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THE UNIVERSITY OF ALBERTA

Use of Non-Market Values in Fire Management Decision-Making Processes

by

(C) Sharon A. McKinnon

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

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Abstract

The purpose of this thesis was to develop a methodology for the inclusion of non-market values, such as wildlife and recreation, in forest fire management decision processes. A measure of welfare changes stemming from changes in forest values as a result of fire was required. Boreal forests of Alberta, Saskatchewan and Manitoba were considered where current fire management practices in these provinces concentrate mostly on protection of timber values. Non-market value information is not generally collected in any of the three provinces. Thus, fire management decisions do not reflect total welfare changes resulting from fire.

An extensive literature review was performed to identify methods of calculating non-market values, and to examine approaches to fire damage appraisal. A three phase conceptual model consisting of fire behavior, fire effects and economic evaluation components was developed. A case study was performed to illustrate use of the model. The case study involved wildlife values, specifically moose values for which data were readily available. The fire behavior component primarily involved determination of fireline intensity levels. Information was provided by personnel at the Canadian Forestry Service regarding fire behavior factors. Effects of fire on resource values were derived using fireline intensity information. Derivation of fire effects was complicated by the highly variable nature of both fires and resource values. Alberta Fish and Wildlife Division personnel provided estimates of moose carrying capacities given several fire and forest vegetation scenarios. Biophysical fire effects data were then used in the economic evaluation component. A marginal analysis was used to study changes in resource values with and without fire. Net present values of resources, at several stages following fire, were calculated and the change in value noted. Timber value changes resulting from fire were calculated as a comparison to wildlife value changes.

Results showed that positive value changes for moose occurred due to fire, most notably in aspen and mixedwood forest types. Timber value changes, conversely, were zero or negative indicating detrimental effects of fire on timber value.

Several conclusions were drawn from results of the research. Substantial effects of fire on non-market values are indicated. Neglecting those effects may result in economically inefficient decisions being made regarding forest and fire management.

The conceptual model used in the study was useful for deriving information required on non-market values. More data are needed to derive better estimates of biophysical fire effects on non-market values other than moose and wildlife, and more specific regional data would be useful. Non-market values thus derived can be used in fire management for more efficient decisions regarding fire control.

Dedicated to my parents

In memory of my mother

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I. Introduction

The purpose of this study is to develop a method for the derivation and incorporation of non-market values into a fire management decision framework. Non-market values reflect goods and services for which consumer preferences are not directly observable through marketplace decisions. Essentially a pilot study, this research is concerned with an evaluation of the effects of fire on non-market resources and how these values can be used in the fire management decision process. The need for improvements in evaluation of fire effects has been expressed by fire managers who are faced with limited or decreasing budgets for fire control. Increased public awareness of fire management activities has added further importance to the collection of better fire effects information (Smith, 1985). Despite this recognized need, progress has been limited. This study includes an attempt to identify reasons for deficiencies and to outline a process for evaluating non-market values. An analysis of the process of inquiry is included in this chapter as well as an illustration of problems that have led to the current situation.

A. Problem Identification

Fire managers are faced increasingly with an optimization problem - one of trying to allocate capital and manpower in an economically efficient manner to derive an optimal level of fire control. Generally, fire management objectives are often based on the physical problems of controlling forest fires. Criteria that ignore forest values have often been used in the determination of fire presuppression and suppression activity levels. Objectives such as complete fire exclusion, placement of limits on the maximum size of fires and the 10 o'clock policy (that required the control of a fire by 10 AM) were used. Economic objectives have been adopted fairly widely in Canada and the U.S. following the realization that there are diminishing benefits from increased fire control levels. Despite the fairly common use of economically based fire control objectives, inadequate applications of economic theory to practical optimization solutions, including determination of benefits and costs of fire control, still exist.

Forests in the prairie provinces are largely publicly owned. Over three quarters of the forested land in each province is under provincial crown control. Publicly owned resources could be managed to maximize net social benefits in which case, all resources in a forest must be considered in decisions governing their use. A problem with fire management in the past has been the general exclusion of non-timber resource values from consideration in fire control activities. The full interests of society are not served in terms of economic efficiency (welfare effects) when non-market benefits, which are often substantial, are neglected.

A study by Phillips et al. (1986) involved an intensive survey of forest economics researchers and research users. The study identified existing research activities and defined forest economic research needs. Several areas of research need, namely, economics of forest protection and economics of non-timber forest land uses scored high in order of importance; third and seventh, respectively out of twelve (Table 3 of Phillips et al.) Thus, forest economists recognize inadequacies in the areas of non-market forest valuation and forest protection.

Increasing recreational use of prairie forests and loss of wildlife habitat due to industrial and agricultural expansion have resulted in an increased concern for wildlife. Decision makers and the public in general have begun to realize the importance of wildlife in particular and other non-timber forest resource uses in general. Fire managers are beginning to recognize inadequacies in their view of fire effects appraisal that excludes non-timber resources. The current appraisal process for evaluating forest values affected by fire consists essentially of an estimation of timber production values and possibly, improvement values[1]. Non-market forest resource values are not currently used in the three provinces in pre-fire or post-fire planning processes. Criticisms of current appraisal methods include the following points (Brady, 1978).

1. There are significant deficiencies in "values-at-risk" (values affected by fire) information that is being collected and used for appraisal.
2. Fire effects appraisal does not adequately reflect the true value changes resulting from fire nor as they affect individuals and society.
3. Current appraisal methods do not account for the effects of fire on forest resource uses other than timber.

[1] Improvements are defined as man-made structures or facilities such as buildings, roads and bridges.

An accurate appraisal process is important to fire managers who face a limited budget for fire control and who may need to maximize net benefits from control. Appraisal processes that rely mainly on timber values provide a biased picture of fire effects. Control decisions are not likely to be economically optimal. All fires are usually detrimental to the timber. However, they may provide some benefit to other resources, particularly wildlife. The ecological role of fire in Boreal forests has been largely overlooked. Strict fire control has disrupted fire cycles that are natural to Boreal forests. Fire management theory and its application has been incomplete partly as a result of the restrictive view of fires as completely detrimental. Thus, attempts at finding optimal solutions for fire control have been constrained. This indeterminant situation can, therefore, be described as one of an inadequacy in fire control objectives that have neglected to account for the full economic value of a forest and, in the current appraisal system, that reflects only timber values and excludes potentially valuable non-market resource use values. The desirable situation would be one in which the importance of all forest values were recognized in the fire management process and non-market resource benefits affected by fire were known and quantified.

Fire effects appraisal systems tend to be filled with uncertainty regarding resource value changes that can occur due to fire and the significance of those changes. The exclusion of non-market values from appraisals reveals the lack of methodology for measuring those values that has been adapted and applied to prairie forest conditions. A number of studies have been completed that have attempted to incorporate non-market values as well as timber values in fire appraisals (Althaus and Mills, 1982; Gorte and Gorte, 1979; Marty and Barney, 1981; Mills and Flowers, 1985). However, none have been attempted that relate specifically to the prairie provinces. In addition, the use of objectives for fire control levels that are not based on economic efficiency criteria would appear to indicate a lack of information regarding data needs for such criteria. Concerns may also be raised as to which individuals and groups are affected by the situation and as to how various aspects of the situation affect them. The provincial forest services carry out the appraisal processes for actual and potential resource values at risk and are thus limited by the availability of data and methods for evaluating fire impacts on non-market resources. Even where impacts are known, they are not used in fire management decisions. Agencies that allocate funding for fire control budgets are affected in that they have inadequate information regarding resource values. Therefore, their budget allocations may be less than efficient. Society is affected whenever economic inefficiencies exist and net benefits of fire management that accrue to society are not adequately determined.

A statement summarizing the existing situation can be made as follows. While non-timber forest resource values are beginning to be considered vital to fire management planning processes, there are inadequacies regarding methods for both measuring and incorporating non-market values in planning decisions. Thus the planning processes for fire management tend to be inefficient.

B. Problem Analysis

There are several underlying causes for the omission on non-market values in fire management. One of the most basic of these involves the concept of value, that is, what constitutes value and who assigns value. Forests take on value only in the context that they serve human needs. The value of a forest, therefore, is not intrinsic but is assigned by individuals according to their system of preferences (Brown, 1984). The assignment of value to forests by an individual or group will reflect the perception of the forest and its environment, the held values of the individual or group, and the context of the valuation or circumstances that exist at the time of the valuation. The constituency of the valuation, where the constituency is an individual or group that the valuator is representing, also affects the context. Environmental values are particularly affected by constituency. Widely differing values may be assigned to forest resources by individuals representing conservation groups, industry or government. The "held values" of these groups may be quite different and various value estimates reflect those differences. Forest fire management in provincially-owned forests is publicly controlled. Therefore, one would expect that the constituency being represented by fire managers is society as a whole and not any one interest group or set of groups. Society may not always be considered in situations where interests of the timber industry receive primary attention. Protection of timber values may take precedence over wildlife values where wildlife value changes resulting from fire are uncertain and undefined.

The term "value" has various meanings among economists. Value is most frequently equated with price in a market sense and as such is quantifiable. The marketability of wood products makes price (stumpage price) determination relatively straightforward. As a result, fire disturbance appraisal processes have relied mainly on timber values in evaluations of direct or indirect losses due to burning. Non-timber values have been excluded for a number of reasons including the difficulty in measuring at least some of the values. The market system that provides prices for timber does not adequately measure values related to recreation, wildlife, watershed and soil resources. These resources are not traded in a recognized market, therefore market prices have not been derived. Non-market resources are subject to the same forces of supply and demand as market resources but their values are not commonly expressed as prices. Therefore, in forest management, these values have been largely ignored.

The stochastic nature of fire behavior and effects have contributed to the uncertainty surrounding non-market values. Numerous factors contribute to the way a fire will behave in a given situation. Accounting for all possible inputs makes fire behavior prediction less than straightforward. As well, fire effects are highly variable in terms of type, timing, size etc. and their evaluation for fire control planning purposes is difficult.

Attempts to find an optimal level of fire control so that net benefits are maximized are restricted by gaps in information. What is the relationship between the level of control effort and damage averted or values increased or decreased? If a fire is allowed to burn what will be the net gains or losses to forest resource values. How will the watershed be affected by fire and what happens to recreation values? The time factor is also an unknown,- how far into the future will the forest values be affected as a result of fire? Failure to account for fire benefits as well as damages flags inadequacies in the theory that previously assumed all fires were detrimental and provided for optimization schedules based on this limited view.

The current fire management situation can be described as one in which non-market values that are affected by fire are not currently included in appraisal processes and the exclusion of these values may have biased estimations of the value of a forest that is affected by fire. There are several research objectives recognized in this study. The identification of non-market forest resource values is important. For the purposes of this study, the wildlife component will be stressed in an effort to remain concise, although there are a number of other resources and resource uses that are recognized (Chapter 2). An evaluation of common fire behavior under given sets of circumstances is required to determine fire effects on the resources being studied. Fire effects on wildlife and wildlife habitat need to be evaluated strenuously since the value of those effects will be significantly affected by both extent and variability of the fire induced biophysical effects.

After a detailed analysis of the research problem, the following problem statement can be made.

> *A method is required that allows for the identification and measurement of non-market values affected by fire, and that enables fire managers to include those values in their management decision framework.*

There are considerable data available that are relevant to the study. Extensive research has been carried out on fire modelling that provides information on fire growth, intensity and rate of spread under given sets of conditions, such as: weather, fuel load, topography and other biophysical factors. An examination of fire growth models and the determination of common fire characteristics from the models are key in determining effects of fire on wildlife. One of the stumbling blocks is the lack of data specifically relating to determination of the bridge between fire behavior and fire effects on wildlife. Habitat changes due to fire are the primary causes of wildlife population changes and neither the habitat nor the population reactions are certain. Research on the ecological effects of fire has revealed some habitat related data. Wildlife population effects may be determined indirectly through indexes relating habitat suitability and carrying capacities. Actual population statistics associated with changes in numbers of certain wildlife species due to fire are limited. Data exist for the valuation of selected species of wildlife, especially for big game species. The integration of factual information into a system that determines fire risk and behavior for an area and then allows for measurement of possible changes in resource values due to fire is the ultimate goal. The development of a method to achieve this goal forms the basis of this study. Data collected for this study relies heavily on several government agencies involved in fire control and wildlife management. Where there are data deficiencies, expert opinion is used to represent the state-of-knowledge regarding the information sought. Previous theoretical analyses of forest and fire management processes are relied on for the theoretical background required. A classification and an analysis of the facts are necessary. Part of this study involves the development of a method for finding and incorporating the facts into a useful form.

Method determination is restricted by the need to work within the current fire management system used in the prairie provinces. It is not the purpose of this study to determine efficient suppression or presuppression activity levels for fire control organizations that will minimize losses. It is expected that methods described will be useful within the existing management framework. This study is also not a definitive guide to value appraisal for fire management. In essence, it is a pilot study that attempts only to describe a logical framework for non-market value appraisal and inclusion into fire management processes. Data sources and deficiencies are identified and recommendations for further studies are made. A case study based on a somewhat hypothetical situation is included to illustrate the use and effectiveness of methods developed where actual data may be insufficient for evaluation purposes.

C. Thesis Outline

Chapter two outlines factual material relevant to the problem. An overview of forest and fire management in the prairie provinces is included and the incidence and nature of wildfire in forested areas of these provinces is discussed. A characterization of wildlife activity and use that outlines the importance of wildlife in the prairies is included.

A conceptual analysis which describes the theoretical aspects of non-market valuation for fire control is presented in the third chapter. Sections are included which describe the economics of fire management, the multiple-use characteristics of forests and tradeoff principles involved in these uses, and problems associated with measuring non-market values. As well, the integration of the parts, that is, the determination of linkages or functional relationships between components of the inquiry are included.

In chapter four, methods for characterizing fire effects on wildlife, given the nature of fire and of wildlife, and for determining the associated values of those effects are developed. The methods developed in chapter four are used in chapter five in a case study for illustration purposes. Chapter six contains a summary of the study and evaluates the usefulness and limitations of the research results. Also included are suggestions for further study.

II. Background

This background chapter contains some of the factual information identified in the introduction as necessary for an understanding of the existing situation concerning fire and resource management, the biophysical nature of the resources and their relative values. A section on forest values is included. The complexity of the forest and its multiple use characteristics are emphasized. Forest fire incidence, behavior and effects are dealt with where the stochastic nature of fire, its effects and underlining difficulties in predicting effects are considered. A section is included that describes wildlife in particular. Wildlife was chosen to illustrate the methods used for appraisal. Economic values of timber and wildlife are presented and indications of economically efficient fire management spending limits are given. Current resource evaluation methods used in the prairie provinces by the forest services are outlined. The chapter contains a factual synthesis of that which is known and that which is needed by way of further study. Both are examined in relation to the problem analysis of Chapter I.

A. Forest Values

Values associated with the forest are numerous. Vegetation has value in terms of timber, wildlife habitat, erosion protection, precipitation interception, energy storage, oxygen production and scenic attributes. Wildlife in a forest ecosystem is diverse and includes small and large game animals, furbearers, birds and fish. Watersheds provide value in terms of fish habitat, streamflow and as nutrient sources. Soil is valued for its moisture storage capabilities, as a nutrient source and as a seedbed. Forests provide valuable range used by both wild and domestic animals. Amenity services or recreational uses of a forest constitute part of the forest value.

Resource economists define several kinds of value associated with resources. Use value implies actual use of a resource which can be further divided into consumptive and non-consumptive uses. Consumptive use involves harvesting activities such as timber harvest and wildlife hunting. Non-consumptive use would include activities such as hiking and wildlife photography where a resource is used but not consumed. There are non-use values as well. Option value describes individuals' willingness to pay to retain the option to use a resource sometime in the future. Existence value is associated with knowing that a resource exists regardless of whether or not it is ever used. Another category, often termed bequest or inheritance value, refers to the value associated with the desire to leave resource services to future generations. Consumptive use value is market related since the resources concerned are usually traded in a market situation. Prices can, therefore, be assigned through the market system. There is a non-market component of consumptive value as well that adds to the total willingness to pay for use. Option, existence and bequest values are difficult to quantify although there have been recent attempts to derive those kinds of values (Brookshire et al., 1983).

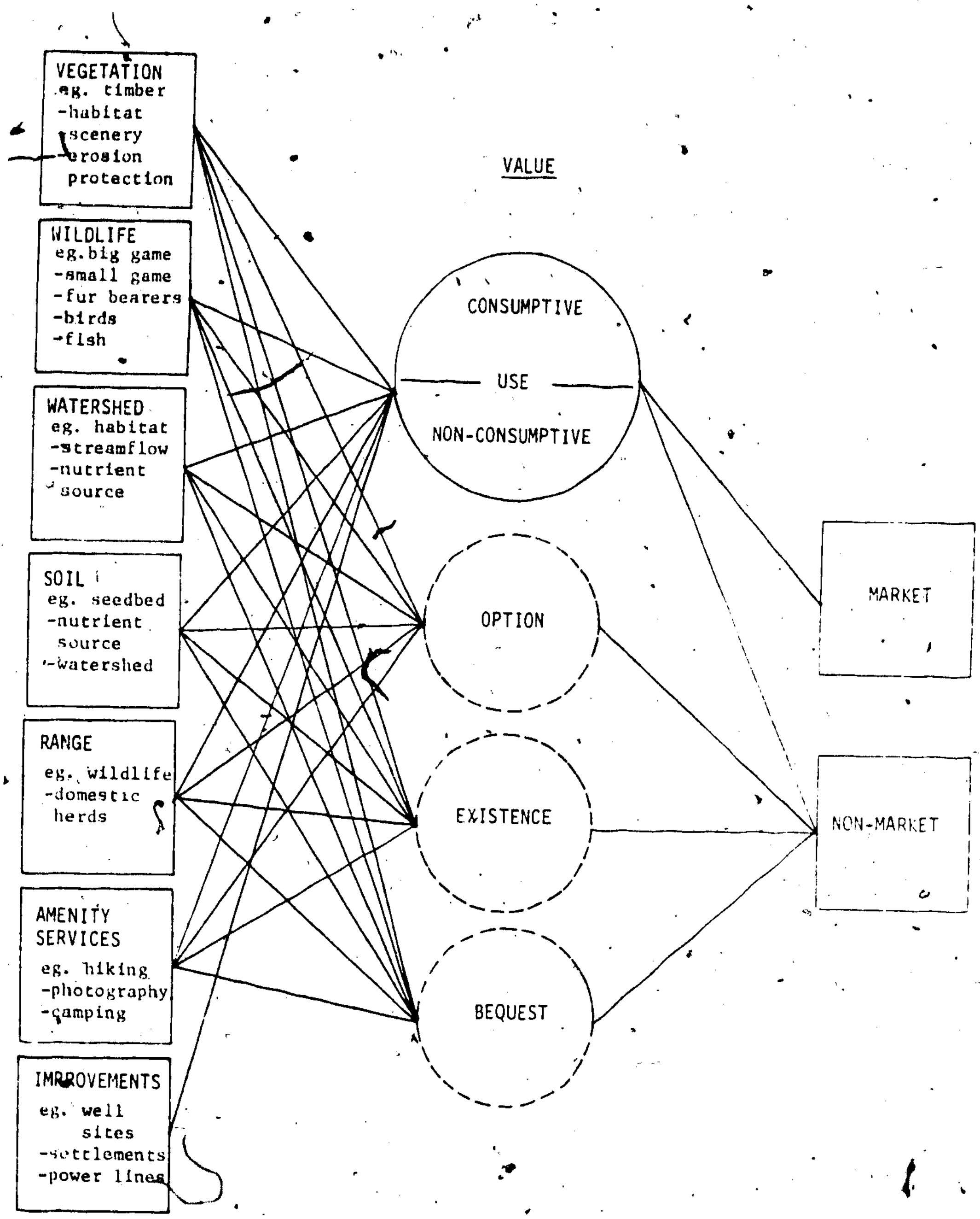
A flow chart, shown in Figure II.1 illustrates the complexity of forest values and interrelationships. Most of the resource categories are closely linked with each other to make up the whole forest system. Studies of a single resource and its use are not complete, therefore, without some consideration of the other resources and their uses. Magnitudes of both physical and economic fire effects on wildlife for example, are determined partially by fire effects on vegetation and recreation uses. Where possible, fire effects on all uses need to be studied to derive a clearer estimation of changes in the economic value of wildlife.

