, 1, 2, 3, or 4 where 0 is unmanageable and 4 is very manageable. WILDWOOD will not consider cutting units with a WORK CLASS of 0 but will include all the other classes.

11. COMMENTS - Any short comments on the cutting unit.
12. CUT ORDER - Used to sequence treatment of cutting units. Optional element.

The optional elements may or may not be filled in. The others must be filled in or WILDWOOD will abort in an error. Similarly, WILDWOOD will abort if any character other than a number is present in the ACRES, SI, AGE, BA, TPA, or WORK CLASS fields.

When the dataset is entered, reports can be written by PCFile with customized report formats or a report format can be used that is included on the data disk called STANDREP.

Hit **F10** when through.

**The Species Database:** From the main menu of PCFile type **end** and then **c**. Now enter the SPECIES database, hit **F1** and look at the elements along the left hand side of the input screen.

1. NAME - This is the common name of the species in question.
2. NUMBER - This is an arbitrarily assigned species number. Optional.
3. VALUE - This is the value that the user wishes to place on the species for subsequent analysis.  
The values may range from 0 to 99 where 0 eliminates the species from consideration and 99 is the highest possible weight for a species. When altering species weights, first make a list of all the species to be considered then give the most important or sensitive species a 99. All other species can then be valued relative to the highest.
4. SEEDLING - This is the habitat value of a seedling stage upland oak forest (live trees that are less than 1.0 inch in diameter). Habitat values may range from 0.0 to 1.0.
5. SAPLING - Habitat value of a sapling stage upland oak forest (live trees 1.0 to 5.0 inches in diameter).
6. POLE - Habitat value of a pole stage upland oak forest (live trees 5.0 to 10.0 inches in diameter).

7. MATURE - Habitat value of a mature stage upland oak forest (live trees 10.0 to 17.0 inches in diameter).
8. OVERMATURE - Habitat value of an overmature stage upland oak forest (live trees over 17.0 inches in diameter).
9. COMMENTS - Any comments the user may have on this species. Optional.
10. MODEL REFS - Citation numbers separated by commas. Optional. Citation numbers must first be retrieved from the SPECREFS database. These numbers connect the two databases.

The 5 points, SEEDLING, SAPLING, POLE, MATURE, and OVERMATURE make up the species model. These points can be modified for the user's particular situation or area. In the case of a highly valued species, multiple models can be set up for different life requisites such as feeding, nesting, brooding, or thermal cover. In the SPECIES database the wild turkey has two models, an adult model and a poult model. SPECIES includes 43 models but experienced technicians and workers familiar with the literature should realize that many others are possible. The author recommends that citations be recorded for each model to document the model and provide a more defensible result. Reports may be written from this database using the report format SPECREP found on the data diskette.

**The Species Reference Database:** As before, access the SPECREFS database and look at one input screen.

1. REF NUMBER - An arbitrary key number for this reference.
2. ADD UPDATE - Date of last edit or entry.
3. REF1 - The first line of the reference.
4. REF2 - The second line of the reference.
5. REF3 - The third line of the reference.
6. REF4 - The fourth line of the reference.
7. REF5 - The fifth line of the reference.



8. SPECIES - The names of the species using this citation to create a model.

Reports may be written from this database using a report format called REFREP found on the data diskette.

## Making It Work

Once the databases are set up properly, put the WILDWOOD program diskette in the A drive and enter WW from DOS. The program will first ask for file names of the species and cutting unit databases. Answer **b:havens** and **b:species** for each question if using a two diskette system. If using a hard disk and all programs and data files are in one subdirectory then omit the **b:** drive designations. Next the program will ask, "How many years into the future do you wish to project?". The answer must be less than or equal to 35 For the next question "What is the beginning year?", answer 1987 or the current year.

The next question is a multiple choice that allows the user to specify the priority of cutting units. They should be self explanatory except for choice 0, Input Order. Input order means the cutting units will be cut in the order in which they are retrieved from the PCFile database. In that database there is an element called CUT ORDER. If need be, the cutting units in the database can be sequenced by placing numbers in the CUT ORDER element. Number 1 would be cut first and so on down through the database. The database **must** be sorted using the PCFile sort module before WILDWOOD is run for this procedure to work. For now, enter 1. The last question is another multiple choice that allows you to choose between a simple simulation, a binary search on average yearly wildlife benefits, or a binary search on using a measure of stability, Q, where

$$Q = \text{benefits} - (\text{a specified goal} - \text{benefits})^2$$

For now, enter 1 then enter an annual cutting limit. No optimization will be done. WILDWOOD will use the annual cutting limit you give it. Enter a 2.2 for this demonstration.

From now on the program runs itself until the report menus come up. The author recommends that the new user try all the different report possibilities to get a feel for each. Also, trying the program with several different annual cutting limits in simulation mode would be instructive noting how the histograms change in relationship to differing cut levels. Running an optimization analysis is not recommended until the user is familiar with the program. Optimization analyses can take many hours to complete.

A simple help facility is available at every prompt prior to, but not including, the report menu by typing **help** at the prompt.

The program may be aborted in most places by holding down the **CTRL** key and hitting the **SCROLL LOCK/BREAK** key.

## Reading the Reports

There are three types of reports available from the WILDWOOD report menu: the summary, tabular reports, and histograms. The summary and the histograms should be self-explanatory if the user remembers that wildlife benefits are relative measures only and are intended to allow an avenue for the program to work and give some measure for comparing two cutting units, two annual cutting limits, or two different age classes of trees.

The tabular reports are self-explanatory as well. MDBH stands for mean dbh of the cutting unit. The only tricky part to the tabular reports is how to read the forest cutting plan. Basically, when the report says cutting unit age for a given cutting unit goes to zero, that means cut that unit in

that year. If the cutting unit never records a reduction to zero age, then do not cut that unit. This is a very simple process once a full print out or disk file is made of the tabular reports.

## **Conclusion**

Have fun. Explore as many different options as possible. Don't accept the results if you don't understand and agree with them. Contact the author if any serious problems crop up.

## **Literature Cited**

- Dale, M.E. 1972. Growth and yield predictions for upland oak stands. USDA For. Serv. Res. Pap. NE-241.
- Perkey, A.W. 1985. Grow Oak (GROAK) on the Radio Shack PC-2. USDA For. Serv. Morgantown, WV 30 pp.

## Sample Session.

1. Boot up the machine.
2. Put the WILDWOOD program diskette in drive A.
3. Put the data disk in drive B.
4. Type **WW**
5. Hit any key when that request comes to the bottom of the screen.
6. Type **b:havens** at the request for cutting unit file name.
7. Type **b:species** at the request for species file name.
8. Type **5** at the request for number of years in analysis.
9. Type **1987** at the current year request.
10. Type **1** at the request for cutting priority to signify the program should harvest cutting units in order of oldest cutting unit first.
11. Type **1** at the request for choice between setting up an annual cutting limit or letting WILDWOOD search for an optimum.
12. Type **2** at the request for an annual cutting limit.
13. All other prompts are either report related or screen related. Just read the instructions on the screen.

## Appendix C. WILDWOOD Source Code

WILDWOOD is written in TURBO-PASCAL ver. 3.0, a product of Borland International Inc. TURBO-PASCAL is a compiler that requires 256 kilobytes of internal read-access memory. It does not access extra memory beyond 256k or other hardware such as an 8087 math chip without additional programming. WILDWOOD does print reports to a printer or disk file.