B. Fire Incidence, Nature and Effects

An understanding of the nature of forest fires and their biophysical effects on forest uses and values is necessary as a preliminary step in valuation exercises. This section covers the role of forest fire in the prairies, fire behavior and background material describing fire effects on some of the forest resource uses with particular emphasis on wildlife and vegetation responses to fire.

Forested land comprises nearly half the total land area of the prairie provinces and accounts for 20 percent of the total forested area in Canada. Softwood species, especially spruce and pine, dominate the forests. In Alberta, 69 percent of the total land area is forested with 73 percent of the forests on provincially owned crown land. This area consists of forest lands withdrawn from settlement and managed for multiple uses (forestry, recreation, natural areas, grazing etc.) (Ondro and Williamson, 1982). Saskatchewan has nearly 25 percent of its total land area forested and over 90 percent of the forests are provincially owned and managed (Ondro and Williamson, 1985).

Figure II.1: Forest Values and Their Interrelationships



Sixty-four percent of Manitoba's land area is forested and 93 percent of the forests are owned and managed by the province (Ondro and Williamson, 1984). Boreal forest dominates the forested land in the three provinces. Jackpine (*Pinus banksiana*), lodgepole pine (*P. contorta*), black spruce (*Picea mariana*), white spruce (*P. glauca*) and hardwood species including aspen (*Populus tremuloides*), balsam poplar (*P. balsamifera*) and white birch (*Betula papyrifera*) are the major tree species[2].

Fire has been an integral part of the ecosystem of Boreal forests during the nearly 10,000 years of their existence. A natural fire cycle of 50 to 100 years in the Boreal forest has been determined through ecological research and the forests depend on fire for renewal and regeneration. There is a higher incidence of fire in Boreal forests compared to other forests of Canada (Kelsall, Telfer and Wright, 1977). Table II.1 shows forest fire incidence statistics for the prairies and for Canada averaged over the years 1980 - 1983. Prairie forests account for between one fifth and one third of all fires in Canada during those years while area burned in the prairies amounted to more than half of the total in the more severe fire years of 1980 and 1981. Variability is high in both fire size and intensity; the largest fires (approximately 3 percent) account for over 90 percent of total area burned. This indicates a large number of small, less intense fires.

Fires grow in several ways; by intensity (a measure of energy produced), size and shape. As noted previously, the majority of fires on the prairies are small and of low intensity or low energy. However, the remoteness of much of the forested area precludes suppression of some fires in their initial stages. Hence, large, intense fires result. Conditions of fuel continuity, weather and topography also contribute to size and intensity of fires. Most fires are man-caused although lightning-caused fires account for a greater annual area burned (Pyne, 1980). Lightning fires can occur in remote areas limiting the ability of fire fighters to control the fires quickly whereas man-caused fires tend to occur closer to civilization and nearer to fire control resources.

Fire behavior depends on numerous factors including fuel load and composition, weather, topography and suppression activities. Most fires tend to be roughly elliptical in shape; especially under windy and/or sloped conditions. Fuel composition is

---

[2]Budd's Flora of the Canadian Prairie Provinces (1979) serves as the scientific authority for Latin names of vegetation species.

Table II.1: Forest Fire Incidence in the Prairies and Canada.

	Number of Fires	Area Burned (ha)
MANITOBA	689	256,336
SASK.	685	778,380
ALBERTA	1,221	680,140
PRAIRIES	2,594	1,714,856
CANADA	9,291	3,281,825

Source: Canadian Forestry Service. "Selected Forestry Statistics - Canada, 1984".

heterogenous over a large area and can cause deviations in fire shape and intensity. Unburned islands are common in large burns as a result of the admixture of slow burning fuels such as aspen and more flammable conifers. There has been extensive research on the development of fire models that attempt to predict the occurrence and behavior of wildfire (Rothermal, 1972, 1983 and Alexander et al. 1984).

An overview of biophysical fire effects aids in understanding the manner in which resource values can change due to fire. Fire effects have been well documented and a number of sources have been used for this overview, specifically Ahlgren and Ahlgren (1960), Chandler et al. (1983), Lyon (1978), Lotan (1981), Pyne (1984), Tiedemann (1979), Wells et al. (1978), Kelsall et al. (1977) and Lutz (1953).

The effects of fire on vegetation are highly variable depending on the intensity of the fire, the pre-burn vegetation composition and season of burn. Immediate effects include tree mortality due to complete burning, cambium heating and scorching of foliage and roots. Fire damaged trees are susceptible to disease. The tree species of the Boreal forest have varying degrees of resistance to fire. Spruce, aspen and balsam fir (*Abies balsamifera*) are the least fire resistant species of northern coniferous forests. White pine (*Pinus monticola*) and jackpine have moderate resistance to fire and the thick bark of ponderosa pine (*Pinus ponderosa*) and western larch (*Larix occidentalis*) provides a degree of protection from fire. Lodgepole pine, with its thin bark, is easily damaged by fire. Fire stimulates the production and height growth of suckers in aspen and other hardwood trees and shrubs resulting in rapid regeneration in the years following fire. During the summer when aspen trees are in full leaf, they are difficult to burn; spring and fall burns are more common in aspen than summer burns. In mixed-wood forests, fires often leave islands of unburned aspen within burned out coniferous stands. Older jackpine and lodgepole pine produce serotinous cones that usually require heat to release seeds - regeneration of these species is thought to require the regular presence of fire. Summer fires tend to be hotter and pines are more easily damaged while spring fires may not cause serious damage (Pyne, 1980). Low to medium intensity fires may not affect cones and seed release may be inhibited contributing to a lack of reproduction in older stands. Spruce has a moderate resistance to fire with white and black spruce differing in their seed resistance. White spruce has non-serotinous cones with seeds easily killed by fire. Summer and early fall fires result in good reproduction where seed bearing trees are left standing and cones are undamaged. Spring and early summer fires generally cause more damage to seeds and stand reestablishment is slow. Mature black spruce trees are more easily killed by fire than white spruce. Black spruce are, however, quick to reestablish due to their semi-serotinous cones. Trees produce seeds at an earlier age and more frequently than white spruce so there is a ready seed supply. Less severe burns result in good seedling growth where the cones of the tallest trees are not destroyed by fire.

Succession following fire has been studied extensively. In the Boreal forest, succession is a complicated process since vegetation changes at any site following a disturbance such as fire or logging can follow several pathways. Determination of succession is further complicated by the lack of data on old (300+ years) stands since Boreal forests are disturbance forests and seldom grow as old as 300 years. Long term successional trend data are almost non-existent for frequently disturbed Boreal forests. For these reasons, Boreal forest vegetation is best considered as being at some stage of a cyclical fire climax stand with multi-successional possibilities (Russell et al., 1984). Some general comments may be made on successional trends despite the ambiguities involved. Black spruce most often succeeds black spruce on burned areas due to prolific seed production. On upland areas, white spruce may become the climax species provided there is a seed source. Where aspen occurs in a stand, rapid regeneration is found following fire and especially with frequent fires, aspen dominated forests may replace coniferous forests eventually. Where fires are infrequent (less than 100 years) aspen forests are usually replaced by white spruce. Lodgpole pine and jackpine are considered fire dependent species and tend to be self-perpetuating, regenerating rapidly following fire. On drier, sandier sites the pines often replace stands of other coniferous species in the presence of frequent fires. Shrub species generally grow prolifically following fire. They are fairly susceptible to fire but resprout vigorously from roots and stems. Willow comes in very quickly both vegetatively and from wind disemminated seed. Shrub species common to the Boreal forest such as willow (*Salix sp.*), green alder (*Alnus sp.*), saskatoon (*Amelanchier alnifolia*), highbush cranberry (*Viburnum sp.*), buffaloberry (*Shepherdia canadensis*), blueberry (*Vaccinium sp.*), rose (*Rosa acicularis*), pincherry (*Prunus pensylvanica*), chokecherry (*P. virginiana*) and labrador tea (*Ledum groenlandicum*) reach their maximum biomass production 15-20 years following fire, depending on climatic and moisture conditions, after which production decreases as tree species become dominant. Grasses and forbs invade newly burned sites immediately and gradually give way to woody plants. A general pattern of succession outlined by Thomas (1979) consists of six developmental stages in revegetation. These are the grass-forb stage immediately following fire; the shrub-seedling stage from 0-10 years consisting of both annuals and seedlings of tree and shrub species; the pole-sapling stage from 11-39 years; young forests 40-79 years; mature forests 80-159 years; and old growth over 160 years. Not all plant communities experience the full range of stages. The 80-120 year fire cycle common in the Boreal forest restarts the successional process before old growth forests develop. More frequent fires also result in consistently young forests and in some areas the grass-forb stage may be perpetuated.

The effects of fire on animals vary with the species. Vertebrates are rarely killed outright in large numbers and large animals including moose, caribou and furbearers generally move calmly away from a fire although mortality in the larger species is not uncommon. Fish and stream fauna may be adversely affected by the increase in water temperatures and increased sediment load from soil runoff. Secondary effects of fire on wildlife are related to the often severe changes in vegetation following fire. There may be a temporary or more permanent displacement of species such as grizzly bear (*Ursus arctos*), caribou (*Rangifer tarandus caribou*), martin (*Martes sp.*) and spruce grouse (*Canachites canadensis*) which are dependent on mature forests. Other game animals are reported to increase following fire. Moose (*Alces sp.*), deer (*Odocoileus hemionus*), elk (*Cervus canadensis*), black bear (*Ursus americanus*), beaver (*Castor canadensis*) and some game birds prefer the more diverse vegetation of a recently burned forest. Prime ungulate habitat is created by fire 10-15 years following a burn when hardwood browse species are at their maximum production. After about 15 years the trees and shrubs are generally too tall for the animals to reach and benefits from the fire decrease. While the carrying capacity for some species may increase substantially in a burned forest, there is no certainty that animal populations will increase proportionally. Diversity of habitat appears to be of primary importance with food and cover areas of mature forest interspersed.

Fire effects on water are largely a result of vegetation losses that contribute to erosion. Increased streamflow may result from the loss of precipitation-intercepting vegetation. Soil shows varying effects from fire depending largely on fire intensity. Intense fires may cause some degree of impermeability of the soil surface however those effects are usually temporary. The release of nutrients bound in the organic matter can be beneficial to regrowing vegetation and often new vegetation contains more nutrients for wildlife.

Recreation is affected by fire largely through the degeneration of scenic quality. Hikers and sightseers generally prefer more mature forests and tend to avoid burned over areas. Timber is adversely affected by fire where valuable stands may be destroyed by intense fire. Low to moderately intense fires may not completely destroy the trees. Rangeland may benefit from fire where grasses and forbs are encouraged and woody plants are controlled.

C. Wildlife Characteristics

Wildlife has been selected specifically to demonstrate the valuation methods. Hence, some background on wildlife is presented. Wildlife of the Boreal forest is diverse and includes big game animals (e.g. moose, elk, deer, caribou, black and grizzly bears), furbearers (e.g. marten and ermine (*Mustela sp.*)), birds (e.g. partridge (*Perdix sp.*), pheasant (*Phasianus colchicus*) and songbirds), and fish species (eg. trout (*Percopsis sp.*)). Biological data regarding species' responses to wildfire are sparse for many species. However, data do exist for selected species. Caribou, grizzly bear and furbearers prefer older forests and fire destroys their habitat displacing them for years depending on the size and intensity of the fire. Moose, deer, elk and Black bear benefit from the more diverse habitat created by fire. Their populations have been reported to increase following fire. Population dynamics are complicated and factors besides habitat affect population growth or decline. Disease, predation, hunting pressure and habitual use of an area as well as food affect population.Therefore, predicting population change based solely on improved or degenerated habitat is likely to be inaccurate. Habitat carrying capacity can be estimated, however, such that the prediction of potential populations is more straightforward than prediction of actual populations.

Habitat consists basically of two components, food and shelter. Animals require both within their range. Ungulates generally require cover of mature forests of at least 200 m wide to be effective. Forest areas cleared through burning or clearcutting are utilized by wildlife mainly around the edges in close proximity to cover. Large fires often leave unburned islands that can be used for cover. Therefore, fire size is not always a major factor in determining wildlife use changes. Winter browse is generally the limiting food factor for ungulates and height of browse and snow depth affect the availability of the browse.

Moose are often used to study population fluctuations due to fire. In a study by Telfer (1978), elk and deer distributions were not found to be well-correlated with browse production while moose distribution did appear to be well-correlated and so were easiest to study. Some estimated moose population density figures illustrate the variation that can arise. Gasaway and Dubois (1983) found low moose densities of 0.1-0.2 moose/km² in mature or climax forests with low browse potential. The authors found that under favorable conditions (e.g. improved habitat), the moose population could double in 3-4 years. Nietfeld et al. (1985) reported mean densities of moose in the parkland region of Alberta of 1.25 moose/km²; in the mixedwood region of 1.10 moose/km² and in the foothills region of 1.31 moose/km². A habitat assessment of an area in B.C. (Fuhr, 1983) showed moose potential carrying capacities from 0 to 6.0 moose/km²/year with densities of up to 7.6-9.0 moose/km²/year on a productive floodplain.

Hunting activity is the main measurable portion of wildlife use value, especially for big game. Hunting and trapping are regulated by fish and game authorities in the prairie provinces. For example, Alberta has had big game license sales of around 300,000 annually for the past five years indicating a large demand for hunting. Hunting pressure has been increasing over the last two decades (Adamowicz, 1983). Wildlife habitat is constantly threatened by agricultural and forestry demands on the land putting wildlife populations at risk. With increasing demands for wildlife as part of recreational pursuits, wildlife needs require greater consideration than ever. Fire is a tool that can be used to improve habitat for selected species. Timber values are, however, negatively affected by fire. In the following section, economic values and expenditures on fire management, timber and wildlife resources are discussed. The various demands on the forest are put into perspective and the importance of both timber and wildlife resource uses are outlined.

D. Economic Perspective

Forest fire control costs in the prairie provinces are high reflecting a high incidence of fire in Boreal forests and beliefs that high values are at risk and that all fires are damaging and require control. Table II.2 shows average fire control expenditures in the prairies, both budgeted and actual for 1980 to 1983. An average of forty-five percent of the total expenditures for fire control in Canada originated from the prairie provinces during those four years. Presuppression expenditures are tending to become greater than direct suppression costs due to an effective presuppression preparedness system. Such a system, for example, was introduced by the Alberta Forest Service in 1983. Costs of forest protection in Alberta in 1984 were $41 million

Table II.2: Fire Control Expenditures for the Prairies and Canada (1980 - 1983)

	Budgeted Costs ($ 000)	Fire Control Costs ($ 000)
MANITOBA	5,248	6,373
SASK.	2,663	13,286
ALBERTA	20,447	40,324
PRAIRIES	28,358	59,984
CANADA	106,989	133,157

Source: Canadian Forestry Service. "Selected Forestry Statistics - Canada, 1984".

with less than $8 million direct suppression costs (Alberta Energy and Natural Resources Annual Report, 1985). Forest protection, of which fire protection is the main part, constituted 25 percent of total management costs in Canada in 1981 indicating the relatively large part fire management plays in forest management activities.

A comparison between timber resource and wildlife values illustrates the relative values of both. Table II.3 shows timber values based on stumpage value estimates and harvest volumes for 1981 in 1981 dollars. The stumpage or conversion return estimate was derived from Table IX.I in Phillips, et al. (1985). The value of $7.50/m³ was the medium revenue (price) level and the medium cost level at a 100 km haul distance [3]. Harvest volumes were derived from Canadian Forestry Service Information Reports for Alberta, Manitoba and Saskatchewan respectively (Ondro and Williamson, 1982, 1984, 1985). Timber values for the three provinces totalled $93,194,669 in 1981. Wildlife economic benefits are shown in Table II.4 and were derived from Filion, Jacquemot and

[3] Phillips et al. (1985) considered only a small area of Alberta in deriving stumpage values. Personnel in the Timber Management Branch of Forestry, Lands and Wildlife use considerably lower stumpage values than Phillips et al. but Branch personnel indicated that actual values may be somewhat higher than $7.50/m³. Chapter V discusses stumpage in more detail.

Table II.3: Timber Values for 1981

	Harvest Volumes (m^3)	Stumpage Value ($ / m^3)	Total Value ($)	Prairie Total ($)
ALBERTA	7,356,172	7.45	54,803,480	
SASK.	2,816,249	7.45	20,981,057	93,194,669
MANITOBA	2,336,931	7.45	17,410,132	

Source: Volume figures from Ondro and Williamson (1982, 1984, 1985)

Stumpage value from Phillips et al. (1986)

Table II.4: Wildlife Related Recreation Benefits for 1981

	Direct Benefits ($ 000,000)	Prairie Total ($ 000,000)
ALBERTA	114	
SASK.	38	195
MANITOBA	43	

Source: Compiled from Filion, Jacquemot and Reid (1985).

Reid (1985). A value of $ 195,000,000 in non-market economic benefits alone (direct benefits as determined by participants) of residential wildlife-related recreational activities was determined for the Prairie provinces. License fees, constituting a market portion of total willingness-to-pay for participation, add considerably to benefits. Both timber and wildlife values are substantial indicating their importance to the provinces.

E. Current Resource Evaluation Procedures

Appraisal methods for forest resources in the prairie provinces are less precise than desired, especially for non-timber resources. In Alberta, for example, post-fire resource appraisal consists of forest inventory cover map uses with overlays of the fire areas. A volume per area figure is calculated for timber and value lost is determined by multiplying volume figures by current stumpage values for the particular forest cover type. There is no formal evaluation of non-timber resources by fire managers due both to a lack of understanding on their part of evaluation methods and a lack of site specific data for those resources. Prediction of value changes due to potential fires is also not considered for non-timber resource uses. The Alberta Forest Service uses four priority zones to guide fire control activities. Zone 1 areas surround population centres and are high priority zones in terms of fire control activities. Priority Zone 2 consists of the south and western forested areas of the province which contain major recreation and watershed values as well as merchantable timber-producing areas. Most of the commercial timber-producing areas of the northern part of the province are included in Zone 3. Zone 4 consists primarily of low-value timber management areas as well as grazing areas and these are found mainly in the north and east-central regions of Alberta. There are no stated quantitative resource values associated with the priority zones. While recreation values, for example, are recognized in Zone 3 areas, those values are not quantified. In general, Alberta's fire control policy is one of protection of all forested areas at least at a minimal level (Murphy, 1985). Saskatchewan is divided into three zones for fire control purposes. The Intensive Protection Zone consists of an area of commercial forestry operations. Three districts make up the zone, located in a belt across the middle third of the province. There are 15.6 million ha. in the zone. The Secondary Protection Zone consists of all land north of the Intensive Protection Zone and is alternately termed The Northern Reconnaissance Zone. While there is some potential for timber production, the zone does not currently contain commercial operations. No fire detection system is used in the zone which comprises 19.7 million ha. The Non-protected Zone in the southern third of the province consists of agricultural land in which there is no provincial forest fire protection. Protection of human life, public and private property, commercial forest land, and non-commercial forest land in that order, are the priorities for fire control. In Manitoba, the forested area is divided into the protected area of 24.9 million ha. and the non-protected area of 40.2 million ha. The protected area consists of two forest zones, 2 and 3, located in the centre of the province. These areas receive vigorous fire control measures. North of Zones 2 and 3, the non-protected area consists of Zone 1 and all areas north and east of Zone 1. The region is considered inaccessible and beyond the economic margin for fire control purposes. Agricultural land in the southern part of Manitoba is not protected (Murphy, 1980). For the most part, only timber values are considered and no non-timber values are used in determining fire control responses in the three provinces.

Information provided in this chapter has outlined the importance of both timber and non-timber values in Alberta, Saskatchewan and Manitoba. At the same time, the emphasis placed on timber value by fire protection policies in the three provinces and the general lack of consideration for non-timber values is evident. Some theoretical concepts underlying forest values and fire management are presented in Chapter III.

III. Conceptual Analysis

The measurement of public welfare change that results from fire management decisions is basic to this study. Welfare changes are reflected in changes to resource values from which individuals derive benefit. In this conceptual analysis, measures of welfare in the context of forest management, and the problems involved with measuring non-market benefits, are examined. Production theory is discussed along with how the theoretical concepts fit with fire management economics. As well, the intertemporal nature of forests and their uses are considered. Ultimately, the conceptual analysis seeks to provide the theoretical background that will illustrate the need for measurements of welfare changes resulting from fire. How those measurements are incorporated within production and optimization techniques in a forest fire management framework is considered.

A. Willingness To Pay Measures

Public policy decisions such as those made in forest and fire management processes affect consumer welfare. The measurement of changes in consumer welfare levels is not as straightforward as measures of producer welfare or performance. Parameters such as profit are observable measures of producer welfare - there is no comparable measure of consumer welfare since utility is not measurable. An alternative, therefore, to measuring utility or consumer preferences is the amount of money an individual is willing to pay to move between levels of consumption. Willingness to pay (WTP) has become central to applied welfare economics as a reflection of utility. Marshall (1930) was instrumental in the derivation of money measures of welfare gain and considered consumer surplus - the area under the demand curve and above the price line - to be representative of "true" WTP on the part of the consumer beyond what he is required to pay. Consumer surplus (CS) has been criticized as a measure of consumer welfare because the assumptions that assure that CS is a good approximation of true surplus are restrictive (Just, Hueth and Schmitz, 1984) and not supported by empirical evidence. Hicks (1943) considered alternative measures of consumer gain or loss, namely compensating variation (CV) and equivalent variation (EV) that more closely represented WTP. Compensating variation is the amount of income which must be taken away from the consumer after a price and/or income change in order to restore the consumer's original welfare level. Equivalent variation is the amount of income that must be given to a consumer in lieu of price and/or income changes to leave the consumer as well off as if there actually had been changes. Compensating variation, therefore, measures gains or losses to the consumer associated with making a change from the original level of consumption whereas EV is associated with not making the change. Technically, CV measures WTP for a change while EV measures willingness to accept compensation (WTAC) for not making a change. In the case of fire control, demand can be revealed through the consumers WTP to move from one level of control to another or WTAC for not changing the level. Both CV and EV are associated with Hicksian compensated demand curves that account for income effects while CS is derived from Marshallian or ordinary demand curves. For zero income effects, the ordinary and compensated demand curves coincide and the three values are the same. A zero income effect is unlikely to occur in the real world and the restrictive assumptions associated with CS therefore make CV and EV estimates preferable although the difficulty of estimating compensated demand curves is recognized. Assuming relatively small income effects, EV and CV and their proxies, WTP and WTAC, are used in empirical work. The two measures should be similar however empirical studies show WTAC estimates to be higher than WTP estimates. Often, estimates of both WTP and WTAC are given (Just, Hueth and Schmitz, 1982). Equivalent variation and CV estimates are more accurate measures of the CS portion of total WTP however there is considerable difficulty involved with determining those estimates due to data deficiencies and problems with measuring the Hicks compensated demand curve. WTP estimates in the literature therefore are likely to be measures of CS from Marshallian demand curves (Sinden and Worrell, 1979; Just, Hueth and Schmitz, 1982).

Some note needs to be made as well on the controversy surrounding the appropriateness of CS since it does not represent money that has actually been exchanged for the resource. Loomis, Peterson and Sorg (1984) assert that for non-market resource uses such as recreation, CS is a tangible economic benefit and represents consumers WTP despite the fact that government does not attempt to collect the full WTP for the resource use. The authors further discuss the issue of expenditures versus total value of resources. Often, expenditure information is used to determine value of a resource and this is useful in some kinds of economic analyses. The use of only expenditure information in the determination of total value of non-market resource uses especially results in an underestimation of that value since expenditures are only a portion of what the consumer would be willing to pay to use that resource.

The usefulness of WTP measures lies in the fact that WTP includes both market revenue and CS portions of the total value of a resource. Therefore, for measuring the value of fire control and alternatively the value of the resources protected by fire control, both market and non-market resource values can be estimated using a single valuation measurement. This is important for comparing benefits derived from both market and non-market portions of the system. WTP estimates of market based resource values such as timber are reflected in the market through prices. For non-market resources, existing price information is inadequate and misrepresents value of those resources. WTP estimates must be derived by other methods. There are three methods commonly used for non-market benefit estimation. These are the travel cost method, the hedonic price technique and the contingent valuation method. The use of these methods and assumptions underlying their use are discussed in Chapter IV. Estimates of WTP are thus required as inputs into the analysis process involving production of fire protection.

B. Production Theory and Fire Management Economics

The production function represents an input-output relationship that describes the transformation of resources into products. Output is seen as a function of a set of inputs or factors of production as follows:

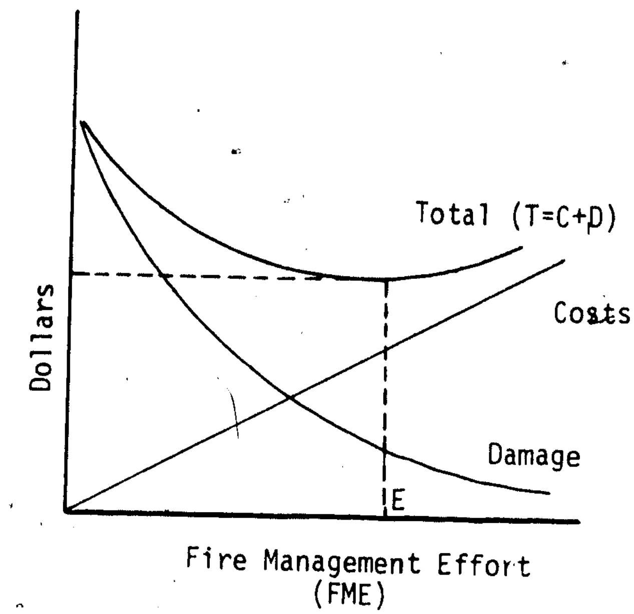
$$y = f(x_1, x_2, x_3, \ldots, x_n)$$

The theory of production is concerned with an analysis of how the producer combines the inputs in an economically efficient manner. More specifically, the producer seeks to use inputs or resources to the point where the marginal factor cost of each input equals the marginal value product, where the cost of the last input unit of production equals the value of the last unit of product being produced. A thorough knowledge of input and output prices and respective marginal productivities are therefore necessary for efficient resource allocation.

Fire managers, as producers of fire protection, face a problem of optimization - determining the most efficient allocation of scarce budget and manpower resources to achieve management objectives. Those objectives have evolved over the years from physical goals of minimizing the area burned to the more recently accepted economic goals of minimizing fire suppression costs and damages resulting from burning. The least-cost-plus-loss theory of fire control was developed by Sparhawk (1925) and continues to be a reference for many fire management policies. Its basic form is presented in Figure III.1. In theory, as fire management costs increase linearly, damage decreases at a decreasing rate. Total expenditures (T) are the sum of costs (C) and damages (D). The optimum level of fire management effort occurs at the minimum of the total (T) where marginal cost equals marginal damage. Fire management effort is measured in several ways. These include suppression and presuppression expenditures, acres burned, and attack time. The diagram remains essentially the same regardless of the effort parameter used. The ambiguity involved with effort measurement is a serious flaw in the use of the LCPL concept. Other deficiencies in the concept concerned the implied relationship between damage and cost that is not adequately explained through production theory. The assumption that fire behavior, size and severity can be influenced by the amount of effort applied is inaccurate. Despite the obvious inadequacies associated with the LCPL theory, it has remained basic to fire economic theory. There have been numerous revisions and additions to the theory and its usefulness has improved considerably.

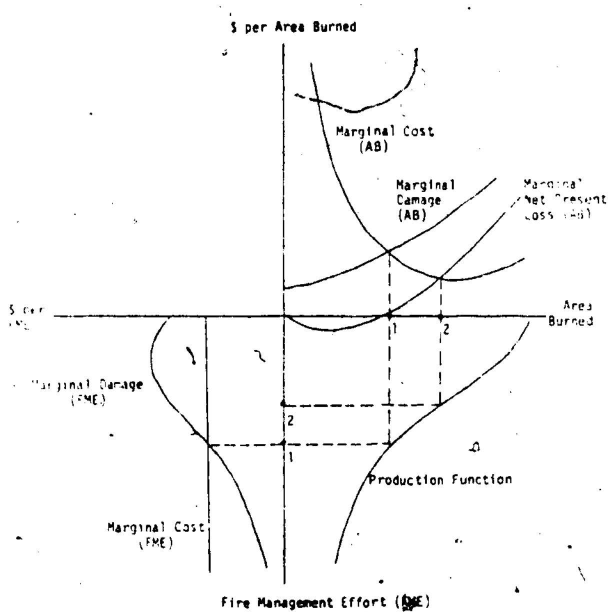
A conceptual view of the economic theory of fire management is illustrated in Figure III.2. Relationships between area burned, fire management effort and dollars spent are explained in the diagram, adapted from Simard (1976) and Gamache (1969), that can be used to derive optimal levels of fire control. Each quadrant is considered as it contributes to the whole theory.

Figure III.1: The Least-Cost-Plus-Loss Theory



Source: Adapted from Simard (1976).

Figure III.2: The Derivation of Optimum Levels of Fire Management Effort and Area Burned



Source Adapted from Simard (1976).

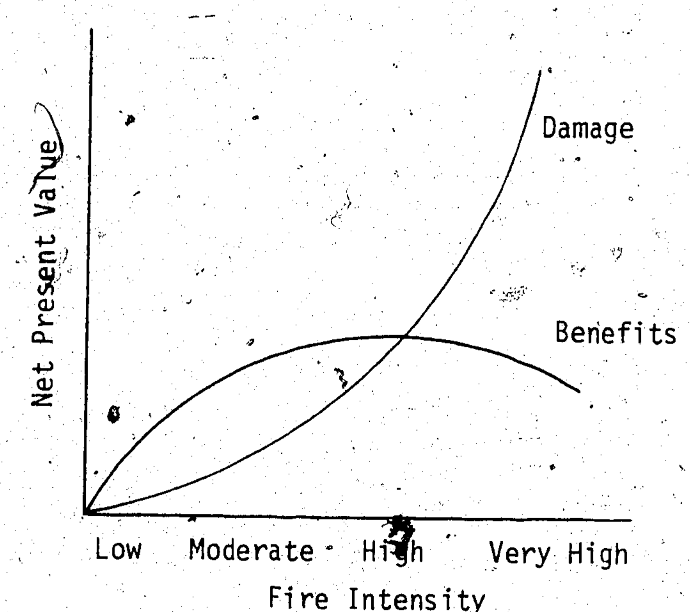
The production function in quadrant III was an important development in applications of the theory as it helped to explain the relationship between costs and damage. The function specifically relates fire management effort (input) to area burned (output) as follows:

Area Burned = f(Fire Management Effort)

Initially, increases in fire management effort result in greater than proportional returns to scale to reduce area burned. Decreasing returns to scale become evident at greater effort levels as fire control resources remain unused for longer periods of time. The function differs from the traditional form of a production function in that output or area burned is actually the inverse of production. Output may alternately be thought of as reduction of area burned in a more traditional form of the function. Other authors (e.g., Davis, 1965; Gamache, 1969) have succeeded in incorporating production theory into the field of fire economics.

Costs of fire management increase linearly with the level of effort. Theoretically, one would expect the function to curve downward slightly at greater effort levels as cost savings were realized. The effect on the total cost function, however, would be minor. Damages increase exponentially in dollar terms as the area burned increases. Empirical observations have shown that large fires tend to be more intense thus causing more damage than many small fires in comparable areas. The extreme variability of wildfire, however, lends a degree of uncertainty to the nature of damages incurred so that while this form of damage function is generally acceptable, it may not be entirely applicable in many instances (Chandler et al., 1983; Kelsall et al., 1977). A damage function of this form carries the assumption that all fires result in a loss of value and fail to account for possible benefits due to fire. Simard (1976) splits the damage function into damages and benefits, introducing the benefit function into fire management theory in recognition of both beneficial and detrimental effects of fire. As with damages, benefits vary considerably with fire intensity. Figure III.3 illustrates the hypothetical relationship between benefits, damages and fire intensity. At low fire intensities, damage may be minimal and there may be positive benefits resulting from the fire. As fire

Figure III.3: A Schematic Relationship Between Damage, Benefits and Fire Intensity



Source: Adapted from Simard (1976) and Noste and Davis (1975).

intensity increases, benefits may reach a maximum and begin to decrease while damages may increase significantly.

Several characteristics affect the evaluation of damage. Degree of substitutability between recreation sites, for example, will have an effect on perceived damages due to fire. Consumers are assumed to maximize their utility from a recreation visit. A consumer is indifferent between two recreation sites of similar characteristics and chooses only to be on the highest indifference curve within his budget. When a recreation site is burned and there are no equal substitutes, users move to a lower indifference curve. Travel costs to a new site may be higher or the level of satisfaction gained from using the same site may be lower. Uniqueness of the area is, therefore, significant (Crosby, 1977). Substitutability and the marginal rate of substitution (MRS - defined as the amount of one good that must be substituted to compensate for the loss of another good) would be very low and there would be a high opportunity cost involved in substitution of that unique experience. Fire characteristics influence the substitutability of resource uses. Large fires can greatly reduce the MRS causing recreation users to travel longer distances and incur higher costs. The availability of substitutes is therefore a characteristic that needs to be considered in evaluation of damage.

Damage is dynamic and can eventually be reduced to zero given sufficient time. For example, vegetation will regrow on a recreation site over time. Damage can also be zero or negative if a superior site results from the fire as in the case of an improvement in wildlife habitat. A net present value (NPV) formulation for damage should therefore be utilized so as to account for the flow of benefits from a forest, and changes in fire-induced damage over time.

A risk premium is the amount a user facing risk is willing to pay to reduce that risk. Presuppression activities fall into this category and are the responsibility of forest managers. Users face little direct risk from fire although from a social standpoint, fire risk is substantial. The risk premium is relatively unimportant to the public owner of forests and resource goods and services. Losses to fires represent minor percentages of the total area owned so payment of risk premiums above the expected value of the loss is unlikely.

Total net benefit is defined as the difference between benefits and damages where the difference is greater than zero, i.e. it is the cumulative net present value resulting from fire. Ideally, the optimum size and intensity at which a fire should be controlled would be where total net benefit is at a maximum. In other words, the optimal level of fire control would be at the point where marginal damages equal marginal benefits. Practically, the application of the concepts may be difficult. Identification of the point of maximum positive net benefits may not be possible or may be only crudely identifiable. Fires cannot be controlled at precisely the optimum point. Recent acceptance of these concepts is not obvious but is manifested in the emergence of controlled burn policies that acknowledge beneficial fire effects.

Fire management can thus be summarized as a production process comprised of three functions:

1. The cost function - money spent on aquisition of factors of production
2. The production function - employment of factors of production to produce output
3. The damage function - the generation of economic returns from output

Redefining the damage function to include benefits is a significant advancement in the theory of fire economics. The overall economic theory that combines the cost, production and damage and benefits functions can now be considered. The damage and benefit functions are combined into a single net present loss (NPL) function defined as the present value of marginal losses minus marginal benefits. The term is analogous to net present value (NPV); loss is used only because a positive NPL is desired when losses exceed benefits. In this analysis, changes in net benefits as area burned and fire management effort change are considered, therefore, marginal functions are most useful. Referring to Figure III.2, marginal damage and marginal cost of fire management effort and area burned are illustrated with the production function relating the two parameters. Quadrant I shows marginal cost (MC) and marginal damage (MD) functions for area burned. Quadrant III illustrates MC and MD functions for fire management effort. As area burned increases, marginal costs decrease then increase at higher levels of area burned. The upward sloping marginal damage function indicates exponentially increasing damages as area burned increases. Total costs of fire management effort are assumed to be linear as effort increases giving a constant marginal cost function as indicated in Quadrant III. The shape of the marginal damage function indicates that at low levels of fire management effort, total damage increases at a decreasing rate. Beyond some moderate level of effort, damage begins to decrease at a decreasing rate. Thus, at low effort levels, there is an increasing return to prevention of damage as the level of effort increases while at higher effort levels, decreasing returns to damage prevention are indicated. At the point where marginal cost equals marginal damage, optimal area burned and optimal effort level are reached as indicated by point 1 on the two axes.

Use of marginal net present loss (MNPL) rather than marginal damage results in a different optimum. Assuming some level of benefit, however small, from every fire, MNPL will always be less than MD. Determining an optimum based on equating MC, MD and area burned will result in a lower area burned and higher effort level than the optimum based on MC, MNPL and area burned. By incorporating benefits from wildland fire into the economic theory, the optimum solution is achieved with a greater area burned and lower management effort.

These findings fit more closely to current thinking on economic efficiency analysis in fire management where net value change as opposed to only loss from fire is considered. Althaus and Mills (1982), Mills and Flowers (1985), Gorte and Gorte (1981) and Mills and Bratten (1980) all use the net value change concept in the determination of economic fire effects. This discussion of theoretical concepts underlying fire management processes illustrates the need for valid willingness-to-pay estimates of net benefits of forest fire. The theory indicates linkages between components but does not provide the means with which those components are measured. This is accomplished through the welfare concepts discussed earlier regarding willingness to pay for benefits of fire control.

C. Optimization Over Time

Underlying the previous discussions is the fact that the forest resource uses being considered are mostly non-market therefore valuing them is not simple. Part of the valuation process involves determining the flow of benefits over time rather than the static value of those resource uses. Many factors affect the flow of use from a forest including fire. Even the most destructive fire does not stop the flow completely. It only delays portions of the benefits. Therefore, a study of fire and its effects on forest values must be intertemporal.

The background chapter provided some insight into the dynamic nature of the forest and the variations in degree and kinds of benefits the forest provides at different stages. The difficult task of determining the optimum level of fire control to maximize benefits and minimize damage is further complicated by the changing benefits over time. A fire may decrease benefits from all resources in the first years and then benefits from various uses may peak at different time periods as the forest recovers from a fire. The optimization process therefore involves a study of changes in benefits at different stages. Choice of the time frame to consider depends specifically on the resource use. Timber values peak roughly at eighty years and decline as the trees overmature and succumb to disease or insects. Wildlife values vary; furbearers prefer more mature forests and following fire, their values may be low for many years and peak again as the forest matures. Ungulate values are likely to be higher in recently burned forests with better food supplies. Recreationists usually prefer older forests. A period of sixty to a hundred years therefore may well be a suitable time frame in which to study the flow of benefits and damages in a forest as a result of fire.