Program WILDWOOD;

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(703) 961-7348

last revised 4/1)

{SI typedef.sys}  
{SI graphix.sys}  
{SI kernel.sys}  
{SI windows.sys}  
{SI hatch.hgh}  
{SI histogrm.hgh}

{These files must be}  
{included and in this order}  
{for histogram routines.}  
{They are Turbo-Pascal include}  
{files that may be given away in}  
{a compiled program.}

{SI sort.box}

{Compiles sort.box with program.}

{SR + }

{Sets compiler directive}  
{range checking on. }

Label IN1, IN2, IN4, IN5, IN6, IN7, IN8,  
HISTOGRAMMENU,  
REPORTMENU;

{Allows logical jumps in program flow. }

Const

K :Integer = 0;  
KK :Integer = 0;  
I :Integer = 0;  
J :Integer = 0;  
Q :Real = 0;  
N :Integer = 0;  
IT :Integer = 1;  
E :Real = 0.1;  
HP :Array[1 .. 5] OF Real = (0,0,0,0,0);  
HCBC :Array[1 .. 5] OF Real = (0,0,0,0,0);  
MAXCBCVALUE :Real = 0;  
SORTATTRIBUTE :Integer = 0;  
NUMBEROFSTANDS :Integer = 0;  
STANDMAX = 106;  
YEARMAX = 36;  
SUMACRES :Real = 0;  
CUTNUMBER :Integer = 1;

{These are all counters. }

{Error term for binary search. }

{Array of individual species model points. }

{Array of cumulative species model points. }  
{Maximum point in HCBC array. }

{Used for choosing element of cutting unit record to sort on. }

{Number of stands. }

{Maximum number of stands. }

{Maximum length of analysis. }

{Sum of area cut in any one year. }

{Number of times the forest is cut over during planning horizon. }

	BARATTRIBUTE TOTALBEN MEANYEARLYBEN	:Integer = 1; :Real = 0; :Real = 0;	{Used to branch bar graph routine. } {Total benefits generated. }  {Average yearly benefits generated over planning horizon. }
	CHOICE	:String[1] = '0';	
	WORKABLEACRES	:Real = 0;	{Used as choice variable in user input sections. }
	YN	:String[1] = 'Y';	{Total forest acreage. }
	MAXTOTYEARLYBEN	:Real = 0;	{Used as choice variable in user input sections. } {Highest benefit level achieved in any one year. }
	CORDSUM CORDSUMHIGH CORDSUMLOW COUNT DONE	:Real = 0; :Real = 0; :Real = 0; :Integer = 1; :Boolean = false;	{Used to scale bar graph. } {Sum of cords cut over planning horizon. } {Reporting variable for CORDSUM. } {Reporting variable for CORDSUM. } {Used to page tabular output reports. }
	CUT LOWBEN HIGHBEN HighQ LowQ	:Real = -1.0; :Real = 0; :Real = 0; :Real = 0; :Real = 0;	{Used to control report program loop. } {Maximum area to be cut in a given year. } {Result of low cut in binary search. } {Result of high cut in binary search. }
Type	ASTAND = RECORD STANDNUM TPA	:String[4]; :Array [0 .. YEARMAX] OF Real;	{Cutting unit identifier. } {Array of trees/unit area by year. }
	BA	:Array [0 .. YEARMAX] OF Real;	{Array of basal area/unit area by year. }
	ACRES AGE	:Real; :Array[0 .. YEARMAX] OF Integer;	{Area of cutting unit. }
	SI WORKCLASS XCOORD,YCOORD	:Integer; :String[1]; :Integer;	{Array of cutting unit age by year. } {Site index of cutting unit. } {Working class rating for cutting unit. } {X and Y coordinates for map}
	END;		
Var	YEAR, STARTYEAR, HORIZON, CODE INGROWTH, MORTALITY, BAGROWTH, MDBH, CORDS, BPA STANDFN, SPECIESFN, OUTFN	{Year of report. } {Beginning year. } {Number of years for analysis specified by user. } :Integer; {Number of trees/unit area entering stand. } {Number of trees/unit area leaving stand. } {Change in basal area/unit area in one year. } {Mean diameter breast height in inches. } {Number of cords on a cutting unit. } :Real; {Benefits/unit area for a given year. } {Input file name for cutting unit file name. } {Input file name for species file name. } :String[30];	{Error code returned by VAL function. }
	STANDFILE, SPECIESFILE, OUTFILE TEST	{Text file of cutting unit data used by Turbo-Pascal. } {Text file of species data used by Turbo-Pascal. } :Text; :String[1];	{Text file used to store tabular reports on disk. }
	VALUE L	:Real; :String[81];	{Test variable to check for blank database records and end-of-file. } {Species value stored in species database for each species. }
	STAND	:Array[1 .. STANDMAX] of ASTAND;	{Line input variable used to read databases. }
	TESTMAX, CUTMIN, CUTMAX TOTYEARLYBENHIGH, TOTYEARLYBENLOW, TOTYEARLYBEN	{Number of iterations of binary search required to achieve designated precision. } {Low cut figure tested by binary search. } :Real;	{Array of stand records defined by ASTAND. } {High cut figure tested by binary search. }
	REPORTFORMAT	:Array[0 .. YEARMAX] of Real;	{Array of yearly benefit figures used for reporting. }
	REPORTFORMAT	:String[1];	{Used to choose between reporting formats. }
	ST	:String[10];	{Dummy string used in formatting tabular reports. }
	CH, SCROLL CUTSTR, SORTATTRIBUTESTR, STARTYEARSTR, HORIZONSTR RUNCODE BF GOAL	{Used in screen pause algorithm. } :Char;  :String[4]; :String[3]; :Char; :Real;	{Used in screen control algorithm in tabular reports. }  {Input test variables}
Procedure HELP;		{Writes the help files to the screen}	
LABEL	HELPMENU, Endhelp;		
VAR	LINE INFILE	:STRING [80]; :TEXT;	

```

BEGIN
HELPMENU:
CLRSCR;
GOTOXY(1,5);
WRITELN('
HELP FOR WILDWOOD');
GOTOXY(1,10);
WRITELN('
Pick an option:');
WRITELN('
1) getting started');
WRITELN('
2) number of years in simulation');
WRITELN('
3) cutting priority');
WRITELN('
4) annual cutting limit');
WRITELN('
5) search/analysis options');
WRITELN('
e) exit and return to the program');
GOTOXY(1,18);
WRITE('
= > '); READ(CHOICE);
IF CHOICE = '1' THEN ASSIGN(INFILE, HELP1.WW);
IF CHOICE = '2' THEN ASSIGN(INFILE, HELP2.WW);
IF CHOICE = '3' THEN ASSIGN(INFILE, HELP3.WW);
IF CHOICE = '4' THEN ASSIGN(INFILE, HELP4.WW);
IF CHOICE = '5' THEN ASSIGN(INFILE, HELP5.WW);
IF (CHOICE = 'E') OR (CHOICE = 'e') THEN GOTO Endhelp;
IF (CHOICE < > '1') AND (CHOICE < > '2') AND (CHOICE < > '3') AND (CHOICE < > '4')
AND (CHOICE < > '5') THEN GOTO HELPMENU;
CLRSCR;
(
This next section of code reads lines from the input file,
and writes them to the screen. No more than 40 lines permitted
in the help file.
)
I:=0;
RESET (INFILE);
WHILE NOT EOF (INFILE) DO BEGIN
READLN(INFILE,LINE);
I:=I+1;
WRITELN(LINE);
IF (I=20) OR (eof(infile)) THEN BEGIN
GOTOXY(2,24);
WRITE('HIT ANY KEY TO CONTINUE');
READ(KBD,CH); I:=0; CLRSCR;
END;
END;
Endhelp: clrscr; CLOSE (INFILE);
END;

(#####
##### The following 3 procedures are for the Sort.box. #####
#####)

Procedure INP; (Input values to Sort.box. )
Begin
gotoxy(2,10);Write('Sorting ... Please Wait ');
FOR I:=1 TO NUMBEROFSTANDS DO (For all the stands -)
SORTRELEASE(STAND[I]); (send the data. )
end;

Function LESS; (Ascending or Descending sort procedure. )
Var
FIRSTSTAND:ASTAND ABSOLUTE X; (Described in Turbo-Pascal)
SECONDSTAND:ASTAND ABSOLUTE Y; { user's manual. }
Begin
If SORTATTRIBUTE=4 then LESS:= FIRSTSTAND.STANDNUM < SECONDSTAND.STANDNUM;
{Sorts on stand number. }
If SORTATTRIBUTE=1 then LESS:= FIRSTSTAND.AGE[0] > SECONDSTAND.AGE[0];
{Sorts on initial age. }
If SORTATTRIBUTE=2 then LESS:= FIRSTSTAND.SI > SECONDSTAND.SI;
{Sorts on site index. }
If SORTATTRIBUTE=3 then LESS:= FIRSTSTAND.WORKCLASS < SECONDSTAND.WORKCLASS;
{Sorts on working class. }
end;

Procedure OUTP; (Return sorted records to program. )
Begin
For I:=1 TO NUMBEROFSTANDS do
SORTRETURN(STAND[I]);
end;

Procedure MAP;

Const
Mapyear :Integer= 0;
var
X,Y,YMAX,XMAX,
bwX,bwY,
Movemap,
Hatchden :Integer;