Benefits and costs of fire control may be realized at different times in the future so some method must be used to weigh the benefits and costs from different time periods in terms of a common base. The net present value or discounted value accomplishes this by discounting future benefits and costs to the present. Choice of a discount rate is simple for market resources such as timber and inputs into fire control for private feasibility studies; the market interest rate is used. For "public goods" kinds of resources the market interest rate is unsuitable. Publicly managed forest resource uses are intended to provide benefits to society. If one considers the future welfare of society to be of value and in need of protection, then use of a market interest rate would be unsuitable since future benefits would be valued at zero or near zero. The social discount rate used for public goods is lower than a market interest rate. However, the choice of discount rate is subjective. Consumption at some point in the future, as opposed to the present, is "weighted" according to the rate of social time preference. There is no concensus on what constitutes an appropriate weighting of consumption in time. Discount rates used in the literature have ranged from zero, placing future consumption ahead of present consumption, up to a rate reflecting the opportunity cost of capital, illustrating the controversy surrounding social discounting (Fisher and Krutilla, 1975; Harou, 1985). Social discount rates preferred by economists for publicly owned resources range from 5 to 7 percent [4]. A sensitivity analysis using several discount rates is preferable in order to evaluate variability in net present values as a function of discount rate.

D. Summary

This chapter presented production and optimization theory in relation to fire management and explored willingness to pay measures for non-market values as well as intertemporal concerns relating to forest uses. The optimization process involves a marginal analysis approach that explores changes in inputs and outputs of fire control activities. The theory serves to emphasize the need for accurate input information on the kinds of costs and benefits that result from fire control and points out the problems involved in deriving that information from an imperfect market. There are other bodies of theory that could be applied to this study, particularly wildlife management and valuation and outdoor recreation demand theory that has received much attention in recent years. A more intensive study would require greater consideration of some of these concepts than is provided with the methodology of this study. The next step involves development of methods by which non-market benefit evaluation techniques can be incorporated into fire management processes.

[4]Alberta government studies commonly use a rate of 5 percent in real terms as in the Alberta Land Base Study (unpublished at this time) and an Alberta Environment study on Drainage. Federal Treasury Board Guidelines suggest the calculation of present values based on a range of discount rates including 5 percent (Fraser, 1985).

IV. Methods

This chapter details methods used to derive and incorporate non-market values into fire planning systems. A review of the literature concerning resource appraisal methods is included in the first section. The second section introduces a three part methodology including flow charts for collecting and analyzing biophysical and economic data to derive the desired values. The third section contains a discussion on uses of the methods and values and the presentation of those values in a practical form for end users of the information.

A. Current Appraisal Methods

Resource value appraisal methods have been discussed by several authors. Brady (1978) proposed a National Standard Appraisal Guide that consists of a series of questions designed to determine a qualitative appraisal of fire effects. The problem with the guide is that it is fairly subjective; fire effects are given ratings that may range from, for example, a very positive effect to a very negative effect and there are no quantitative values available. Crosby (1977) developed a guide to the appraisal of wildfire damages and benefits that uses a ratings scale of various classes for most resources considered. Values are assigned primarily on the basis of expenditure on the resource i.e., costs of restoration of a watershed or erosion repair, expenditures on hunting and costs per day per person for participating in a recreation activity. There is some consideration of willingness-to-pay determination for recreation. Pre-fire and post-fire situations are considered in order to compare changes in willingness-to-pay values. Several authors including Althaus and Mills (1982) and Marty and Barney (1981) use Resources Planning Act (RPA) values in their appraisal systems. The Resources Planning Act program in the U.S. provides periodically updated resource values that are average willingness-to-pay estimates derived from the results of past studies and adjusted to a common base. No equivalent values exist for Canada. Therefore, other methods must be utilized to derive desired values. Gorte and Baumgartner (1983) use available expenditure data to derive wildlife and recreation values. Criticisms of the expenditure approach were outlined in Chapter three and concern the fact that the total value of the resource is not reflected in expenditure formulations. Therefore, these expenditure approaches are not acceptable. Noste and Davis (1975) discussed some of the limitations of fire damage appraisal systems.They cited reasons for the lack of a universally accepted system as uncertainty in damages to values and problems with acceptance of appraisal systems by fire managers.

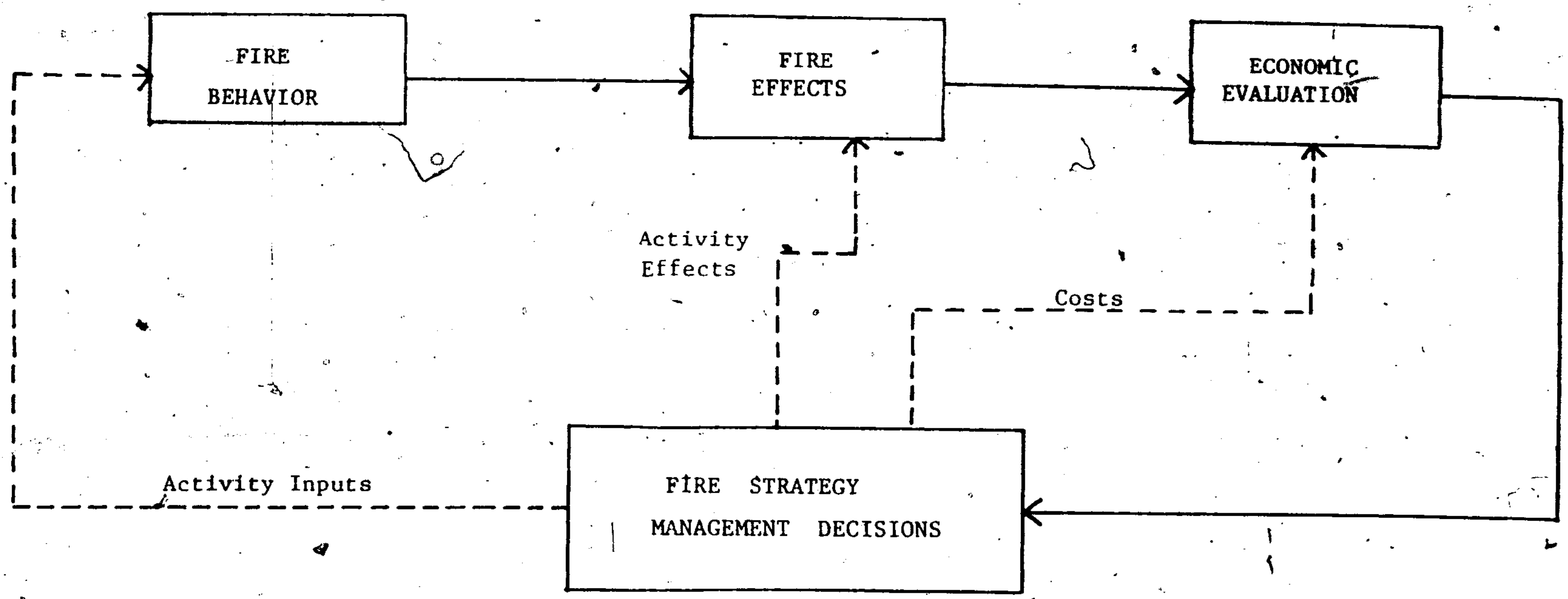
Although there have been attempts to develop a useful appraisal system for forest resources, there are problems associated with adapting the methods to Canadian conditions. There are no equivalent RPA values in Canada and some of the methods noted are not sufficiently vigorous for the information required. The next section outlines the methods determined for this study to derive biophysical fire effects and subsequent economic values.

B. The Conceptual Model

The basic form of the conceptual model developed here is not new. For example, see Egging, Barney and Thompson (1980). Figure IV.1 illustrates the basic model with its three components or subsystems; fire behavior, fire effects and economic evaluation. As well, fire strategy management decisions that include fire presuppression, suppression and fire use (prescribed burning) activities are included in the model. The fire behavior subsystem provides information on the nature of the fire; fire intensity, rate of spread and other outputs aid fire managers in strategy decisions. Fire effects depend partially on behavioral characteristics of a fire. The economic evaluation of resource values that are affected by fire requires biophysical fire effects data. Fire fighting activities influence the three subsystems. Although this study does not deal specifically with fire suppression activities, their place within the fire management framework is illustrated in Figure IV.1.

The economic evaluation method used in this study is based on work by Mills (1980) and others, and uses the cost plus net value chahge (C + NVC) criterion introduced in Chapter III. Resource values are required for cases of with and without fire to derive net value change figures. The simple model in Figure IV.1 is modified slightly to include a section on fire effects and economic values for both cases. In this section, the three subsystems are developed separately and the model progressively expanded to include data requirements and sources, and methods of deriving the

Figure IV.1: Conceptual Model for Fire Strategy Management Decisions



outputs of each subsystem. The final outcome is a detailed conceptual model that outlines the derivation of resource values affected by fire and how those values fit into fire management decision processes.

C. Fire Behavior Subsystem

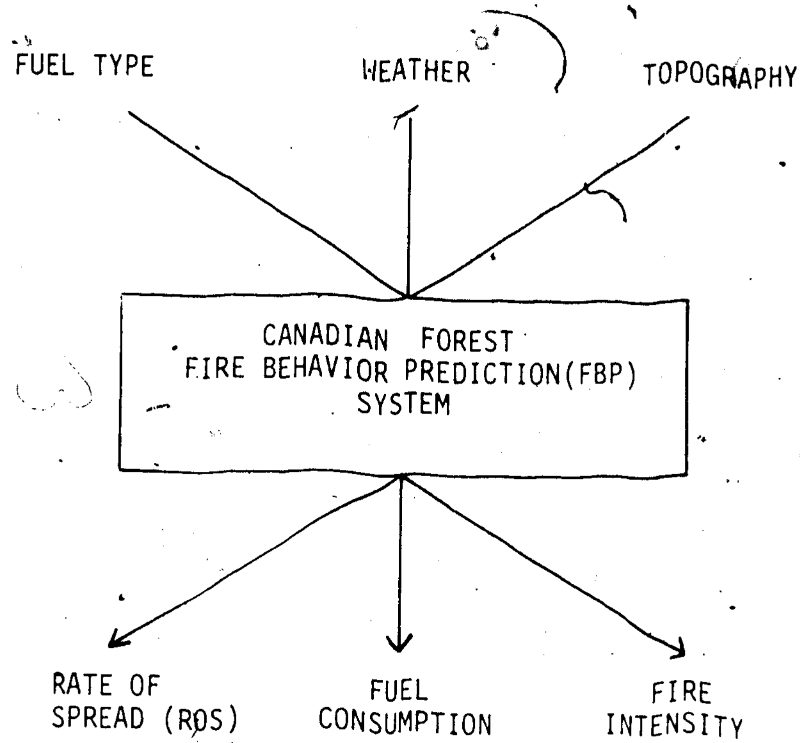
The determination of fire behavior, although not an exact science, has at least developed to the point where fire behavior can be predicted with some degree of accuracy. Based on years of observations of actual fires and laboratory experiments, models have been developed for behavior prediction. A mathematical model to predict fire spread developed by Rothermal (1972) became the standard for fire prediction. Further research and refinement of techniques since 1972 has made fire modelling highly sophisticated. The models have high data requirements with inputs on weather, fuels and topography. All inputs can vary within a particular forest and fire situation and inputs can vary over the life of a fire. This variability complicates the predictive power of the models. Experienced fire managers can, however, derive valuable data from the models. Output data include information on rate of spread and fireline intensity (Rothermal, 1983). These fire behavior forecasts are site specific taking into account local variations in topography, fuels and weather. Fire danger ratings are estimates of burning conditions over a large area accounting for generalized topography and fuel types (Chandler et al., 1983). The development of fire behavior prediction systems are discussed in detail in Chandler et al. (1983). In brief, Canada developed the Fire Weather Index (FWI) system of numerical ratings for relative fire potential and regional Fire Behavior Indexes (FBI) of actual fire behavior in specific fuel types which together were used to represent fire intensity potential in the fire danger rating system. It has since been replaced by the Fire Behavior Prediction (FBP) system. Fire behavior forecasts are made based on several rules of thumb that affect behavior including changes in fuel loading, fuel moisture, wind speed and direction, and slope (Chandler et al., 1983). In areas with fuel types representative of those in the fire danger rating system, behavior forecasts are best made based on indexes from the danger rating system that can predict rates of spread and intensity.

While the FBP system is still under development, its generalized structure is shown in Figure IV.2. There are three inputs, fuels, weather and topography, and three primary outputs, rate of spread, fuel consumption and fire intensity. Although the purpose of the system is to provide data for fire control purposes, the intensity information is of particular interest in this study as fire intensity largely influences fire effects. On the input side, fuel types are of interest in determining fire effects. Fuel types have been divided into fourteen discrete classes that are organized into five major groups; coniferous, deciduous, mixedwood, slash and open. A summary description of fuel types is found in Appendix A. Currently, only the rate of spread component of the three outputs is completed. The other two components are under development and the intensity component is partially completed.

As noted previously, intensity and size are the two components of fire behavior of interest in this study. The fire intensity component consists of two parts; a chart to determine intensity ranks and a table explaining the ranks. Inputs used on the chart to derive intensities are rate of spread (ROS) and initial spread index (ISI). These components require a detailed set of inputs. The procedure for deriving ROS and ISI figures is outlined in the FBP user guide (Alexander et al., 1984). In its present form, subject to revision, there will be a customized chart for each of the fourteen fuel types. Intensity charts and tables have been completed for several of the fuel types - a sample provided in Appendix B shows the upland jackpine fuel type. The chart provides a straightforward method for deriving and portraying fire intensity with intensities ranked from 1 to 6. Ranks 5 and 6 (greater than 4000kW/m) exceed the intensity necessary to completely destroy forest vegetation and most other forest resources. Therefore, those two ranks may not be of much use in this study. Intensity ranks are, thus, derivable from the charts and/or tables given the pertinent fire information.

A modified table developed by M. Alexander at the Canadian Forestry Service gives a description of general fire impacts on the forest vegetation for the jackpine fuel type for each fire intensity rank (Appendix C). Coupled with information from the literature on fire damage to vegetation and other resources, initial fire effects can be derived. Similar charts for the other fuel types and for other resources can be developed using various literature sources.

Figure IV.2: The Canadian Forest Fire Behavior Prediction System



Source: Adapted from Alexander et al., 1984.

The primary output from the fire behavior sub-system is fire intensity. Other fire characteristics such as fire size and season of burn are modifiers used for fire effects determination. The FBP system coupled with the intensity rank tables will provide a predictive capability useful for planning purposes. Specifically, fire managers will be able to predict the intensity of a fire in a particular fuel type and derive fire effects information from the predictions. Intensity data are not yet available for all of the fuel types. Hence, use of the system is limited at this time. Once the data are available, the fire behavior sub-system will be useful.

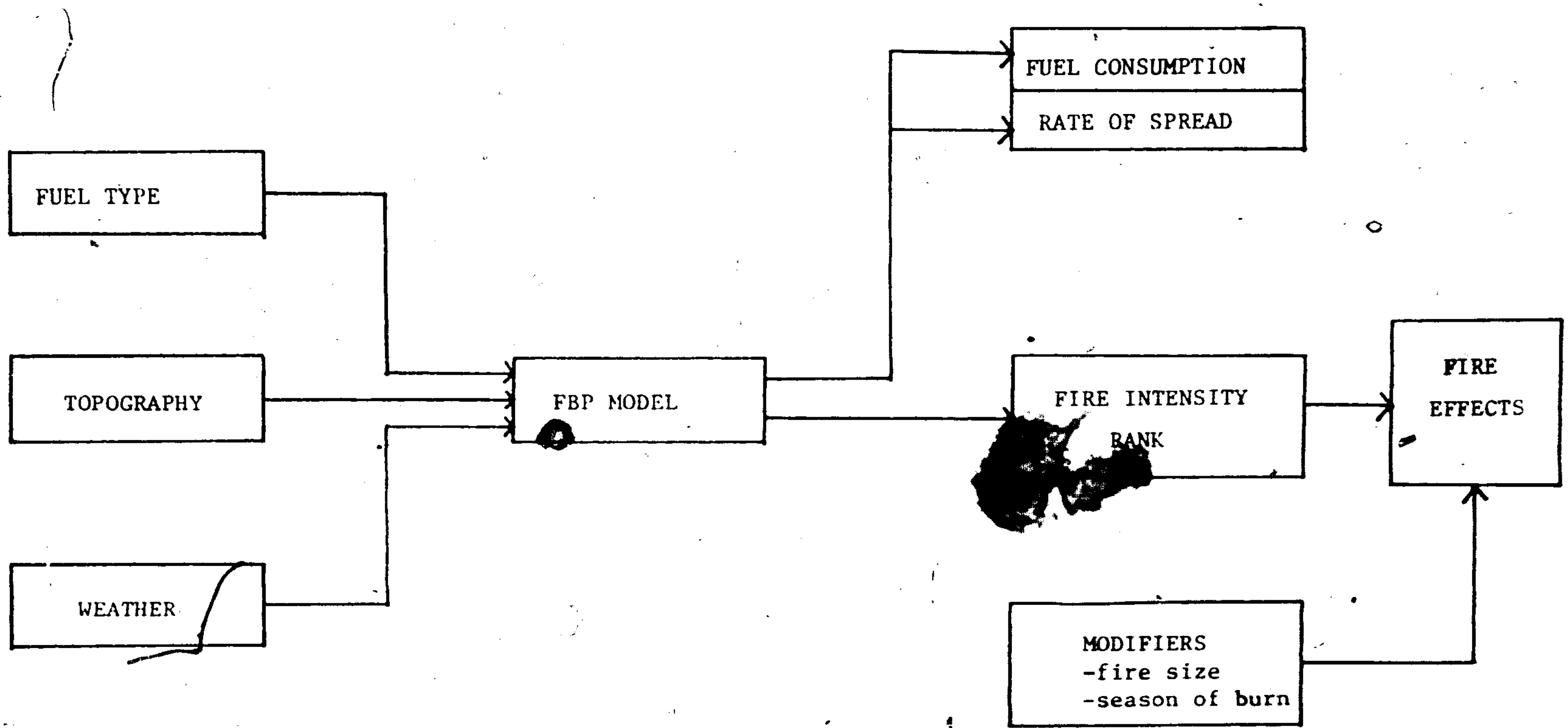
The fire behavior component of the simple model presented earlier can now be expanded to include the inputs and outputs developed in this section. Figure IV.3 shows the expanded model. Fuel type, topography and weather variables are used in the FBP model as inputs. Outputs include fuel consumption, rate of spread and fire intensity. Intensity output is then used with modifiers as input into the fire effects sub-system.

D. Fire Effects Subsystem

Linkages between fire behavior and fire effects are difficult to establish. An attempt is nevertheless made here to provide a conceptual model of the methods by which fire effects information can be derived. A short review of data sources and kinds of outputs available for several forest resources is provided followed by a general conceptual model. Wildlife is considered in detail and a more specific conceptual model for wildlife is derived.