```

```

BEGIN
Clearscreen;
WriteIn( ' For what year of the analysis [0 through ',Horizon,'] do you want');
Write( ' the mean dbh map? ');
Read(MapYear);
If (MapYear > Horizon) or (MapYear < 0) then MapYear:= 0;
Clearscreen;
YMAX:= 0;
XMAX:= 0;
MOVEMAP:= 10;
For J:= 1 to Numberofstands do with STAND[J] do begin {looking for scaling factors}
If XCOORD > XMAX then XMAX:= XCOORD; If YCOORD > YMAX then YMAX:= YCOORD;
End;
{Initialize graphics display}

SETLINESTYLE(0);
SELECTWORLD(1);
DEFINEWINDOW(5,1,5,57,175);
DEFINEWINDOW(6,59,5,75,175);

( Draw legend )

SELECTWINDOW(6);
DEFINEHEADER(6, 'LEGEND');
DRAWBORDER;
DRAWTEXTW(200,80,1, 'SEEDLING');
DRAWSQUARE(200,110,500,160,FALSE);
HATCH(200,110,500,160,1);
DRAWTEXTW(200,230,1, 'SAPLING');
DRAWSQUARE(200,260,500,310,FALSE);
HATCH(200,260,500,310,4);
DRAWTEXTW(200,380,1, 'POLE');
DRAWSQUARE(200,410,500,460,FALSE);
HATCH(200,410,500,460,-6);
DRAWTEXTW(200,530,1, 'MATURE');
DRAWSQUARE(200,560,500,610,FALSE);
HATCH(200,560,500,610,-6);
HATCH(200,560,500,610,6);
DRAWTEXTW(200,680,1, 'OVERMATURE');
DRAWSQUARE(200,710,500,760,FALSE);
HATCH(200,710,500,760,10);

{Draw grid}

SELECTWINDOW(5);
DEFINEHEADER(5, 'DISPLAY OF CUTTING UNITS BY AGE. HIT P TO PRINT .. Q TO QUIT');
DRAWBORDER;

XMAX:= XMAX + MOVEMAP; YMAX:= YMAX + MOVEMAP;

BWY:= ROUND(1000/YMAX);
BWY:= ROUND(1000/YMAX);

For X:= 0 to XMAX do
for Y:= 0 to YMAX do BEGIN
DRAW SQUARE(X*BWY,Y*BWY,X*BWY + BWY,Y*BWY + BWY,false);
End;

{Hatch selected cells}
MOVEMAP:= ROUND(MOVEMAP/2);

For J:= 1 to Numberofstands do with STAND[J] do begin

MDBH:= sqrt(183.3464944*BA[MAPYEAR]/TPA[MAPYEAR]);
If MDBH < 1 then HATCHDEN:= 1;
If (MDBH < 5) and (MDBH >= 1) then HATCHDEN:= 4;
If MDBH >= 17 then HATCHDEN:= 10;
If (MDBH >= 5) AND (MDBH < 17) then HATCHDEN:= -6;

HATCH((XCOORD-1 + MOVEMAP)*BWY,(YCOORD-1 + MOVEMAP)*BWY,
(XCOORD-1 + MOVEMAP)*BWY + BWY,(YCOORD-1 + MOVEMAP)*BWY + BWY,HATCHDEN);

If (MDBH >= 5) AND (MDBH < 10) then begin
HATCHDEN:= 6;
HATCH((XCOORD-1 + MOVEMAP)*BWY,(YCOORD-1 + MOVEMAP)*BWY,
(XCOORD-1 + MOVEMAP)*BWY + BWY,(YCOORD-1 + MOVEMAP)*BWY + BWY,HATCHDEN);
End;
End;
Read(KBD,CH);
If Upcase(ch) = 'P' then hardcopy(false,3);
End; {of procedure MAP}

Procedure BARGRAPH;

Var I,DISPLYLEN,HATCHDEN :Integer;
B :PlotArray;
R :Real;
NUMTEXT :Wrkstring;
HATCH :Boolean;

{Special variables}
{ used by graphics. }

Begin
Clearscreen; Gotoxy(1,1);
If BARATTRIBUTE= 1 then
Begin
DISPLYLEN:= 5; {Draw five bars. }

```



```

For I:= 1 to DISPLYLEN do
  B[I,2]:= HCBC[I]/MAXCBCVALUE*700;    (Set values into plot array. )
Selectwindow(1);
DefineHeader(1,'CHANGE IN WILDLIFE HABITAT VALUE DURING SUCCESSION ... HIT ANY KEY TO CONTINUE');
Drawborder;
HATCH:= true;          (Enable hatching. )
HATCHDEN:= 10;         (Draw hatch lines this far apart. )
Drawhistogram(B,-DISPLYLEN,HATCH,HATCHDEN); (Draw the bar chart. )
Drawtextw(50,25,1,'Seedling');
Drawtextw(250,25,1,'Sapling'); (Draw the legend. )
Drawtextw(460,25,1,'Pole');
Drawtextw(650,25,1,'Mature');
Drawtextw(850,25,1,'Overmature');
Str(hcbc[1]:3:1,NUMTEXT);
Drawtextw(50,70,1,NUMTEXT);
Str(hcbc[2]:3:1,NUMTEXT);
Drawtextw(250,70,1,NUMTEXT);
Str(hcbc[3]:3:1,NUMTEXT);
Drawtextw(460,70,1,NUMTEXT);
Str(hcbc[4]:3:1,NUMTEXT);
Drawtextw(650,70,1,NUMTEXT);
Str(hcbc[5]:3:1,NUMTEXT);
Drawtextw(850,70,1,NUMTEXT);
end;

If BARATTRIBUTE= 2 then
begin
  DISPLYLEN:= HORIZON+1;    (Horizon + 1 bars. )
  For I:= 0 to DISPLYLEN do
    B[I+1,2]:= TOTYEARLYBENhigh[I]/MAXTOTYEARLYBEN*700; (Set values in plot array. )
    (Scale to 700/1000 of window. )

  Selectwindow(2);
  DefineHeader(2,'CHANGE IN WILDLIFE BENEFITS DUE TO CUTTING ... HIT ANY KEY TO CONTINUE');
  Drawborder;

  HATCH:= true;          (Enable hatching. )
  HATCHDEN:= 12;         (Draw hatch lines this far apart. )

  Drawhistogram(B,-DISPLYLEN,HATCH,HATCHDEN); (Draw the bar chart. )
  Str(totyearlybenhigh[0]:6:1,NUMTEXT);
  Drawtextw(50,25,1,NUMTEXT+ ' units');
  Drawtextw(250,25,1,' .. .....');
  Str(totyearlybenhigh[hORIZON]:6:1,NUMTEXT);
  Drawtextw(825,25,1,NUMTEXT+ ' units');

  Str(((1-totyearlybenhigh[0]/totyearlybenhigh[HORIZON])*100):3:1,NUMTEXT);
  Drawtextw(450,90,1,'A + NUMTEXT + % change. ');
end;
Read(kbd,ch);
end; (of procedure Bargraph. )

(#####
##### This is the simulation subprogram. #####
#####)

Procedure SIMULATE;

{
  Read data from stand database and set into array.
}
Begin
  Gotoxy(1,3);
  Writeln(' Analyzing File ',STANDFN,' for ',HORIZON,' years. ');
  Writeln;
  Writeln(' Cut = ',CUT:2:2);

  YEAR:= STARTYEAR;    (Initialize YEAR to beginning year supplied by user. )
  SUMACRES:= 0;        (Initialize SUMACRES. )
  {
    Year loop
  }

  For I:= 1 to HORIZON do begin (for the number of years desired. )
    Gotoxy(2,13);
    Writeln(' In year number ',I,' working on stand number .. ');

    {
      Annual growth simulator : Eqns from Dale 1972
    }

    For J:= 1 to NUMBEROFSTANDS do (Grow each cutting unit one year. )
      With STAND[J] do begin
        Gotoxy(40,15); Write(J:3);
        If AGE[I-1] < 3 then begin (working on cutting units too young for
          regression equations. )
          AGE[I]:= AGE[I-1]+1;
          TPA[I]:= 1000;
          BA[I]:= 2;
          end;

        If AGE[I-1] >= 3 then begin (working on cutting units over 2 years old. )
          MDBH:= sqrt(183.3464944*BA[I-1]/TPA[I-1]); (Calculates mean dbh. )
          AGE[I]:= AGE[I-1]+1; (Advances age one year. )

          {
            BAGROWTH is the change in basal area/acre or hectare/year.
          }

```

```

BAGROWTH: = (-BA[I-1]/exp(0.8*ln(AGE[I])))*Ln(BA[I-1]) + 3.68521*(BA[I-1]/
exp(0.75*ln(AGE[I])) + 0.011383*SI*(BA[I-1]/exp(1.05*ln(AGE[I]))));
BA[I]: = BA[I-1] + BAGROWTH;           (Update basal area.)
{
  INGROWTH = number of trees/acre that enter stand for year I.
}
If AGE[I] > 50 then Begin
INGROWTH: = 9.264291E-02 + 1.13E-06*sqrt(AGE[I]) - 0.015674*Ln(BA[I-1]) -
0.076175*MDBH/exp(0.8*ln(AGE[I])) + 0.0010186*TPA[I-1]/exp(0.8*ln
(AGE[I])) - 8.3E-07*TPA[I-1]*SI;
{ MORTALITY is the number of trees/acre that die in year I. }
MORTALITY: = -0.15021 - 1.181/exp(1.05*ln(AGE[I])) + 0.029721*ln(SI)
+ 0.007847*Ln(TPA[I-1]) + 0.11115/MDBH;
end;
{ INGROWTH and MORTALITY are different after age 50. }

If AGE[I] < 50 then Begin
INGROWTH: = 9.264291E-02 + 1.13E-06*sqrt(AGE[I]) - 0.015674*Ln(BA[I-1]) -
0.076175*MDBH/exp(0.8*ln(AGE[I])) + 0.0010186*TPA[I-1]/exp(0.8*ln(AGE[I])) -
8.3E-07*TPA[I-1]*SI
- ((1.391E-05*sqrt(90-SI)*exp(3*ln(50-AGE[I])))/(900-sqrt(TPA[I-1])));
MORTALITY: = -0.15021 - 1.181/exp(1.05*ln(AGE[I])) + 0.029721*ln(SI)
+ 0.007847*Ln(TPA[I-1]) + 0.11115/MDBH
+ ((3.70714E-03*(90-SI)/(90-AGE[I]))*exp(3*ln(TPA[I-1]))/(1E+08));
end;
{ Eliminate nonsensical results. }
If (TPA[I-1] > 850) OR (INGROWTH < 0) then INGROWTH := 0;
If MORTALITY < 0 then MORTALITY := 0;

{ Update trees/acre figure. }
TPA[I]: = TPA[I-1] + INGROWTH*TPA[I-1] - MORTALITY*TPA[I-1];

{ This section assigns benefits for year to cutting unit based on MDBH
(mean diameter-breast-height). }
end; (of growth simulator for cutting units > 3 years old. )

MDBH: = sqrt(183.3464944*BA[I]/TPA[I]); {Calculate mean dbh. }

{ Determine yearly benefits from cumulative species model. }
If MDBH < 1 then BPA: = HCBC[1];
If (MDBH < 5) and (MDBH >= 1) then BPA: = HCBC[2];
If (MDBH < 10) and (MDBH >= 5) then BPA: = HCBC[3];
If (MDBH < 17) and (MDBH >= 10) then BPA: = HCBC[4];
If MDBH >= 17 then BPA: = HCBC[5];

TOTALBEN: = BPA*ACRES + TOTALBEN;           (Sum of benefits overall. )
TOTYEARLYBEN[I]: = TOTYEARLYBEN[I] + BPA*ACRES; (Sum of benefits for year. )
If TOTYEARLYBEN[I] > MAXTOTYEARLYBEN then MAXTOTYEARLYBEN: = TOTYEARLYBEN[I];
{ Set MAXTOTYEARLYBEN to maximum yearly figure for forest. }
end; (of growth simulator)

{ Cutting simulator }

If I = 1 then K: = 1;
While SUMACRES < CUT*I do with STAND[K] do begin
  K: = K + 1;
  If K > NUMBEROFSTANDS then begin K: = 1; CUTNUMBER: = CUTNUMBER + 1; end;
  If (WORKCLASS <> '0') and (SI >= 60) then begin
    { Record the cords cut under this cutting simulation. }
    MDBH: = sqrt(183.3464944*BA[0]/TPA[0]);
    If (MDBH < 16) and (AGE[I] > 3) then
      CORDS: = (-0.052676 + 0.787605/exp(exp(10*ln(1.29872-0.08117*MDBH))))*
      (exp(3.0904 + 0.00930176*SI + 1.03909*ln(BA[I]) - 20.1104/AGE[I]))/80
    else CORDS: = 0;

    If MDBH >= 16 then
      CORDS: = 0.735*(exp(3.0904 + 0.00930176*SI + 1.03909*ln(BA[I]) - 20.1104/AGE[I]))/80 ;

    If CORDS < 0 then CORDS: = 0;
    CORDSUM: = CORDSUM + CORDS;
    BA[I]: = 2;           {Initialize cut stands to a basal area}
    TPA[I]: = 1000;       { of 2, a tpa of 1000, and an age of 0. }
    AGE[I]: = 0;
    SUMACRES: = SUMACRES + ACRES;
  end;
end; (of stand cutting simulation)

Q: = Q + ((Totyearlyben[I] - (exp(2*ln(abs(Goal-Totyearlyben[I]))))/1000000.0);

YEAR: = YEAR + 1;           {Increment YEAR counter. }
end; (of year loop. )
MEANYEARLYBEN: = TOTALBEN/HORIZON;
CLOSE(STANDFILE);
end; (of Procedure SIMULATE)

Procedure Bimodal_Trap;

Const