Fire effects on the biological and physical properties of soil are generally considered temporary (Wells et al., 1978). Field and laboratory experiments can be performed to determine both the output of soil as it is affected by fire and the output of soil in the absence of fire. Soil erosion can be measured through field experiments to give a fairly accurate estimate of fire effects on soil. Field experiments can similarly be used for water to determine changes in quality and quantity of water due to burning. For recreation, effects of fire are determined through studies of recreation site use involving surveys to derive individual preferences. A common method uses photographs depicting recreation sites before and after fire. Individuals are then asked to rate their preferences for sites. Production of forage provided by forest range resources is

Figure IV.3: Fire Behavior Subsystem

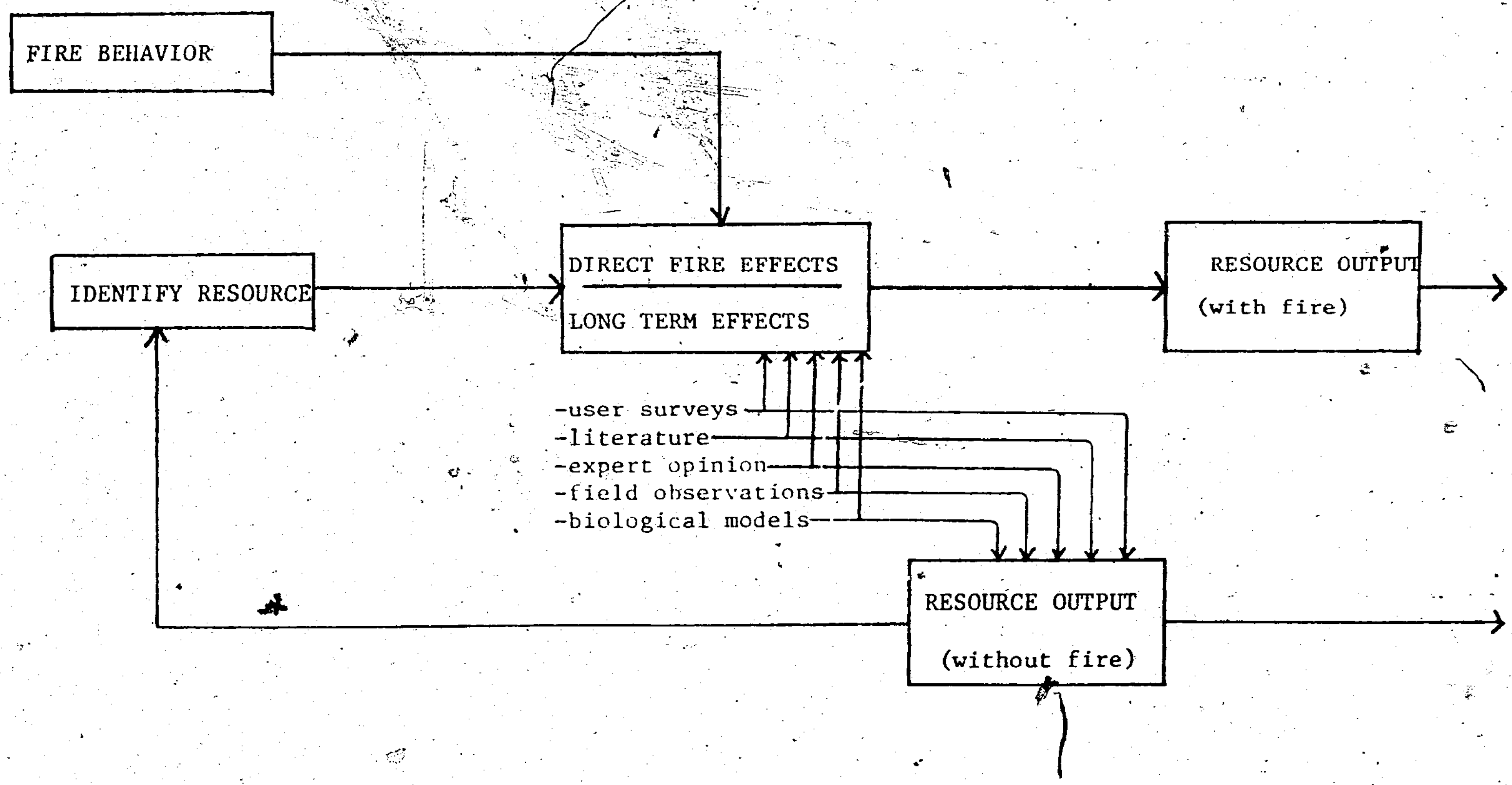


measurable using standard clip plot procedures that determine forage production by weight and species composition. Timber production figures are available and fire effects can be calculated in terms of complete loss of timber and/or salvageability of partially burned trees where fires are less intense. The flow chart in Figure IV.4 outlines general procedures for determining fire effects on forest resources. Primary effects are determined for each of the fire intensity types. Long-term or secondary responses are then determined using available information from literature sources, expert opinion, field observations and biophysical models. Resource output with fire is compared to output without fire that is derived using the same data sources. The production figures are then used in the economic evaluation subsystem.

Consumptive value of wildlife can be derived from hunting data. Therefore, fire effects on hunting need to be determined. Two approaches can be taken. The biological approach uses assumptions regarding linkages between hunting value and animal populations. For example, as populations change due to fire or some other factor, hunting value will similarly change. The problem then remains to identify population responses to fire. A method suggested by Mills and Flowers (1985) conversely uses recreational values (hunting values) determined for with and without fire situations through hunter surveys. The authors contend that the biological variables are too great to be able to infer population responses to fire. For most areas, however, and at least for the prairie provinces, no hunting or recreational data are available for comparison of actual hunting responses to burns. Therefore, a biological approach, involving the determination of population responses to burning, is needed for deriving fire effects on wildlife.

Wildlife populations are closely linked to vegetation or habitat factors. Therefore, the two are jointly discussed. The following series of steps describes a process for determining wildlife population responses to fire. Sources of information and data needs are identified and gaps in the body of knowledge surrounding fire effects are noted.

Figure IV.4: Fire Effects Conceptual Model



1. Determination of habitat effects of fire:
    a. Identification of fuel type/habitat type;
    b. Determination of primary effects of fire (Use of literature on susceptibility of vegetation species to fire intensity using intensity ranks from fire behavior subsystem);
    c. Determination of secondary fire effects (Use of literature on suckering, seed release, disease etc.);
    d. Description of succession possibilities.
2. Determination of species response to habitat change:
    a. Identification of species requirements for food and shelter;
    b. Determination of carrying capacities over successional time span in without fire situations;
    c. Determination of carrying capacities over successional time span in with fire situations.

O

The identification of fuel or habitat type is relatively straightforward. Fuel types described in the FBP system can be used initially to identify the habitat. A more elaborate description of vegetation using forest cover maps, air photos, previous studies, and ground observations of an area provides a more detailed base on which to build successional scenarios. Determination of direct fire effects can be derived from the literature and from field studies of burns. Fire behavior variables from the behavior subsystem are used as an aid in determining direct fire effects. Secondary fire effects are not completely predictable although effects can be determined in a general manner. Reliance on both previous studies and on expert opinion from plant and fire ecologists are required. A description of a likely successional process within each fuel type is formed by considering fire behavior variables, especially fire intensity, for with and without fire cases. The successional processes may be verified by ecologists again to ensure that the processes are reasonable. There has been research on the development of models that attempt to predict vegetation changes over time in the presence or absence of disturbance. A greater degree of accuracy may be possible with the models in terms of more quantitative measurements of vegetation response. Data requirements are high for such models and the data are not always available, thus limiting the use of the models for some areas.

Information is available regarding wildlife requirements for food and shelter. An Alberta Energy and Natural Resources publication on wildlife habitat requirements (Nietfeld et al., 1985) for example, provides a detailed summary of requirements for selected wildlife species in Alberta. The local nature of the report increases its value for this study. Data are probably indicative of requirements for these wildlife species in Saskatchewan and Manitoba as well.

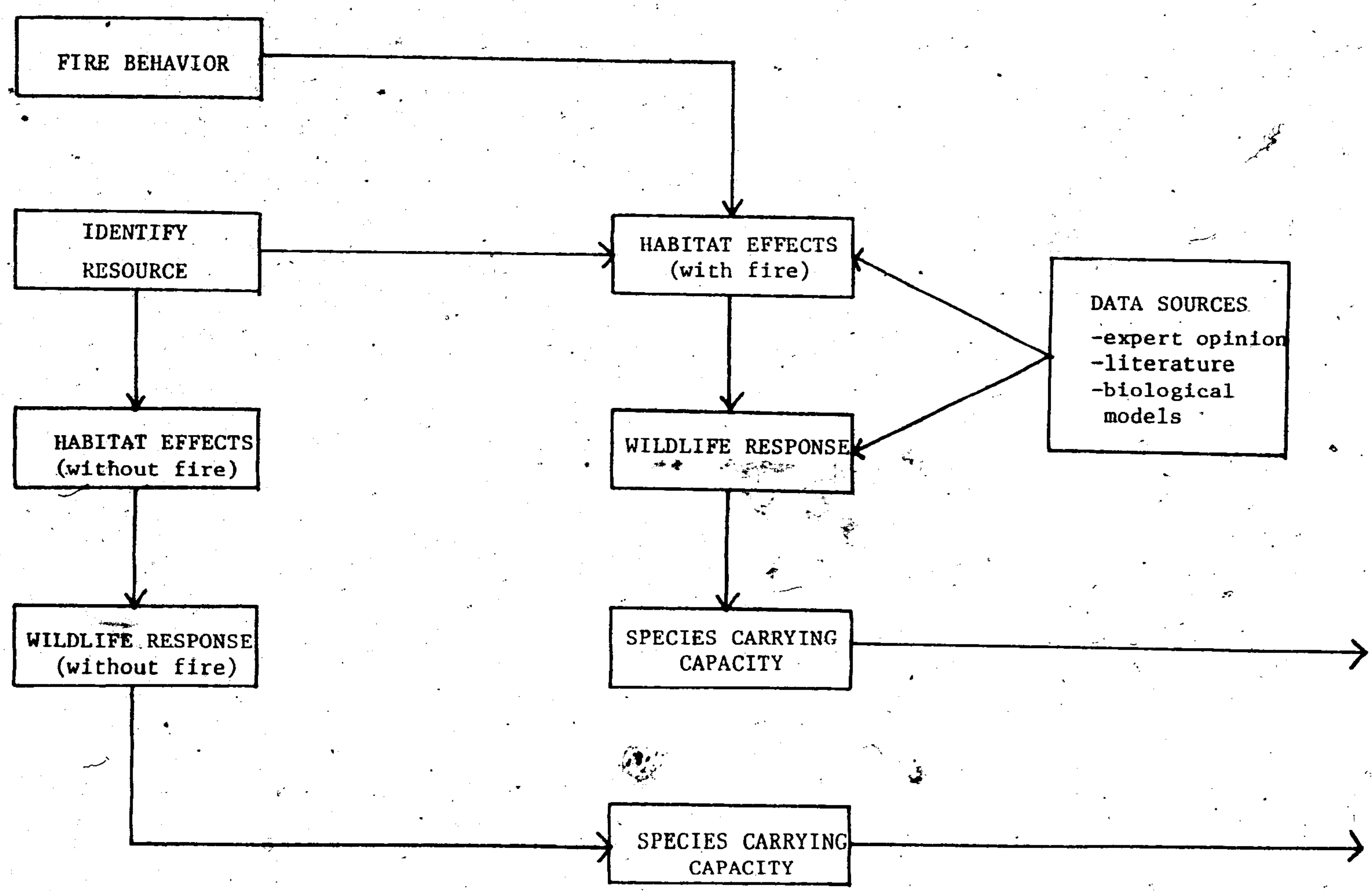
Carrying capacity is used frequently as a measure of population potential and as a substitute for actual population estimates. Carrying capacity describes the ability of a habitat to support a particular population of wildlife species. It does not reflect an actual population which may be greater or lesser than carrying capacity due to non-habitat factors such as disease, predation and hunting. As noted in Chapter II, many variables act on actual populations including availability of food and shelter, age distribution of the existing population and access to alternative habitat. Carrying capacity is therefore the preferred measure of wildlife effects. The carrying capacity numbers generated constitute the biological data or resource output required for use in the economic evaluation subsystem. Figure IV.5 outlines the specific fire effects model for wildlife. The resource outputs are carrying capacities with and without fire.

E. Economic Evaluation Subsystem

The economic evaluation of biophysical output data from the fire effects subsystem constitutes the third portion of the study. Included in this section are a description of methods used for determining non-market values, net present value and value change calculations, and an expansion of the conceptual model to include the economic evaluation subsystem.

An extensive review of valuation methods for unpriced benefits and costs is found in Sinden and Worrell (1979). The authors review the methods in terms of data requirements and policy decisions for which the derived values are used. While most of the methods are not suitable for the kind of information required in this study, three

Figure IV.5: Conceptual Model for Fire Effects on Wildlife



methods do stand out and are commonly employed in non-market valuation procedures. These are the contingent valuation method, the travel cost method and the hedonic price technique.

Contingent Valuation Method

The contingent valuation method, also called the direct or survey method, was developed in the early 1960's by Davis (1964) to derive willingness to pay values for big game hunting. The method involves asking individuals what they would be willing to pay (WTP) over and above their actual expenses for participating in recreational hunting. Conversely, they may be asked their willingness to accept compensation (WTAC) for not using the resource. A hypothetical market situation is established and a survey is carried out, usually through mail questionnaires, in which participants are asked to indicate the monetary value they place on the recreational experience. Demand curves are developed using regression analysis of survey responses to WTP questions and other socioeconomic variables. Davis used the following form in his studies

WTP = f(income, experience, length of stay).

Hammock and Brown (1974) used an extended form of the model

WTP = f(income, experience, expenses, bag rate, days).

Other researchers (Cocheba and Langford, 1978; Dwyer, Kelley and Bowes, 1977; and Bishop, Heberlein and Kealy, 1983) have used the technique to derive not only WTP estimates but also the marginal value of a recreation day and the marginal value of an animal bagged. Sinden and Worrell discuss several different forms of questioning within the one method including the single direct question and various trade-off games (bidding games) among others to elicit WTP estimates. The accuracy of the WTP measures derived will depend on the types of questions asked and care must be taken in the development of the questions.

There are several assumptions associated with the method. Consumers are assumed to be familiar with the situation (ie. the value of hunting or wildlife for example) and able to actually value a hunting experience to get true WTP estimates. An assumption is also made that a survey can determine this information. These assumptions may not always hold true. There are technical biases associated with this method as discussed in Sinden and Worrell. Hypothetical bias is a concern. Since the questions asked relate to a hypothetical issue, the participants may not consider the issue important and may under or overstate WTP or WTAC. Strategic bias may enter into the responses when the participant perceives that his answer may affect future costs of the recreation activity and he may bias his answers downward. In other cases, since the participant knows that he won't actually have to spend the money, he may overstate values for the activity. These and other biases are valid although their relative importance in a survey varies with the researcher.

Concerns regarding biases in contingent valuation techniques are being addressed to a greater extent in recent research. A study by Bishop et al. (1984) compared hypothetical WTP and willingness to sell estimates and actual cash offers for deer hunting permits. Although there were differences found in the values obtained, the authors attributed them to hypothetical bias and considered the estimates obtained through the contingent valuation method to be reasonable and valid.

There is also some controversy concerning WTP and WTAC estimates. Although economic theory suggests that these two values are measures of consumer surplus and should be similar (Just, Hueth and Schmitz, 1982), actual studies reveal much greater estimates of WTAC than of WTP (Adamowicz and Phillips, 1983). The reasons for this discrepancy have not been adequately resolved and more research is needed in the area.

Several advantages to the technique include the ease of administration of surveys, the ability to determine benefits of non site-specific resources, the ability to distinguish between types of values - consumptive and non-consumptive, option and existence values, and the ability to separate the wildlife component from the value of the total experience (Adamowicz and Phillips, 1983).

Travel Cost Method

The travel cost model was first introduced by Hotelling (1949) and was further refined by Clawson (1959) and Clawson and Knetsch (1966). The method uses an inferential approach to non-market benefit valuation commonly applied to recreation site valuation that involves observations of actual market transactions associated with the recreation activity. That is, the method uses costs incurred travelling to the recreation site that are then used to infer value of recreation days or trips (Adamowicz and Phillips, 1983; Dwyer, Kelly and Bowes, 1976). The basic premise of the technique is that the number of visits made to a site is influenced by the distance travelled and thus by the costs of visiting. Visiting costs are then used as a proxy for the price of the recreation experience. A demand schedule for the site can be determined from cost data with quantity of activity per unit time as a function of travel cost and other explanatory variables such as income and age. Willingness to pay for the recreation activity in terms of travel costs is the area under the demand curve. Although widely used, the method has many restricting assumptions. Travel costs are site specific and for multipurpose trips, there are difficulties in separating activities for valuation purposes. Utility derived from travel itself is not considered, site quality characteristics are assumed to be constant throughout the study area and users from all zones are assumed to consume the same amount of recreation at a given cost. Attempts have been made to overcome some of these limitations. Incorporating the value of time into travel cost models reduces bias to some extent, although deriving a value for time is not straightforward. Several researchers have dealt with the value of time in the travel cost model and with some of the other biases noted in order to improve the model (Haspel and Johnson, 1982; Cesario, 1976; Mendelsohn and Brown, 1983). Site quality variability and substitutability between sites are specifically discussed in several advanced travel cost methods proposed by Mendelsohn and Brown (1983).

Hedonic Price Method

The hedonic price technique was developed within the last decade and is similar to the travel cost method in that it involves using recreation expenditure data to derive demand curves for recreation activity (McConnell, 1979; Freeman, 1979). The theory behind the model assumes that a good such as hunting activity can be broken down into a number of characteristics that make up the activity including days spent, harvest or bag rate and travel miles and that these characteristics can be valued. The hedonic price function is of the following form:

Expenditure = f(days, harvest,...).

Expenditure is the total spent on the activity with the independent variables, days and harvest, as inputs into the activity. The implicit price of each input is derived by differentiating the function with respect to each input (Adamowicz, 1983). The implicit prices are then used in a demand function for the activity as follows:

Days = f(price of days, price of harvest, income, experience.)

Determining the change in expenditure on hunting for a change in hunting days or bag rate gives the value of an additional day of hunting or an additional animal bagged. There are limitations associated with this method that restrict its use. The expenditure function must be non-linear, otherwise implicit prices are implied to be constant and the demand curve cannot be derived. The incorporation of time presents some difficulties since time spent can yield utility or disutility. The choice of functional form for the demand equation is important as it affects values obtained for marginal days of hunting (Adamowicz and Phillips, 1983). Despite these limitations the method provides a valuable tool for benefit estimation.

An extension of the hedonic method for estimating extra-market benefits involves using a household production function approach. The approach forms the basis for hedonic price estimates however general household production theory allows for the consideration of special problems in recreation activities ie. the value of time and the congestion factor. Although not specifically used in the derivation of WTP values for wildlife in Adamowicz (1983), the author's study includes a detailed account of the approach.

Present Value Calculations

Chapter three presented the rationale behind intertemporal analyses of the flow of costs and benefits from forest resource uses. The following equation gives the net present value formulation for a time stream of costs C_0, C_1, C_2,.... and benefits B_0, B_1, B_2,...,:

$$NPV = B_0 - C_0 + \frac{B_1 - C_1}{1+r} + \frac{B_2 - C_2}{(1+r)^2} + \ldots$$

where r is the discount rate. A social discount rate is appropriate for public goods and non-market resource values and is lower than the market interest rate. Real as opposed to nominal social discount rates are appropriate where costs and benefits are evaluated in real terms removing inflationary effects. Regardless of the use of real or nominal discount rates, a sensitivity analysis using a range of rates is necessary to determine the effects of discount rates on values obtained.