```

```

Var
    Counter                :Integer = 0;

    DataPoint
    Delta                  :Array[0 .. 8] of Real;
    Slope                  :Array[0 .. 7] of Integer;
    II                     :Real;
    II                     :Integer;

Begin
    Clsrscreen; Gotoxy(2,1);
    Writeln('Trapping for bimodal benefit functions ... please wait');

    For II:= 0 to 7 do begin
        CUT:= CUTMAX/7*II;
        Simulate;
        If bf = '2' then DataPoint[II] := MeanYearlyBen else DataPoint[II] := Q;
    end;
    For II:= 1 to 7 do begin
        Slope := DataPoint[II]-DataPoint[II-1];
        If Slope >= 0 then Delta[II] := 1 else Delta[II] := -1;
    end;

    For II:= 2 to 7 do If Delta[II]+Delta[II-1] = 0 then Counter:= Counter + 1;
    If Counter > 1 then begin
        Clsrscreen;
        gotoxy(1,1);
        Writeln('WARNING: Objective function is bimodal. ');
        Writeln('          Convergence may be hindered by local maxima. ');
        Gotoxy(2,24); Write(' HIT ANY KEY TO CONTINUE'); Read(kbd,ch);
    end;
end; {of procedure Bimodal_Trap. }

#####
##### The following is the main body of the program. #####
#####
{
    Title screen
}
Begin
    Clsrs;
    Gotoxy(32,5);
    Write(' Welcome to WILDWOOD');
    GotoXY(33,7);
    Write(' a forest wildlife');
    Gotoxy(35,8);
    Write(' planning tool');
    {
        Hold then clear screen.
    }
    Gotoxy(29,22);
    Write(' HIT ANY KEY TO CONTINUE'); Gotoxy(40,12); Read(kbd,ch);
    Clsrs;
    {
        USER INPUT SECTION
    }
    Clsrs;
    Writeln(' Make sure your data disk is available and the door is shut. ');
    Writeln;
    Writeln(' This version of WILDWOOD can only handle 106 stands for a maximum');
    Writeln(' planning horizon of 35 years. This version also requires a monochrome ');
    Writeln(' or color graphics monitor. ');
    Writeln;
    Writeln(' Also, remember that WILDWOOD appends its own file extensions so use only');
    Writeln(' the PCFILE database name. Do not use the .DTA extension. ');
    Writeln;
    Writeln(' Note: English units are required throughout WILDWOOD. ');
    Gotoxy(2,24); Write(' HIT ANY KEY TO CONTINUE'); Read(kbd,ch);
    IN1:
    Clsrs;
    Write(' What is the name of the stand data file (e.g. B:HAVENS)? ');
    Readln(STANDFN);
    If (STANDFN = 'help') or (STANDFN = 'HELP') then begin help; Goto IN1; end;
    If (STANDFN = 'exit') or (STANDFN = 'EXIT') then halt;
    IN2:
    Writeln;
    Write(' What is the name of the species data file (e.g. B:SPECIES)? ');
    Readln(SPECIESFN);
    If (SPECIESFN = 'HELP') or (SPECIESFN = 'help') then begin help; Goto IN2; end;
    If (SPECIESFN = 'exit') or (SPECIESFN = 'EXIT') then halt;
    Gotoxy(2,24); Write(' HIT ANY KEY TO CONTINUE'); Read(kbd,CH);
    IN4:
    Clsrs;
    Writeln;
    Write(' How many years into the future do you want to project (MAX= 35)? ');
    Readln(HORIZONSTR);
    If (HORIZONSTR = 'exit') or (HORIZONSTR = 'EXIT') then halt;
    If (HORIZONSTR = 'HELP') or (HORIZONSTR = 'help') then begin help; goto IN4; end;
    VAL(HORIZONSTR,HORIZON,CODE);
    IN5:
    Writeln;
    Write(' What is the beginning year (e.g. 1987)? '); Readln(STARTYEARSTR);
    If (STARTYEARSTR = 'HELP') or (STARTYEARSTR = 'help') then begin help; goto IN5; end;
    If (STARTYEARSTR = 'exit') or (STARTYEARSTR = 'EXIT') then halt;
    VAL(STARTYEARSTR,STARTYEAR,CODE);
    IN6:
    Writeln;

```

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WriteIn(' Do you wish to cut stands based on:');
WriteIn;
WriteIn('                                0) input order');
WriteIn('                                1) oldest stand first');
WriteIn('                                2) highest site index first');
WriteIn('                                3) best working class first');
WriteIn('                                e) exit to DOS');
WriteIn('                                h) help');
WriteIn;
Write('                                -> ');
ReadIn(SORTATTRIBUTESTR); SORTATTRIBUTESTR = Copy(SORTATTRIBUTESTR,1,1);
WriteIn;
If (SORTATTRIBUTESTR = 'H') or (SORTATTRIBUTESTR = 'h') then begin help; goto IN6; end;
If (SORTATTRIBUTESTR = 'E') or (SORTATTRIBUTESTR = 'e') then halt;
Val(SORTATTRIBUTESTR,SORTATTRIBUTE,CODE);
IN7:
Clrscr;
WriteIn(' Do you wish to:                                1) do a simple simulation ');
WriteIn('                                2) do a search for an optimum cut ');
WriteIn('                                3) search for an optimum annual cut based on Q ');
WriteIn('                                h) see a help screen ');
WriteIn('                                e) exit to DOS');
WriteIn;
Write('                                -> ');
readIn(bf);

If Upcase(bf) = 'E' then halt;
If Upcase(bf) = 'H' then begin help; goto IN7; end;
If (bf = '2') or (bf = '3') then begin
  Clrscr;
  WriteIn(' The optimization options of WILDWOOD take a minimum of 30 minutes to');
  WriteIn(' run. They may take as long as 5 hours depending on the number of');
  WriteIn(' cutting units. ');
  Gotoxy(1,10); Write(' Do you still wish to do an optimization run (y/n)? ');
  ReadIn(choice);
  If (CHOICE < > 'Y') and (CHOICE < > 'y') then Goto IN7;
end;
IN8:
If bf = '1' then begin
  WriteIn; Write(' What is the annual cutting limit to be tested (e.g. 2.2)? ');
  ReadIn(CUTSTR);
  If (CUTSTR = 'HELP') or (CUTSTR = 'help') then begin help; goto IN8; end;
  If (CUTSTR = 'EXIT') or (CUTSTR = 'exit') then halt;
  Val(CUTSTR,CUT,CODE);
  If CUT < 0 then CUT = 0; (Eliminates negative cutting possibility. )
end;

If (bf < > '1') and (bf < > '2') and (bf < > '3') and (Upcase(bf) < > 'H') and
(Upcase(bf) < > 'E') and (bf < > '4') then goto IN7; (Traps nonsensical choices)

InitGraphic; (Initialize the graphics system. )
SetColorWhite; (Set up the window for the bar chart. )
SetBackground(0);
SetHeaderOn;
DefineWorld(1,0,0,1000,1000);
DefineWindow(1,0,0,XMaxGlb,YMaxGlb);
DefineWindow(2,0,0,XMaxGlb,YMaxGlb);
SelectWorld(1);
SelectWindow(1);

Clearscreen;
Gotoxy(2,5);
Write(' Creating cumulative wildlife benefit model -----');
(
  Open the data files
)
STANDFN = STANDFN + '.DTA';
SPECIESFN = SPECIESFN + '.DTA';
Assign(STANDFILE,STANDFN); Assign(SPECIESFILE,SPECIESFN);
Reset (SPECIESFILE);
(
  Read species data and create CBM array.
)
While not eof(SPECIESFILE) begin
  ReadIn(SPECIESFILE,L);
  TEST = copy(L,1,1);
  If TEST < > \ then
  If TEST < > / then begin

    Val(copy(L,28,2),VALUE,CODE);
    Val(copy(L,30,3),HP[1],CODE);
    Val(copy(L,33,3),HP[2],CODE);
    Val(copy(L,36,3),HP[3],CODE);
    Val(copy(L,39,3),HP[4],CODE); ( This section strips out )
    Val(copy(L,42,3),HP[5],CODE); ( information from the species )
    ( database. )
  end;

  ( This next section weights the 5 model points by the value for species
  H then adds each weighted model point to the 5 cumulative model
  points
  )
  For I = 1 to 5 do begin
    HCB[1] = HCB[1] + (HP[I]*VALUE);
    If HCB[1] > MAXCBCVALUE then MAXCBCVALUE = HCB[1];
  end;
end;

```

```

end;
end;
Close (SPECIESFILE);
Bargraph; {Draw the histogram of the Cumulative Benefit Model. }
Reset(STANDFILE);
J:= 1;
TOTYEARLYBEN[0]:= 0;
Repeat
  Readln(STANDFILE,L);
  TEST:= copy(L,1,1);
  If TEST < > \ then
    If TEST < > '/' then
      With STAND[J] do begin
        J:= J + 1;
        STANDNUM:= copy(L,1,4);
        Val(copy(L,11,4),ACRES,CODE);
        Val(copy(L,15,2),SI,CODE);
        Val(copy(L,18,3),AGE[0],CODE);
        Val(copy(L,21,3),BA[0],CODE);
        Val(copy(L,24,4),TPA[0],CODE);
        WORKCLASS:= copy(L,30,1);
        Val(copy(L,75,3),XCOORD,CODE);
        Val(copy(L,78,3),YCOORD,CODE);

        If (WORKCLASS < > '0') AND (SI > = 60) then WORKABLEACRES:= WORKABLEACRES + ACRES;
          {Generate initial mdbh and then determine initial
           benefits from cumulative species model. }

          MDBH:= sqrt(183.3464944*BA[0]/TPA[0]);
          If MDBH < 1 then BPA:= HCBC[1];
          If (MDBH < 5) and (MDBH > = 1) then BPA:= HCBC[2];
          If (MDBH < 10) and (MDBH > = 5) then BPA:= HCBC[3];
          If (MDBH < 17) and (MDBH > = 10) then BPA:= HCBC[4];
          If MDBH > = 17 then BPA:= HCBC[5];

          TOTYEARLYBEN[0]:= TOTYEARLYBEN[0] + BPA*ACRES; {Determine total benefit level for year 0. }
        end;

      end;
    Until eof(STANDFILE);
    NUMBEROFSTANDS:= J-1;
    Close (standfile);
    Clearscreen;

    If SORTATTRIBUTE < > 0 then begin
      Write(Turbosort(Sizeof(ASTAND))); I:= 1;
      {Sort the records according to user choice. }
    If TurboSort(Sizeof(ASTAND)) < > 0 then begin
      Clearscreen;
      Gotoxy(1,1);
      WriteLn( 'WARNING: The sort procedure had an unanticipated problem. ');
      WriteLn( 'The cutting units may not be in proper order. ');
      Gotoxy(2,24); Write( 'HIT ANY KEY TO CONTINUE' ); Read(kbd,CH);
      end;
    end;
    ClearScreen;

    For I:= 1 to Horizon do TotYearlyBen[I]:= 0;

    If bf= '1' then begin
      Simulate;
      HighBen:= MeanYearlyBen;
      HighQ:= Q;
      CutMax:= Cut;
      For I:= 0 to Horizon do TotYearlyBenHigh[I]:= TotYearlyBen[I];
      CordSumHigh:= CordSum;
      end;

    if (upcase(bf)= '3') or (upcase(bf)= '2') then begin {binary search option}
      CUTMIN:= 0;
      CUTMAX:= WORKABLEACRES/3;
      BIMODAL_TRAP; {Calls Bimodal trap subprogram to test for bimodality. }
      For I:= 1 to horizon do Totyearlyben[I]:= 0;
      MaxTotYearlyBen:= 0;

      If bf= '3' then begin
        Clearscreen;
        GotoXY(1,1);
        Write( 'What is the benefit goal for the area? ');
        readln(goal);
        end;

      while (cutmax-cutmin) > e do begin
        Clearscreen;

        (LOW CUTTING LEVEL TEST)
        cut:= ((cutmax-cutmin)/4) + cutmin;
        Simulate;
        LowQ:= Q;
        Q:= 0;
        LOWBEN:= MEANYEARLYBEN; totalben:= 0;
        CORDSUMLOW:= CORDSUM;
        For I:= 0 to horizon do Totyearlybenlow[I]:= Totyearlyben[I];
        CORDSUM:= 0; {Initialize CORDSUM. }
        For I:= 1 to horizon do Totyearlyben[I]:= 0; {Initialize benefit array. }

```

```

(HIGH CUTTING LEVEL TEST)
cut: = (((cutmax-cutmin)/4)*3) + cutmin;
simulate;
HighQ: = Q;
Q: = 0;
HIGHBEN: = MEANYEARLYBEN; totalben: = 0;
CORDSUMHIGH: = CORDSUM;
For I: = 0 to horizon do Totyearlybenhigh[I]: = Totyearlyben[I];
CORDSUM: = 0; {Initialize CORDSUM. }
For I: = 1 to horizon do Totyearlyben[I]: = 0; {Initialize benefit array. }
If BF = '2' then begin
  if Lowben > Highben then cutmax: = ((cutmax-cutmin)/2 + cutmin) else
  cutmin: = ((cutmax-cutmin)/2 + cutmin);
end;
If BF = '3' then begin
  if LowQ > HighQ then cutmax: = ((cutmax-cutmin)/2 + cutmin) else
  cutmin: = ((cutmax-cutmin)/2 + cutmin);
end;
end;
end;

If Lowben > Highben then begin
  HighQ: = LowQ;
  Highben: = lowben;
  Cutmax: = Cutmin;
  Cordsumhigh: = Cordsumlow;
  for I: = 0 to Horizon do TotYearlyBenHigh[I]: = TotYearlyBenLow[I];
end;

If MAXTOTYEARLYBEN = 0 THEN MAXTOTYEARLYBEN: = TOTYEARLYBENHIGH[0];

(##### Beginning of report section. #####)

REPORTMENU:
While not DONE do begin
  YEAR: = STARTYEAR;
  Clearscreen; Gotoxy(1,1);
  WriteLn(' Would you like
  WriteLn('
  WriteLn('
  WriteLn('
  WriteLn('
  WriteLn('
  WriteLn(' = > '); ReadLn(CHOICE);
  if (CHOICE = 'e') or (CHOICE = 'E') then begin
    Gotoxy(2,8);
    WriteLn('Results from the previous run will be lost. ');
    Gotoxy(2,10);
    Write('Are you sure (y/n)? '); read(CHOICE);
    if (CHOICE = 'y') or (CHOICE = 'Y') then begin
      Leavegraphic; halt;
    end;
  end;

If CHOICE = '1' then begin { analysis summary report. }
  Clearscreen; Gotoxy(1,1);
  WriteLn('-----');
  WriteLn('-----');
  WriteLn('
  WriteLn(' Final Report ');
  WriteLn('
  WriteLn(' The mean benefit figure for this run : ',HighBen:10:0);
  WriteLn('
  WriteLn(' The yearly cutting level to achieve this : ',CutMax:10:2);
  WriteLn('
  WriteLn(' Q : ',HighQ:10:2);
  WriteLn('
  WriteLn(' The number of cords projected to be cut : ',CordSumHigh:10:0);
  WriteLn('
  WriteLn('-----');
  WriteLn('-----');
  Gotoxy(2,24);
  WriteLn('HIT ANY KEY TO CONTINUE');
  Read(kbd,ch);
end;

If CHOICE = '2' then begin { tabular reports. }
  Clearscreen; Gotoxy(2,1);
  WriteLn(' Would you like reports sorted by 0) unsorted');
  WriteLn('
  WriteLn(' 1) stand number');
  WriteLn(' 2) initial stand age');
  WriteLn(' e) return to report menu');
  WriteLn(' = > '); ReadLn(REPORTFORMAT);