The net present value formulation is the appropriate method for evaluating policies or projects. Costs of fire control, including prescribed fire, are recognized as being vital to the overall fire management process. Comparison of net benefits of suppression with associated costs helps derive optimum control levels. Costs are not specifically derived in this study since the study is concerned primarily with benefits, either positive or negative, of fire. Present value calculations take the following form:

$$PV = \Sigma B_n \, / \, (1+r)^n$$

assuming r is the real rate of discount and B_n represents benefits in the future. Using this formula, a series of present values of benefits can be derived that reflect the discount rates used and time periods considered. These present values are then used in net value change calculations.

Computation of fire-induced net value change of resource outputs is relatively straightforward. The general formula is presented here as:

$$NPV = PV_1 - PV_2$$

where NPV = net present value; PV_1 = present value without fire and PV_2 = present value with fire[5]. In situations in which per unit value of the resource output is not affected by fire, the NVC formulation can be described by the formula

$$NVC = PV(Q_1 - Q_2)$$

where Q_1 is the without fire resource output level, Q_2 is the with fire output level and PV is the per unit present value of the output. Wildlife per unit values are assumed not to change with fire since fire does not alter the value of an animal. Therefore, this second NVC formula is appropriate.

As a comparison with wildlife values derived, timber values are calculated as they are affected by fire. Values for timber are derived from market indicators; that is from prices paid in the market for timber.

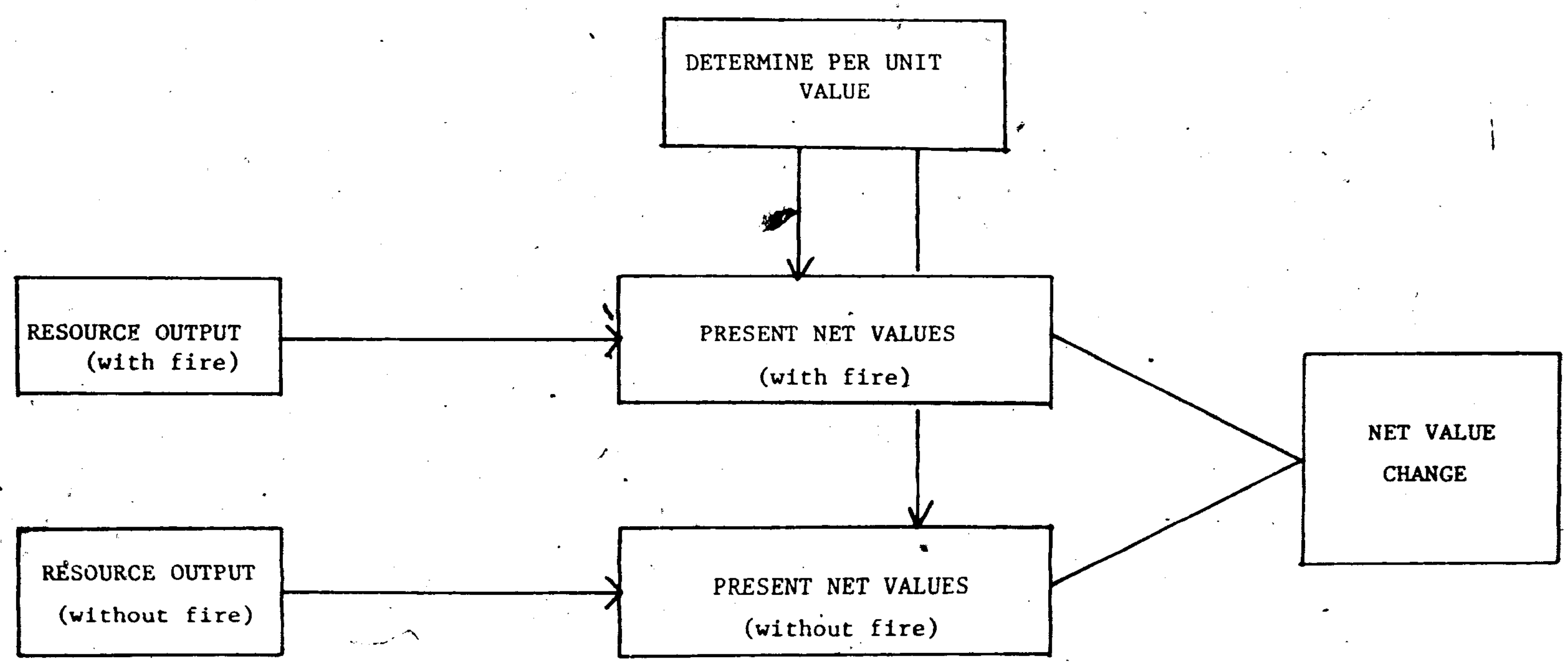
The economic evaluation subsystem is illustrated in the conceptual model in Figure IV.6. The determination of per unit value will depend on the resource use; market values for timber or the extra-market evaluation methods described for wildlife for example. Present net values are calculated using per unit values and outputs from the fire effects subsystem using previously determined discount rates, time periods and fire scenarios. Net value change due to fire is then calculated as the difference between PNV's with and without fire.

F. Summary

Methods outlined in this chapter involved three components; fire behavior, fire effects and economic evaluation. The flow charts served to illustrate data needs and output from each component. Although the three components were oriented towards wildlife, methods are adaptable for deriving other forest values. Recreation values, for example, could similarly be derived. In terms of fire intensities, the same fire behavior component as was used for wildlife could be used for recreation. For the fire effects component, physical changes in recreation use as a result of fire would be measured.

[5]Mills and Flowers (1985) use the equivalent PNV_1 and PNV_2 to equal PV_1 and PV_2 respectively.

Figure IV.6: The Economic Evaluation Subsystem



Direct surveys of users could be performed to determine use of pre and post burn recreation areas.The economic evaluation might consist of eliciting willingness to pay values for recreation sites and noting the change in WTP values as a result of fire. In the following case study, the methods outlined in this chapter are used specifically to determine wildlife value changes resulting from fire.

V. Case Study

An area in the Grande Prairie forest of Alberta was chosen for the case study. The Wapiti (83L) map sheet, designated by the National Topographic System (NTS), is located between Townships 58 to 69 and Ranges 1 to 14 West of Sixth Meridian. A map of Alberta showing the Wapiti map sheet is found in Appendix D. The area was used by Beak Associates (1987) and Knapik et al. (1985) in wildlife evaluation studies; thus, data were available for use in this study. The case study consists of an illustration of the derivation of wildlife values, specifically those of moose, affected by fire using the methods outlined in Chapter four. Timber values are included as a comparison to wildlife values. The three subsystems - fire behavior, fire effects and economic evaluation - are dealt with in sequence with a description of the steps taken and data sources used.

A. Fire Behavior

Fire intensity is the primary output needed from the fire behavior subsystem. Intensity ranks 1 - 6 are described in the FBP System. For this study, however, a compacted ranking system was developed since the low and high ranks in the FBP system are unnecessary in terms of vegetation response. The following intensity ranks are used:

FIRE INTENSITY (kW/m)	RANK
<500	LOW
500-2000	MEDIUM
2000 +	HIGH

Intensity is expressed as a measure of heat produced in kilowatts per meter(kW/m). There is no attempt in this study to perform calculations that predict fire intensities given fuel type and other input data. Fire prediction exercises are beyond the scope of this project and should be performed by fire experts. Intensity charts and tables that are being developed for the thirteen fuel types described in the FBP system, will allow managers to quickly determine fire behavior potential of an ongoing fire in a particular fuel type. Managers will then be able to use the intensity information as inputs in the fire effects subsystem. There are only three fuel types for which intensity data have been developed at this time, namely jackpine, leafless aspen and Boreal spruce. These three broad fuel types, therefore, are used as the vegetation types for the study as well as a Boreal mixedwood fuel type M-2 (Appendix A) although intensity data have not yet been developed for this type. The low, medium and high intensity ranks are the output from the fire behavior subsystem. Modifiers, such as fire size and season of burn, can be included to help evaluate fire effects as indicated in the following section.

B. Fire Effects

The determination of biological fire effects was accomplished in a series of steps. Data, in the form required for this study, were not readily available. As a result, expert opinion (Stelfox, 1986) from the Fish and Wildlife Division of Alberta Forestry, Lands and Wildlife was used. As well, two consultants reports (Knapik et al., 1985 and Beak Associates, 1987) were used extensively to derive additional information. The following section describes the derivation of biological fire effects using the methods outlined in Chapter four. Ideally, succession information would be most accurate if old burns could be studied and current vegetation type determined by age and intensity of burn. Such information on forest fires is not complete however, especially within the Wapiti mapsheet. Other methods must therefore be used to determine successional stages.

Immediate fire effects on vegetation vary with the vegetation type, fire intensity, and season of burn. Table V.1 lists general effects information for the four fuel types. As indicated in the table, low intensity fires cause little damage to most forests aside from some burning of lichens or grasses on the forest floor. Medium intensity fires cause more damage and fire effects variability is high, especially in the Boreal mixedwood fuel type. Season of burn is important in determining effects. Aspen

Table V.1: Initial Fire Effects in Four Vegetation Types

FIRE INTENSITY RANK	MATURE PINE	BOREAL SPRUCE	BOREAL MIXEDWOOD	ASPEN
LOW	-some ground cover burned	-low intensity fires unlikely	-leaf litter burned	-leaf litter partially burned
MEDIUM	-spring fires - trees not killed -summer fires - possibly complete mortality	-spring and early summer fires - hotter with greater tree and seed damage	-islands of unburned aspen -partial mortality of conifers	-mature aspen partially killed -shrub growth burned
HIGH	-complete tree mortality -litter layer burned to mineral soil	-complete tree mortality -seed destroyed	-unburned islands of aspen -complete conifer mortality	-not likely in summer -spring and fall burns - complete mortality

Source: Compiled from Ahlgren and Ahlgren (1960); Chandler et al. (1983); Kelsall et al. (1977).

forests will likely not experience anything more than low intensity fires during the summer months while medium intensity fires in the spring and fall are more common. In the mixedwood fuel type, medium intensity fires will cause partial mortality of conifers and unburned islands of aspen are common. Spruce are especially affected by season of burn where hotter spring and early summer fires may kill seed cones. Later in the season, less intense fires occur with seed cones left intact. High intensity fires destroy all vegetation and burn the forest floor down to the mineral layer!

Typical successional patterns were chosen from the literature for this study and used to determine habitat response to fire. The four fuel types chosen in the fire behavior section were matched with vegetation types described in Russell et al.,(1984) and typical successional pathways were outlined for each vegetation type and each fire intensity - low, medium and high - as well as for a no-fire or baseline situation. A detailed description of the vegetation types is found in Appendix E. Figures V.1, V.2, V.3 and V.4 illustrate the successional pathways thus determined. Vegetation codes are identified in Tables V.2 - V.5.

Determination of Habitat Suitability Class

The current vegetation cover map from the Knapik et al. report was used to match the successional pathways with actual vegetation descriptions in the Wapiti map sheet area. Natural vegetation cover designations in the map were described in general terms as coniferous or deciduous forest, shrubland, grassland etc. without describing vegetation by species. In order to determine individual species within the vegetation types, forest cover maps that indicated tree species were used [6]. This method of determining successional stages in the actual Wapiti map sheet area was considered to be sufficiently accurate for use in determining habitat suitability classes. An equivalent vegetation cover description from the map in the Knapik report was then assigned to each of the four vegetation types from figures V.1 - V.4. These vegetation cover descriptions were given to H. Stelfox of the Fish and Wildlife Division who then determined current habitat suitability (CHS) classes from 1 - 4 for moose. Tables V.2 -

[6] Alberta Energy and Natural Resources forest cover maps at a 1:50,000 scale for the 83L map sheet were used.