If REPORTFORMAT = '1' then SORTATTRIBUTE: = 4;
If REPORTFORMAT = '2' then SORTATTRIBUTE: = 1;
If (REPORTFORMAT = 'E') or (REPORTFORMAT = 'e') then goto REPORTMENU;
If (REPORTFORMAT = '1') or (REPORTFORMAT = '2') or (REPORTFORMAT = '3') then begin
  Write(Turbosort(Sizeof(ASTAND)));
  WriteLn(' error code ... 0 means sort was successful. ');
end;
Clearscreen;
Gotoxy(1,10);

```

```

WriteIn( ' Do you want reports sent to:      1) the screen ');
WriteIn(                                     2) a disk file ');
WriteIn(                                     3) a printer');
WriteIn(                                     e) return to report menu');
WriteIn; Write( = > '); ReadIn(REPORTFORMAT);
If (REPORTFORMAT = 'E') or (REPORTFORMAT = 'e') then goto REPORTMENU;

Clearscreen;
If REPORTFORMAT = '2' then begin
Gotoxy(2,1);
Write( ' What is the name of the output file? '); ReadIn(OUTFN);
Assign(OUTFILE,OUTFN); Rewrite(OUTFILE);
Clearscreen;
end;
For J:= 1 to NUMBEROFSTANDS do with STAND[J] do Begin
COUNT:= 0; Clearscreen; Gotoxy(1,1);

If REPORTFORMAT = '1' then begin
WriteIn; WriteIn;
WriteIn( '-----');
WriteIn( ' Report for cutting unit ',STANDNUM);
WriteIn( '-----');
WriteIn;
WriteIn( ' Year      Age  MDBH    BA  Benefits/Acre  Benefits Cords/AC  Acres');
WriteIn( '-----');

For I:= 0 to HORIZON do begin
YEAR:= STARTYEAR + I;
MDBH:= sqrt(183.3464944*BA[I]/TPA[I]);

If (MDBH < 16) and (AGE[I] > 3) then
CORDS:= (-0.052676 + 0.787605/exp(exp(10*ln(1.29872-0.08117*MDBH))))*
(exp(3.0904 + 0.00930176*SI + 1.03909*ln(BA[I])-20.1104/AGE[I]))/80
else CORDS:= 0;

If MDBH >= 16 then
CORDS:= 0.735*(exp(3.0904 + 0.00930176*SI + 1.03909*ln(BA[I])-20.1104/AGE[I]))/80 ;

If CORDS < 0 then CORDS:= 0;
If MDBH < 1 then BPA:= HCBC[1];
If (MDBH < 5) and (MDBH >= 1) then BPA:= HCBC[2];
If (MDBH < 10) and (MDBH >= 5) then BPA:= HCBC[3];
If (MDBH < 17) and (MDBH >= 10) then BPA:= HCBC[4];
If MDBH >= 17 then BPA:= HCBC[5];

Str(YEAR:4,ST);
Write( ' ',ST, ' ');
Str(AGE[I]:3,ST);
Write(ST, ' ');
Str(MDBH:2:1,ST);
Write(ST, ' ');
Str(BA[I]:3:0,ST);
Write(ST, ' ');
Str(BPA:3:0,ST);
Write(ST, ' ');
Str((BPA*ACRES):6:0,ST);
Write(ST, ' ');
Str(CORDS:3:1,ST);
Write(ST, ' ');
Str(ACRES:3:1,ST);
WriteIn(ST);

If COUNT < 12 then COUNT:= COUNT + 1 else begin
Gotoxy(2,24); WriteIn( ' HIT X TO STOP, ANY OTHER KEY TO CONTINUE');
Read(kbd,CH);
If (CH = 'X') or (CH = 'x') then goto REPORTMENU else begin
count:= 0;
clearscreen;
Gotoxy(1,1);
WriteIn( ' Year      Age  MDBH    BA  Benefits/Acre  Benefits Cords/AC  Acres');
WriteIn( '-----');
end;
end; {of screen output loop. }
Gotoxy(2,24); WriteIn( ' HIT X TO STOP, ANY OTHER KEY TO CONTINUE');
Read(kbd,CH);
If (CH = 'x') or (CH = 'X') then goto REPORTMENU;
end; {of screen output option. }

If REPORTFORMAT = '2' then begin
WriteIn( ' Writing report to file ',OUTFN, ' please wait .. ');
WriteIn(OUTFILE); WriteIn(OUTFILE);
WriteIn(OUTFILE, '-----');
WriteIn(OUTFILE, ' Report for cutting unit ',STANDNUM);
WriteIn(OUTFILE, '-----');
WriteIn(OUTFILE);
WriteIn(OUTFILE, ' Year      Age  MDBH    BA  Benefits/Acre  Benefits Cords/AC  Acres');
WriteIn(OUTFILE, '-----');

For I:= 0 to HORIZON do begin
YEAR:= STARTYEAR + I;
MDBH:= sqrt(183.3464944*BA[I]/TPA[I]);

If (MDBH < 16) and (AGE[I] > 3) then
CORDS:= (-0.052676 + 0.787605/exp(exp(10*ln(1.29872-0.08117*MDBH))))*
(exp(3.0904 + 0.00930176*SI + 1.03909*ln(BA[I])-20.1104/AGE[I]))/80

```

```

else CORDS:=0;

If MDBH >= 16 then
CORDS:=-0.735*(exp(3.0904+0.00930176*SI+1.03909*ln(BA[I])-20.1104/AGE[I]))/80 ;

If CORDS < 0 then CORDS:=0;
If MDBH < 1 then BPA:=HCBC[1];
If (MDBH < 5) and (MDBH >= 1) then BPA:=HCBC[2];
If (MDBH < 10) and (MDBH >= 5) then BPA:=HCBC[3];
If (MDBH < 17) and (MDBH >= 10) then BPA:=HCBC[4];
If MDBH >= 17 then BPA:=HCBC[5];

Str(YEAR:4,ST);
Write(' ST ');
Str(AGE[I]:3,ST);
Write(ST);
Str(MDBH:2:1,ST);
Write(ST);
Str(BA[I]:3:0,ST);
Write(ST);
Str(BPA:3:0,ST);
Write(ST);
Str((BPA*ACRES):6:0,ST);
Write(ST);
Str(CORDS:3:1,ST);
Write(ST);
Str(ACRES:3:1,ST);
Write(ST);
end; {of disk file output loop. }
end; {of disk file output option. }

If REPORTFORMAT = '3' then begin
WriteLn(' Printing ... please wait... ');
WriteLn(Ist); WriteLn(Ist);
WriteLn(Ist, '-----');
WriteLn(Ist, Report for cutting unit ,STANDNUM);
WriteLn(Ist, '-----');
WriteLn(Ist);
WriteLn(Ist, Year Age MDBH BA Benefits/Acre Benefits Cords/AC Acres');
WriteLn(Ist, '-----');

For I:=0 to HORIZON do begin
YEAR:=STARTYEAR+I;
MDBH:=sqrt(183.3464944*BA[I]/TPA[I]);

If (MDBH < 16) and (AGE[I] > 3) then
CORDS:=(-0.052676+0.787605/exp(exp(10*ln(1.29872-0.08117*MDBH))))*
(exp(3.0904+0.00930176*SI+1.03909*ln(BA[I])-20.1104/AGE[I]))/80
else CORDS:=0;

If MDBH >= 16 then
CORDS:=0.735*(exp(3.0904+0.00930176*SI+1.03909*ln(BA[I])-20.1104/AGE[I]))/80 ;

If CORDS < 0 then CORDS:=0;
If MDBH < 1 then BPA:=HCBC[1];
If (MDBH < 5) and (MDBH >= 1) then BPA:=HCBC[2];
If (MDBH < 10) and (MDBH >= 5) then BPA:=HCBC[3];
If (MDBH < 17) and (MDBH >= 10) then BPA:=HCBC[4];
If MDBH >= 17 then BPA:=HCBC[5];

Str(YEAR:4,ST);
Write(' ST ');
Str(AGE[I]:3,ST);
Write(ST);
Str(MDBH:2:1,ST);
Write(ST);
Str(BA[I]:3:0,ST);
Write(ST);
Str(BPA:3:0,ST);
Write(ST);
Str((BPA*ACRES):6:0,ST);
Write(ST);
Str(CORDS:3:1,ST);
Write(ST);
Str(ACRES:3:1,ST);
Write(ST);
end; {of printer output loop. }
end; {of printer output option. }
end; {of tabular report internal loop. }
If REPORTFORMAT = '2' then close (OUTFILE);

WriteLn;WriteLn;Gotoxy(2,24);
WriteLn(' HIT ANY KEY TO CONTINUE'); Read(kbd,ch);

end; {of tabular reports}

If CHOICE = '3' then begin {histogram reports. }
Clearscreen; Gotoxy(1,1);
WriteLn(' Would you like 1) the cumulative wildlife species');
WriteLn(' benefits model histogram');
WriteLn(' 2) or the yearly wildlife benefits');
WriteLn(' histogram. ');
WriteLn(' e) return to report menu');
Write(' = > '); read(REPORTFORMAT);
Clearscreen;
If REPORTFORMAT = '1' then BARATTRIBUTE:=1;

```



```
If REPORTFORMAT='2' then BARATTRIBUTE:=2;
If (REPORTFORMAT < > '1') and (REPORTFORMAT < > '2') then goto REPORTMENU;
    ( Draw the histogram chosen. )
bargraph;
end;

If CHOICE='4' then Map;

end; {of report Writer}
end.
```

## Appendix D. Forest Cutting Unit Information for Havens Wildlife Management Area Demonstration.

CUT					TREES			
UNIT	SITE	FOREST		BASAL	PER		WORKING	
NUMBER	INDEX	TYPE	AGE	AREA	ACRE	ASPECT	CLASS	COMMENTS
0101	50	h	150	90	315	n	0	stream buffer cell
0102	83	h	23	100	297	n	0	stream buffer cell
0103	48	h	56	60	301	ne	0	stream buffer cell
0104	86	h	16	60	442	ne	0	stream buffer cell
0105	35	h	53	60	662	nw	0	stream buffer cell
0106	50	h	87	110	342	n	0	stream buffer cell
0107	55	h	57	60	310	nw	0	stream buffer cell
0108	50	h	75	70	305	nw	0	stream buffer cell
0109	65	h	56	70	598	n	0	stream buffer cell
0110	73	h	81	97	70	nw	0	stream buffer cell
0111	35	m	57	100	677	nw	3	
0112	52	c	60	110	611	nw	3	
0113	75	m	55	90	86	nw	0	stream buffer cell
0114	75	m	57	110	365	nw	3	
0115	52	m	68	50	450	nw	3	
0116	52	m	49	80	542	nw	3	
0117	72	h	60	90	180	nw	0	stream buffer cell
0118	52	h	55	69	528	n	3	
0119	65	h	58	90	415	ne	3	
0120	90	h	61	70	151	n	3	
0121	90	m	58	50	70	n	3	
0201	47	h	75	40	155	n	3	
0202	68	h	52	110	591	ne	3	
0203	77	h	42	70	210	n	3	
0204	55	m	55	60	200	sw	3	
0205	71	h	52	90	200	nw	0	stream buffer cell
0206	45	m	48	30	347	w	3	
0207	55	m	50	50	388	n	3	
0208	47	m	48	40	212	n	3	
0209	75	h	67	50	127	n	0	stream buffer cell
0210	35	m	10	2	20	w	3	no trees on plot...numbers are extrapolated
0211	45	m	75	20	50	n	3	
0212	65	h	50	60	778	w	0	too steep
0213	40	c	85	70	138	nw	3	
0214	52	m	70	70	205	n	2	steep
0215	50	h	48	80	895	n	2	steep
0216	35	h	120	70	271	ne	0	stream buffer cell
0217	58	m	59	50	194	w	0	stream buffer cell
0218	45	h	54	40	176	nw	1	poor access
0219	47	h	61	80	659	nw		
0220	80	h	69	50	257	ne	1	poor access
0221	70	h	60	60	301	w	0	stream buffer cell
0301	82	h	71	70	40	ne	0	stream buffer cell

0302	55	h	80	130	811	se	1	poor access
0303	50	h	60	80	506	nw	1	poor access
0304	52	h	83	180	1194	ne	0	stream buffer cell
0305	57	h	66	50	124	ne	1	poor access
0306	52	h	81	50	259	ne	0	stream buffer cell
0307	51	m	62	80	214	e	1	
0308	40	m	84	40	28	w	2	steep
0309	35	h	73	60	161	n	2	steep
0310	40	m	88	40	171	w	1	
0311	62	h	44	80	287	w	1	
0312	70	h	52	60	111	e	0	stream buffer cell
0313	57	h	63	70	262	e	1	
0314	45	h	58	70	342	nw	1	
0315	45	m	56	40	494	w	1	
0316	40	h	53	50	228	n	0	stream buffer cell
0317	70	h	47	80	299	ne	1	
0318	67	h	53	70	254	w	1	
0319	60	h	4	2	1000	ne	2	steep
0320	60	h	4	2	1000	nw	1	
0321	55	h	53	60	172	w	1	
0401	70	h	106	100	274	n	0	stream buffer cell
0402	75	h	48	70	207	sw	1	
0403	60	h	4	2	1000	nw	1	
0404	57	h	56	30	89	e	1	
0405	45	m	70	50	470	nw	1	
0406	54	h	59	70	220	nw	1	
0407	92	h	18	30	232	nw	0	stream buffer cell
0408	65	h	42	120	1033	w	1	
0409	50	h	56	80	428	n	1	
0410	60	h	53	50	179	se	1	
0411	90	h	53	70	132	e	2	steep
0412	90	m	49	100	703	nw	0	stream buffer cell
0413	55	m	37	70	596	w	1	poor access
0414	40	h	83	60	93	n	1	poor access
0415	57	h	61	70	132	e	1	poor access
0416	70	h	70	60	132	e	1	poor access and steep
0417	55	h	84	70	80	n	0	stream buffer cell
0418	47	h	64	50	220	n	1	poor access
0419	59	h	70	60	132	nw	0	stream buffer cell
0420	70	h	56	50	119	w	1	poor access
0421	70	h	69	80	159	e	1	poor access
0422	67	h	69	90	539	nw	0	stream buffer cell
0501	70	h	72	60	297	nw	0	stream buffer cell
0502	82	h	55	100	497	nw	1	poor access
0503	70	h	52	90	327	n	0	stream buffer cell
0504	87	h	65	110	244	ne	1	poor access
0505	64	m	48	70	181	nw	1	poor access
0506	70	h	50	60	101	ne	1	poor access and steep
0507	45	h	76	70	360	ne	3	
0508	42	h	83	80	622	n	3	
0509	47	m	60	40	81	sw	3	
0510	81	h	49	50	203	w	3	
0511	60	h	46	90	770	nw	0	stream buffer cell
0512	62	h	51	90	227	n	3	
0513	60	h	60	40	254	n	3	
0514	52	m	70	80	191	nw	3	
0515	85	h	55	70	117	w	3	
0516	65	h	45	110	575	nw	0	stream buffer cell
0517	75	m	72	100	349	n	3	
0518	85	h	58	60	292	nw	3	
0519	60	h	4	2	1000	nw	3	
0520	80	h	49	40	311	nw	0	stream buffer cell
0521	70	h	100	50	57	ne	0	

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