Figure V.1: Successional Sequence for Spruce

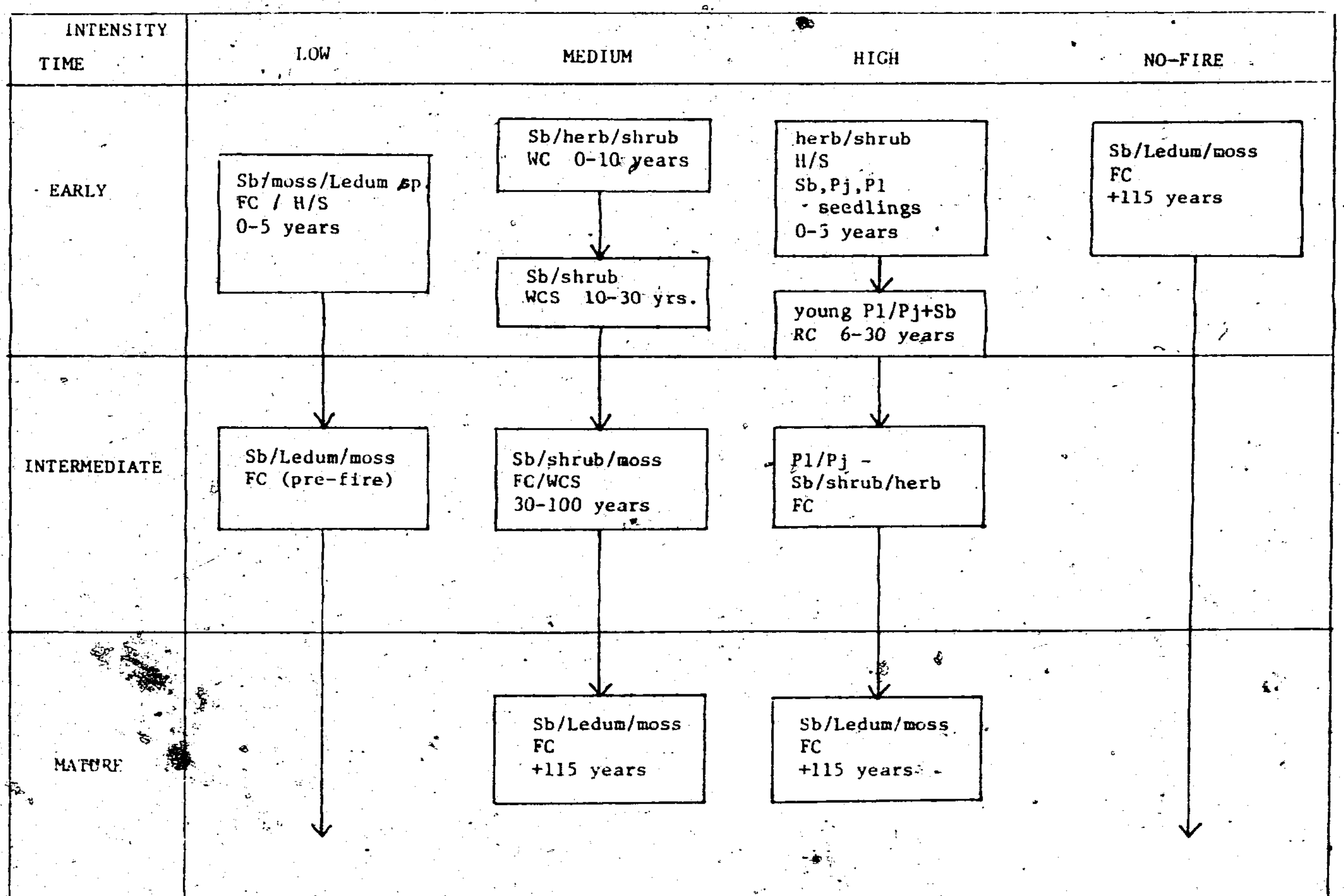


Figure V.2: Successional Sequence for Pine

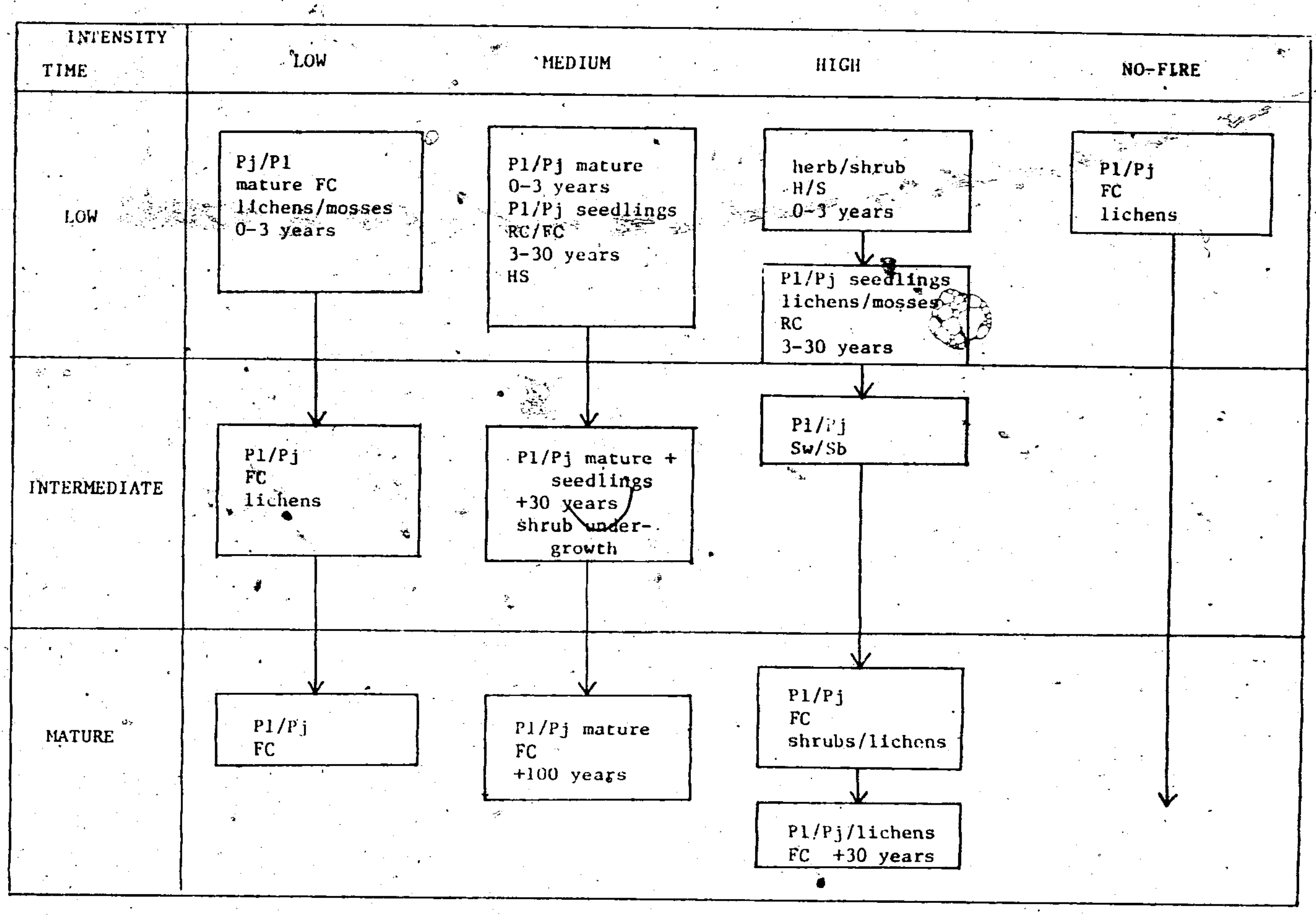


Figure V.3: Successional Sequence for Aspen

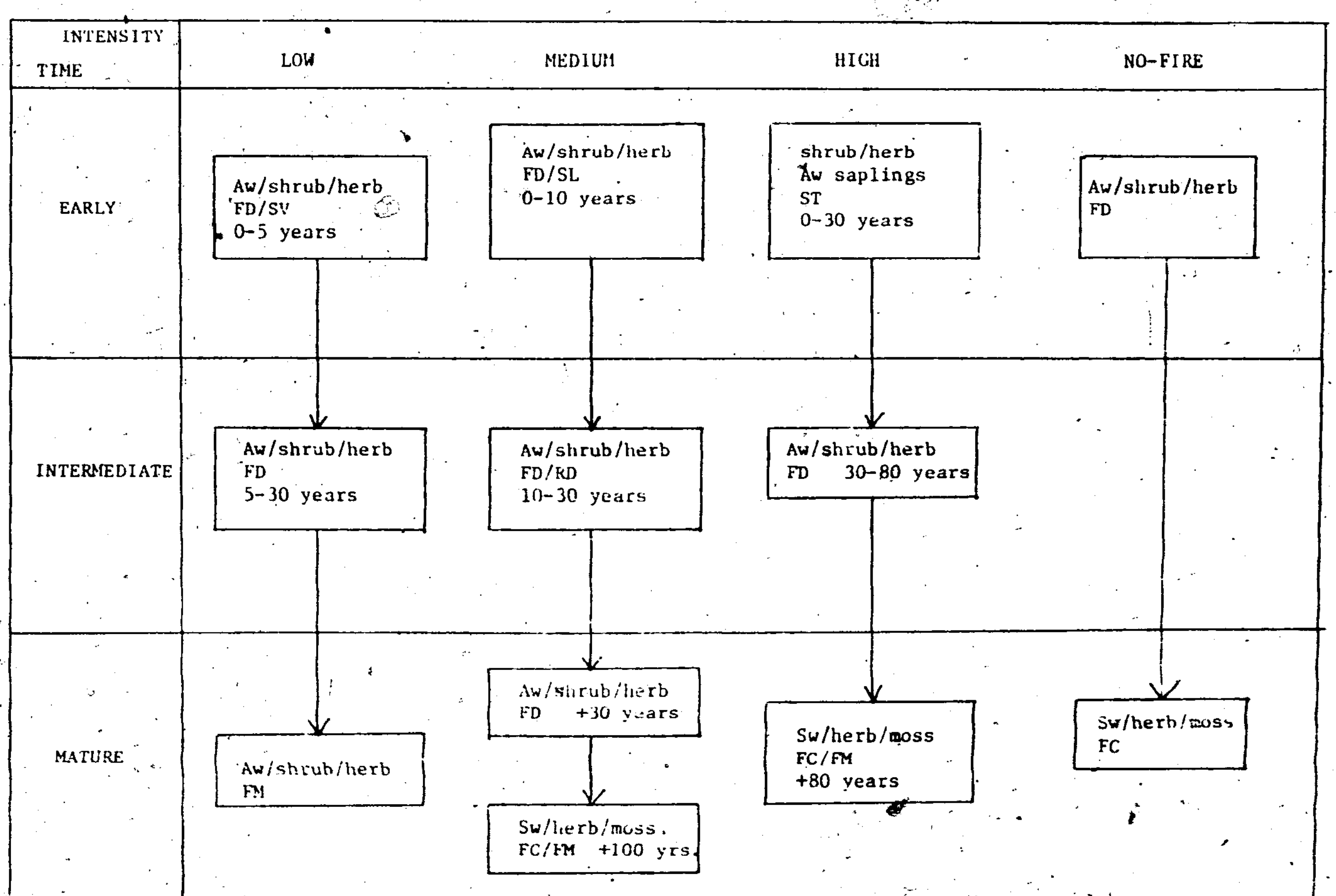
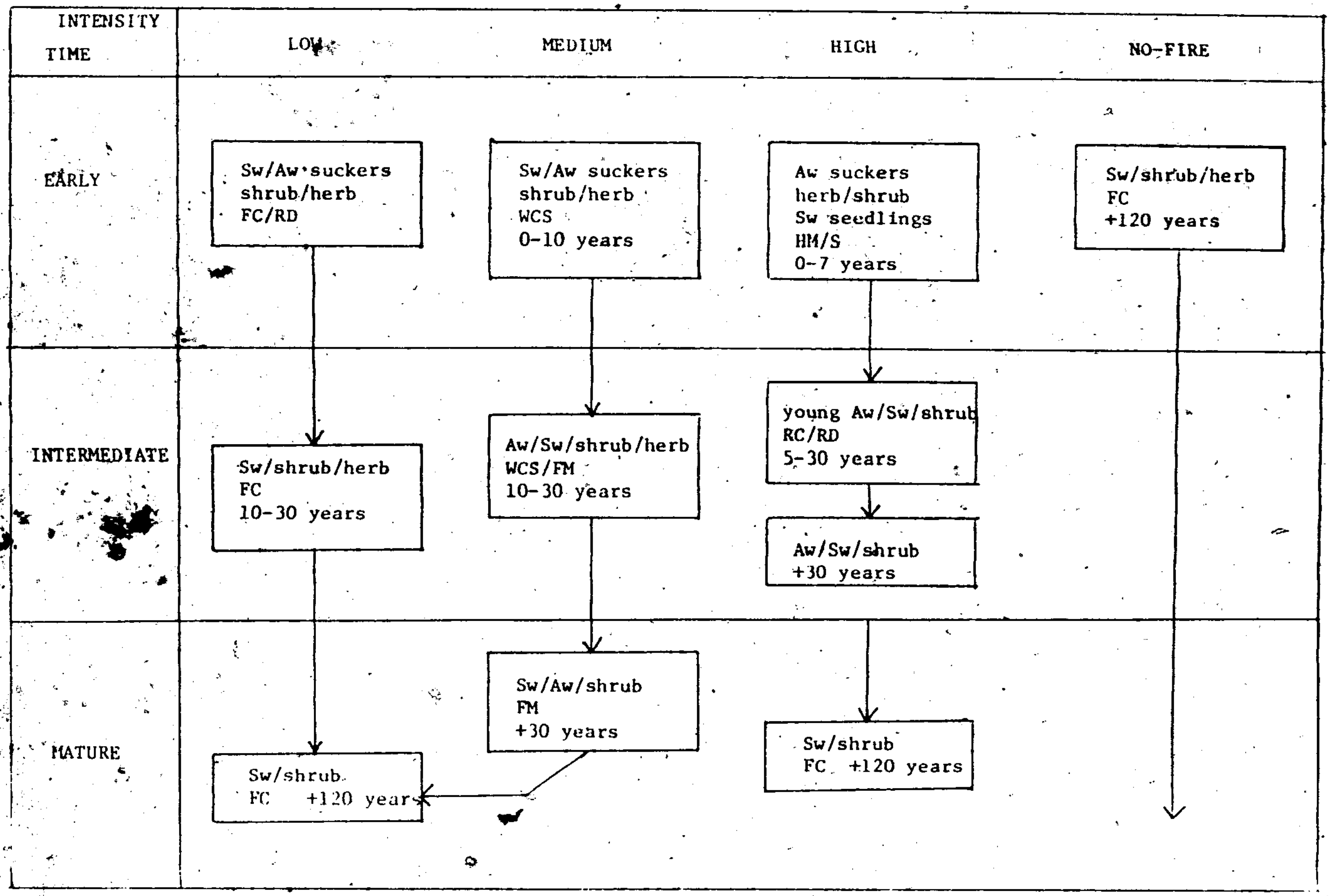


Figure V.4: Successional Sequence for Mixedwood



V.5 show the vegetation cover descriptions and habitat suitability classes assigned by Stelfox for this study. A no-fire or baseline CHS class was assigned for each fuel/vegetation type and that class was assumed to remain constant throughout the successional time frame. This assumption is not quite accurate since mature forests continue to change over time. However, for simplicity, the assumption is made. As well, most of the mature successional stages were assumed to have reverted to a baseline forest and the CHS classes were assigned according to baseline conditions.

The habitat suitability classification system was set up by Beak Associates (1987) in a study of the Wapiti map sheet area. One of the objectives of the study was to determine the average expected population density and range for each of the four CHS classes and for each of the ungulate species studied as an estimate of carrying capacities of CHS classes. The species considered in this study was moose. Therefore, CHS classes were assigned to the vegetation types by Stelfox according to habitat suitability for moose. Expected population densities for moose were determined in the Beak report for four ecoregions found within the Wapiti map sheet area namely, Subalpine, Boreal Mixedwood, Boreal Foothills and Boreal Uplands. For the purposes of this study, the carrying capacities for the three Boreal ecoregions were combined. The Boreal regions were combined to obtain overall Boreal ecoregion carrying capacities with an average carrying capacity for each CHS class thus used. The subalpine region did not contain any of the vegetation types used to determine CHS classes. Therefore, the region was not considered. Table V.6 shows the carrying capacities for moose for each CHS class, for the three ecoregions and an average of the three regions. The mean values are considered to be the moose carrying capacities used in the next section on the economic evaluation of the fire effects.

C. Economic Evaluation

In this section, the valuation of biophysical fire effects determined in the last section is performed. Both consumptive and non-consumptive use values of moose are estimated. Non-use values - option, existence and bequest - are not estimated due to lack of data, however, these values would be expected to be significant for a well-known species such as moose. Methods for determining these forms of value are

Table V.2: Vegetation Cover Descriptions and CHS Classes for the Pine Fuel/Vegetation Type

Vegetation Description	Current Habitat Suitability Class
FC^{9} - HM/S (c7)^{1} -low intensity fire / early	3
FC^{6} - RC (c7)^{3} - S/HM (c7)^{1} -medium intensity fire / early	3
RC (b7)^{8} - HM^{2} -high intensity fire / early	3
FC^{6} - RC (b)^{3} - HM/S^{1} -medium intensity fire / intermediate	3
RC (b) -high intensity fire / intermediate	3

No-fire; low intensity/intermediate; and all intensity/mature forest stages assigned a CHS class of 4.

Vegetation codes are as follows:

FC = coniferous tree-dominated forest
HM/S = herb/dwarf shrub cover with 10-30% shrub cover
RC = coniferous tree-dominated regenerating forest
S/HM = shrubland with 10-70% herb and/or dwarf shrub cover
HM = graminoid, forb, and/or dwarf shrub dominated
(b date) = cover type resulting from burn in given year or decade
(c date) = cover type resulting from clear cut forest removal in given year or decade
Superscripts indicate percent of total cover

Codes are summarized from Pedocan Land Evaluation Ltd. (1985) map on current vegetation cover.

Table V.3: Vegetation Cover Descriptions and CHS Classes for the Boreal Spruce Fuel/Vegetation Type

Vegetation Description	Current Habitat Suitability Class
RC (c6-7)^{8} - FMD^{1} - WC^{1} -medium intensity fire / early	3
FC^{7} - RC (b)^{2} - MM^{1} -medium intensity fire / intermediate	3
RC (b7)^{8} - HM^{2} -high intensity fire / early	3
FC^{4} - S/HM^{4} - FMC^{2} -high intensity fire / intermediate	2

No-fire; low intensity/all stages; and all intensity/mature forest stages assigned a CHS class of 4.

Vegetation codes are as follows:

FC = coniferous tree-dominated forest
RC = coniferous tree-dominated regenerating forest
WC = coniferous tree-dominated woodland
FMD = deciduous tree-dominated mixed forest (50-80% deciduous)
FMC = coniferous tree-dominated mixed forest (50-80% coniferous)
MM = mixed tree and herb/shrub dominated wetland (20-80% treed)
S/HM = shrubland with 10-70% herb and/or dwarf shrub cover
HM = graminoid, forb, and/or dwarf shrub dominated
(b date) = cover type resulting from burn in given year or decade
(c date) = cover type resulting from clear cut forest removal in given year or decade
Superscripts indicate percent of total cover

Codes are summarized from Pedocan Land Evaluation Ltd. (1985) map on current vegetation cover.

Table V.4: Vegetation Cover Descriptions and CHS Classes for the Aspen Fuel/Vegetation Type

Vegetation Description	Current Habitat Suitability Class
FD^{9} - RD^{1} -low intensity fire / intermediate	2
FD^{9} - SV^{1} -medium intensity fire / early	2
RD (c7)^{6} - FD^{3} - FMD^{1} -medium intensity fire / intermediate	1
S/HM (c7)^{7} - FD^{2} - ST^{1} -high intensity fire / early	2
FD^{9} - FC^{1} -high intensity fire / intermediate	2

No-fire; low intensity/early; and all intensity/mature forest stages assigned a CHS class of 3.

Vegetation codes are as follows:

FC = coniferous tree-dominated forest
FD = deciduous tree-dominated forest RD = deciduous tree-dominated regenerating forest
WC = coniferous tree-dominated woodland
FMD = deciduous tree-dominated mixed forest (50-80% deciduous)
ST = tall (+ 2m) shrub-dominated
S/HM = shrubland with 10-70% herb and/or dwarf shrub cover
SV = variable (mixed) height shrubs
(b date) = cover type resulting from burn in given year or decade
(c date) = cover type resulting from clear cut forest removal in given year or decade
Superscripts indicate percent of total cover

Codes are summarized from Pedocan Land Evaluation Ltd. (1985) map on current vegetation cover.

Table V.5: Vegetation Cover Descriptions and CHS Classes for the Mixedwood Fuel/Vegetation Type

Vegetation Description	Current Habitat Suitability Class
FMD^{7} - FC^{2} - S/HM $(c7)^{1}$ -low intensity fire / early	2
S/HM $(c7-8)^{4}$ - FD^{3} - FMD^{3} -medium intensity fire / early	1
FD^{7} - RC $(b6)^{2}$ - MT^{1} -medium intensity fire / intermediate	2
S/HM -high intensity fire / early	3
RD $(b6)^{6}$ - S/HM $(b6)^{2}$ - RC $(b6)^{2}$ -high intensity fire / intermediate	1

No-fire; low intensity/intermediate; and all intensity/mature forest stages assigned a CHS class of 3.

Vegetation codes are as follows:

FC = coniferous tree-dominated forest
RC = coniferous tree-dominated regenerating forest
FD = deciduous tree-dominated forest RD = deciduous tree-dominated regenerating forest
FMD = deciduous tree-dominated mixed forest (50-80% deciduous)
MT = tree-dominated wetland (+80% treed)
S/HM = shrubland with 10-70% herb and/or dwarf shrub cover
(b date) = cover type resulting from burn in given year or decade
(c date) = cover type resulting from clear cut forest removal in given year or decade
Superscripts indicate percent of total cover

Codes are summarized from Pedocan Land Evaluation Ltd. (1985) map on current vegetation cover.

Table V.6: Moose Population Densities (# of animals/km²) expected by Ecoregion for Each Habitat Suitability Class on the Wapiti Mapsheet (83L)

CHS Class	ECOREGION						
	Boreal Mixedwood		Boreal Foothills		Boreal Uplands		Mean
	Mean	Range	Mean	Range	Mean	Range	(all regions)
1	1.2	1.0-1.3	1.0	0.9-1.2	0.9	0.8-1.0	1.0
2	0.7	0.5-1.0	0.5	0.3-0.9	0.5	0.3-0.8	0.6
3	0.4	0.2-0.5	0.2	0.1-0.3	0.2	0.1-0.3	0.3
4	0.1	0.0-0.2	0.1	0.0-0.1	0.1	0.0-0.1	0.1

Source: Compiled from Appendix 8 of Beak Associates (1987), Table 8.2.

now being developed (Brookshire et al., 1983). Net value change compares no-fire wildlife values to values determined for the various fire scenarios to determine changes in value caused by fire.

Wildlife is essentially a non-market resource and as such, values must be derived by methods other than those that determine the value of market goods. Chapter IV.1 outlined current methods used to derive willingness-to-pay (WTP) estimates. Several data sources are used to derive WTP measures for moose. The study by Adamowicz (1983) involved a hunter survey designed to elicit WTP values for selected big game species in Alberta. Data were collected from from a sample of 500 resident and non-resident hunters with a final useable sample of 265 questionnaires. Questions were designed to elicit biographical information, hunting activity, economic information, guide use and general resource use. The study region was the Eastern Slopes of Alberta involving portions of Big Game Zones 5-11. Techniques used to derive non-market benefit estimates for wildlife were the direct questionning method, hedonic price model, household production function approach and a travel cost model. Of particular use to this study are the results of the direct questionning portion of the survey. Two questions were asked regarding the value of hunting. These were:

1. "What are you willing to pay, over and above all other costs, for a day of big game hunting in Alberta?"
2. "How much would you have to be paid not to hunt big game in Alberta for one year?"

The first question derived WTP value and the second derived WTAC. A WTP value of $72.00 per hunter day for moose was determined from the survey. With a total of 626,750 hunter days in 1981 (54,000 hunters X 11.50 days per hunter) the total value of moose in 1981 amounted to over $45 million ($72.00 X 626,750). The figure is substantial, however for the determination of value changes due to fire, a dollar value per moose must be determined. The following procedure was used to derive the value of a moose.

Value/moose harvested = (days/hunter)(WTP/day)/success rate

The success rate used was 15 percent. Moose hunting success rates reported in the literature ranged from 15 percent to 35 percent. However, a rate of 15 percent was considered to be appropriate in this study and is consistent with a recent study by Forestry, Lands and Wildlife (1986) involving results of the 1985 hunting survey for Alberta. License fees for permits to hunt game are part of hunter WTP and, thus, are added to WTP values for moose. Hunters purchase varying combinations of licenses and permits depending on what they hunt. A general fee of $34.00 per resident hunter is used in this study based on methods used in Phillips and Asafu-Adjaye (1987). Resident hunting fees were comprised of a wildlife certificate of $11.00, which all hunters must purchase; a big game fee of $15.00, and a bird game and waterfowl license fee of $8.00 for a total of $34.00. Total WTP, therefore, was $72.00, indexed to 1986 dollars as $91.00, plus $34.00 to give $125.00. Value per moose harvested therefore equaled 11.5 days/hunter multiplied by $125.00/day and divided by 0.15 to give $9,583. The harvestable proportion is the maximum percentage of animals that can be harvested from the population in any year to prevent deterioration of the population. A figure of 25 percent was reported in Phillips et al. (1978). The consumptive value per moose was, therefore, determined to be $9,583 X .25 or $2,396 in 1986 dollars.

The non-consumptive value of wildlife and specifically moose was difficult to derive. A major study on the value of wildlife to Canadians (Filion et al., 1985) determined the total consumptive and non-consumptive values of wildlife through an extensive survey of Canadian wildlife attitudes and wildlife-related activities. Non-consumptive total net value of all wildlife in Alberta was reported as $53.8 million[7]. To determine the moose proportion of the total wildlife figure, the study by Phillips et al. (1978) was used. The survey performed in the study revealed that the contribution of total wildlife value by moose was 11.25 percent. Since no other figures of this nature were found in the literature, this figure was used to determine total non-consumptive moose benefits as $53.8 million X 11.25 percent or $6.05 million in

[7]Non-consumptive wildlife use value per person per day in Alberta was determined by Phillips and Asafu-Adjaye (1987) from the total wildlife value figures reported in Filion. Non-consumptive use value was found to be $209.83 per participant per season with an average of 20.1 days per year spent to give $10.44/person/day in 1986 dollars. A different approach was taken in this study where value changes on an area basis rather than on a per day basis were derived.

total non-consumptive moose benefits. The estimated population of moose in Alberta was reported in Adamowicz (1983) to be approximately 250,000 animals. Non-consumptive use value per moose was therefore estimated to be $6.05 million/250,000 or $24/moose in 1981 dollars indexed to $31/moose in 1986 dollars. Total consumptive and non-consumptive use value per moose was determined to be $2,427 per moose in 1986 dollars.

Net Value Change Determination

The carrying capacities determined in the fire effects section and the dollar value of an animal can now be combined to give the value per square kilometre of a moose. The figures are determined as follows:

CHS Class	$/Moose		Animals/Km²		Value/Km²
1	$2427	X	1.0	=	$2427
2	$2427	X	0.6	=	$1456
3	$2427	X	0.3	=	$728
4	$2427	X	0.1	=	$243

The present value of the stream of benefits derived from moose was determined to account for the receipt of benefits at future times following fire. Present value calculations involve discounting benefits using a selected time period. Several discount rates were used; 3, 5 and 7 percent, to assess sensitivity of results to discount rate. As discussed in Chapter III, social discount rates of 5-7 percent are appropriate for public investments such as fire management. A 3 percent discount rate was included in the sensitivity analysis to illustrate the higher future values involved with lower discount rates. The time periods described in the succession patterns were early, intermediate and mature. Technically, the successional stage described by the three time periods vary depending on the forest type. An intermediate stage in an aspen forest, for example, may occur somewhat earlier than in a pine forest. Average time periods were selected for use in the present value calculations for simplicity. Early was designated as t=15 years, intermediate as t=30 years and t=60 years as mature. Using these specific time periods allows for the comparison of present values between the different forest types. Present values were calculated on the basis of value per square kilometre initially. This starting point allowed the researcher to multiply benefits by the area being considered although as the area becomes larger, the specific nature of the carrying capacity and value figures cause a decrease in accuracy. In larger areas, habitat can be highly variable and a single carrying capacity may no longer apply. Generalizations over large areas, thus, will likely be less accurate than in a smaller area in terms of carrying capacities and subsequent wildlife values.

Present values for each vegetation type, time span, fire intensity and discount rate are presented in Appendix F. Net value change was derived by taking the difference between the with-fire present values and those of the without-fire situations. Results are presented in tables V.7 to V.10 for each vegetation type.

D. Timber Evaluation

Timber values were determined as a comparison to wildlife values. The conceptual model developed for non-market resource valuation was used as well for the timber component. Fire behavior was considered to be the same as that for wildlife; that is, fire intensity was grouped into three categories, low, medium and high. Fire effects on timber are also variable as noted previously. For simplicity, fire effects on timber were considered to be of three types. These were no damage or loss of timber from low intensity fires, 50 percent mortality of timber from medium intensity fires, and 100 percent mortality resulting from high intensity fires. Salvage of partially burned timber is often practiced although salvage was not considered in this case study. A more highly developed model of economic effects would need to include salvage values.

The derivation of timber value was accomplished in a manner similar to that for wildlife where productivity of timber was measured as harvest volume per square kilometre. Harvest volumes were provided by the Timber Management Branch of the Alberta Forest Service (Wrangler, 1987) for several forest management units (FMU's) in

Table V.7: Net Value Change ($) in Wildlife for the Boreal Spruce Vegetation Type

Discount Rate	Fire Intensity	Time Since Fire (years) 15	30	60
	LOW	0.0	0.0	0.0
r=3%	MEDIUM	311.3	199.8	0.0
	HIGH	311.3	499.7	0.0
	LOW	0.0	0.0	0.0
r=5%	MEDIUM	233.3	112.2	0.0
	HIGH	[illegible]	280.7	0.0
	LOW	[illegible]	0.0	0.0
r=7%	MEDIUM	175.8	63.7	0.0
	HIGH	175.8	159.4	0.0

Table V.8: Net Value Change in Wildlife for the Pine Vegetation Type

Discount Rate	Fire Intensity	Time Since Fire (years) 15	30	60
	LOW	311.3	0.0	0.0
r=3%	MEDIUM	311.3	199.8	0.0
	HIGH	311.3	199.8	0.0
	LOW	233.1	0.0	0.0
r=5%	MEDIUM	233.1	112.2	0.0
	HIGH	233.1	112.2	0.0
	LOW	129.3	0.0	0.0
r=7%	MEDIUM	175.8	63.7	0.0
	HIGH	175.8	63.7	0.0

Table V.9: Net Value Change in Wildlife for the Aspen Vegetation Type

Discount Rate	Fire Intensity	Time Since Fire (years) 15	30	60
	LOW	0.0	299.9	0.0
r=3%	MEDIUM	467.3	699.9	0.0
	HIGH	467.3	299.9	0.0
	LOW	0.0	168.5	[illegible]
r=5%	MEDIUM	350.2	393.1	[illegible]
	HIGH	350.2	168.5	0.0
	LOW	0.0	95.6	0.0
r=7%	MEDIUM	263.9	223.2	0.0
	HIGH	263.9	95.6	0.0

Table V.10: Net Value Change in Wildlife for the Mixedwood Vegetation Type

Discount Rate	Fire Intensity	Time Since Fire (years) 15	30	60
	LOW	467.3	0.0	0.0
r=3%	MEDIUM	1090.5	299.9	0.0
	HIGH	0.0	699.9	0.0
	LOW	350.2	0.0	0.0
r=5%	MEDIUM	817.3	168.5	0.0
	HIGH	0.0	393.1	0.0
	LOW	263.9	0.0	0.0
r=7%	MEDIUM	615.8	95.6	0.0
	HIGH	0.0	223.2	0.0

the Grande Prairie forest where the Wapiti block is located. Annual allowable cut (AAC) figures were used as volume estimates as opposed to total timber volumes since the AAC portion of the total provides the allowable economic benefit. Volumes were reported for coniferous and deciduous forests without breaking the volumes down by species. The assumption was made that deciduous volumes would represent aspen forests although birch and balsam poplar are also likely a portion of the total. The value per square kilometre derived from these figures is assumed to be the same for both spruce and pine although that assumption is not completely accurate. Wrangler reported AAC figures for conifers in the G1, G3, G4, G5, G6 and G7 FMU's of 1,289,697m^3/ 1,394,047ha or 92.51m^3/km^2. Deciduous AAC in the same FMU's is 1,544,703m^3/ 1,394,047ha to give 110.81m^3/km^2.

Timber value was determined from Phillips et al. (1985) as conversion return value. The authors reported estimated values, per cubic metre of harvest volume, by revenue and cost levels[8]. Using the medium revenue level and medium cost level for a haul distance of 100 km, a conversion return value of \$7.50/m^3 is derived which is indexed to 1986 dollars giving \$7.80/m^3. Multiplying that value by the volume estimate gives a value estimate for coniferous timber of \$721.58/km^2. Value for deciduous timber was derived from price estimates provided by Pelican Mills of Hinton. Pelican (1987) pays \$16.45 to \$21.00/tonne for aspen depending on haul distance. A midpoint price of \$19.00/tonne was used. Converting tonnes to cubic metres gives a value of \$6.65/m^3 [9]. Value of deciduous timber was therefore determined to be \$6.65/m^3 X 110.81m^3/km^2 or \$736.89/km^2.

The determination of net value change (NVC) for timber resulting from fire is complicated by the continuous growth characteristics of timber. Fire does not destroy timber value but only delays the accrual of benefits. The value of timber at growth stages too early for harvest is not zero - benefits are received at a future harvest date. Determining the effects of fire on timber value therefore involves determining timber value in a no-fire situation compared with the value resulting from delaying harvest for

[8]see Table IX.1 in Phillips et al.(1985)
[9]U.S. Forest Products Laboratory Wood Handbook (1974) reports a specific gravity for aspen of 0.35. Husch, Miller and Beers (1982) outline a procedure for converting tonnes to cubic metres. A conversion factor of 0.35tonne/m^3 for aspen was determined, therefore \$19/tonne converts to \$6.65/m^3.

60 years, the time needed for regrowth of the forest. Although this is a simplified method for determining value changes in timber, the main purpose of the study is to derive a method for eliciting non-market values. More explicit valuation methods for timber would be appropriate in studies primarily concerned with timber.

Discount rates (r) used are the same as for the wildlife section; 3, 5 and 7 percent. Time since fire differs, however, in that no-fire and 60+ years following fire form the basis for timing of benefits received. No values are recorded for 15 and 30 years following high intensity fires. The forest has timber value although benefits are not received until harvest at 60 years[10]. Values for mixedwood forests were taken to be half of the coniferous value plus half of the deciduous value. Present values for timber are presented in Appendix G. Net value change figures for timber in the four vegetation types are presented in Tables V.11 - V.13.

E. Interpretation of Results

Results of wildlife value changes due to fire show some obvious trends. In all situations, net value changes are zero or positive indicating benefits rather than costs of fire to wildlife. Values for the aspen and mixedwood vegetation/fuel types are higher than those of the coniferous types, even in the no-fire situations. This would be expected due to the presence of preferred vegetation species for moose in deciduous and mixedwood forests. Habitat suitability is a combination of food and cover. Thus some of the coniferous-dominated forest stands may have low food value with higher cover value which would contribute to an overall higher suitability class than might be expected on the basis of food value alone.

Fire intensity affected net value change less in coniferous forests than in mixedwood or aspen forests. For spruce, low intensity fires did not result in any change in value compared with no-fire stands. Medium and high intensity fires resulted in the same NVC after 15 years. After 30 years, high intensity fires resulted in the greatest NVC due to an improvement in habitat that was likely due to the increase in deciduous shrubs that were present in the pre-fire forest. Pine forests showed slightly different

[10] Coniferous forests are harvestable at 80+ years however 60 years is used for consistency with the wildlife section.

Table V.11: Net Value Change in Timber for the Coniferous Vegetation Types

Discount Rate	Fire Intensity	Time Since Fire (years) 15	30	60
	LOW	0.0	0.0	0.0
r=3%	MEDIUM	-231.6	-148.6	0.0
	HIGH	-463.2	-297.3	0.0
	LOW	0.0	0.0	0.0
r=5%	MEDIUM	-173.6	-83.5	0.0
	HIGH	-347.1	-166.9	0.0
	LOW	0.0	0.0	0.0
r=7%	MEDIUM	-130.8	-47.4	0.0
	HIGH	-261.5	-94.8	0.0

Table V.12: Net Value Change in Timber for the Aspen Vegetation Type

Discount Rate	Fire Intensity	Time Since Fire (years) 15	30	60
r=3%	LOW	0.0	0.0	0.0
	MEDIUM	-236.5	-151.8	0.0
	HIGH	-473.0	-303.6	0.0
r=5%	LOW	0.0	0.0	0.0
	MEDIUM	-177.2	-85.3	0.0
	HIGH	-354.5	-170.5	0.0
r=7%	LOW	0.0	0.0	[illegible]
	MEDIUM	-133.5	-48.4	0.0
	HIGH	-267.1	-96.8	0.0

Table V.13: Net Value Change in Timber for the Mixedwood Vegetation Type

Discount Rate	Fire Intensity	Time Since Fire (years) 15	30	60
	LOW	0.0	0.0	0.0
r=3%	MEDIUM	-234.0	-150.2	0.0
	HIGH	-468.1	-300.4	0.0
	LOW	0.0	0.0	0.0
r=5%	MEDIUM	-175.4	-84.4	0.0
	HIGH	-350.8	-168.7	0.0
	LOW	0.0	0.0	0.0
r=7%	MEDIUM	-132.2	-47.9	0.0
	HIGH	-264.3	-95.8	0.0

trends in value due to fire intensity. After 15 years, NVC was the same for all fire intensities. Fire in pine stands generally results in revegetation to pine with little deciduous invasion occurring. Habitat suitability, therefore, remains about the same regardless of fire intensity. Although it was not the case in this study, habitat suitability might actually decline with fire as the valuable cover component of the habitat is lost. After 30 years, there is a zero NVC between no-fire and low intensity fire as the forest has nearly completely recovered from any fire damage. Net value changes resulting from medium and high intensity fires are the same. While the degree of damage may differ, vegetation regrowth after 30 years results mainly in pine trees with little shrub growth. Forests of similar habitat suitability class are produced. Aspen forests show no NVC between no-fire and low intensity fire situations. At low intensity, there is little effect on vegetation after 15 years. After 30 years, aspen suckering induced by fire results in an increase in habitat class and therefore a positive NVC over the no-fire scenario. Medium and high intensity fires result in the same NVC after 15 years. However, after 30 years, medium intensity fires provide the greatest NVC over no-fire forests where the combination of mature and regrowing aspen and shrubs provide the most suitable habitat. Mixedwood forests, conversely, have a positive NVC for low intensity fires after 15 years due probably to the stimulation of suckering in aspen and other shrubs that provide a food source. Mature timber remains undisturbed providing the necessary cover portion of habitat. A zero NVC results after 30 years for low intensity fires, indicating a return to pre-fire habitat. Medium intensity fires result in the greatest NVC after 15 years. High intensity fires cause the greatest change in value after 30 years. Aspen suckering induced by medium intensity fires within the first 15 years was responsible for the improved habitat class and positive NVC. The habitat improvement declined after 30 years resulting in a lower NVC. A high intensity fire caused more severe damage and improvements in habitat were delayed until the forest recovered thus the greatest benefits were received after 30 years.

The choice of discount rate affects value and the resulting value changes. As expected, lower discount rates resulted in higher values and greater net value changes. All values determined were still positive regardless of the discount rate used and only the magnitude of benefits was affected by the discount rate.

All of the forest types were assumed to revert to their pre-fire habitat suitability class after 60 years therefore NVC after 60 years was zero for all fire intensities. This was a limiting assumption since many factors account for succession in a forest. Sixty years is actually a short time for recovery from fire to occur, especially in coniferous forests. Since the intention of the case study was to show relative changes in habitat and consequent net value changes for moose, the use of 60 years as the end point was considered to be reasonable. In most cases, the results showed that value peaked at 15 years after fire and then declined slowly. This is consistent with findings in the literature which indicate that the greatest habitat value for moose occurs within the first 15-20 years following a disturbance and then declines as browse species grow too high for the animals (Nietfeld et al., 1985; Fuhr, 1983). In addition, the assumption was made that a forest with no fire will remain at the same habitat class over the span of 60 years used in this study. More likely, the forest will continue to change over time, even if it is mature. This factor was not included in the analysis however.

The analysis does not include situations in which there are frequent fires that prevent succession from continuing to a mature forest. Vegetation in these instances, may be burned every 30 or so years and remain highly suitable as moose habitat. Benefits for moose would be high since the habitat suitability class would remain elevated. Net value change, however, would be minimal since the habitat would remain at a more or less constant level of suitability.

There was no mention made in these results of the effects of fire size. Results were reported as NVC in dollars per square kilometre. Fire size would affect these results in several ways. Smaller fires would have a more local effect and a large permanent increase in moose populations would not be expected. Large fires, on the other hand, could result in permanent increases in moose populations, especially if fires occurred at frequent intervals of less than 60 years. The loss of cover would be a problem with large fires unless there were unburned islands remaining after the fire (Eberhart, 1986).

Another point to note concerns the possibility of a real change in the value of moose over time. One would expect that as moose populations become more scarce as habitat declines, the actual value of a moose would increase. The same may be said of any resource where increasing scarcity tends to lead to increased value. Substitution of one species for another does occur, however, there is some value associated with individual species. There may be real increases over the next 30 years in wildlife or other resource values. Results of a study such as this would be altered by value increases. However, predictions of changes in value, without substantiation by new studies, are subjective. Values may increase or decrease over time and the degree of change is unpredictable.

Findings of the timber evaluation show zero or negative net value changes indicating detrimental effects of fire on timber as expected. High intensity fires result in the greatest damage while low intensity fires show no value change over no-fire situations. No real damage is done to timber by low intensity fires and there may be some benefits derived through partial clearing of underbrush allowing easier logging. As with the wildlife valuation, forests may revert to their pre-fire states after 60 years depending on stand age at the time of disturbance. Most of the damage is felt in the first few years following fire with net value changes gradually decreasing over time indicating the greater value of more mature timber. Net value changes for all forest types were nearly identical in all cases. Coniferous timber value would be expected to be higher than deciduous timber value, however, in this situation, values were similar. Factors such as haul distance, differences in allowable cuts and growth in value and use of deciduous wood may all contribute to the similarity in values and net value changes.

Differences between wildlife and timber values within the forest types are noteworthy. Results showed higher positive effects of fire on wildlife in aspen and mixedwood forests than in coniferous forests and substantial negative effects of fire on timber in coniferous as well as deciduous and mixedwood forests. Where fire caused the greatest decrease in timber value; high intensity fires after 15 years, it also had the least benefit for wildlife. Fire induced benefits for wildlife were greatest in aspen and mixedwood forests.

The analysis included only the value of moose recognizing that there are other wildlife species that would also contribute to the total value of wildlife. Benefits of fire to moose, in terms of NVC, were of the same order of magnitude as losses of timber value although generally, benefits exceeded losses. Moose are often more highly valued than other wildlife species. The addition of benefits from other species would make the differences between timber and wildlife values even higher. However, since some wildlife species such as woodland caribou depend on mature forests, the inclusion of value changes from those species might narrow the gap between timber and wildlife values. As well, wildlife is only one aspect of non-market value. Value changes in other non-market forest uses will influence the net effect of forest fire.

These results indicate some interesting implications for fire managers who work within forests with multiple uses. Although there were numerous simplifying assumptions made in the case study, from a fire control point of view, timber and wildlife uses are not always in conflict and may be complementary in some situations. Fire control efforts could be concentrated in areas that would experience the greatest negative net value change considering not only timber values but other forest values as well.

The case study involved a method for evaluating the effects of fire on non-market forest values and compared the results to timber values. This exercise is only part of the whole net value change method of determining optimum fire control effort levels. Fire control theory as outlined in Chapter III can now be reexamined. Net value change was used in the resource evaluations as the change in value induced by a fire compared to a no-fire situation. The term net value change is more accurately used in the optimization process where NVC is the difference between fire induced losses and benefits. In the case study, this would be the difference between the benefits to wildlife and the losses to timber which mostly resulted in a positive NVC. A more complete analysis would include all measured forest values.

The cost portion of the optimization process has been omitted in this analysis. Costs are defined as prevention, detection, suppression and pre-suppression expenditures. In order to minimize fire control expenditures, control efforts, in terms of suppression and presuppression, need to be minimized. Timber values are commonly the only resource values considered and since fire induces a negative NVC for timber, a high degree of fire control effort is usually desired. The problem lies in trying to minimize costs while maximizing costly effort. Including benefits due to fire changes the optimization picture. A decreased fire control effort level and thus decreased costs can result from the inclusion of benefits. Only by knowing the real net value changes due to fire can more efficient decisions be made on the allocation of fire control effort.

Summary

This case study was performed to use the methods developed in Chapter 4 to derive values for wildlife for use in the overall fire management decision process. Results indicated substantial positive changes in value for moose as a result of fire, especially in aspen and mixedwood forests. On the contrary, there were substantial negative value changes in timber due to fire. Indications are, that conflicts in forest use between timber interests and moose, at least, may be minimal. Fire control in coniferous forests can protect timber values while burns in coniferous forests have a limited positive effect on moose values compared with burns in aspen or mixedwood forests. Burns in deciduous forests adversely affect timber values to a similar extent as in coniferous forests, but benefit wildlife considerably.

In general, the methods used to derive values in the case study represent an initial attempt to determine fire effects on non-timber values. Results obtained were satisfactory and could be used in fire management decision processes. A more comprehensive study involving fire expenditure data would help fire managers make decisions on levels of control effort. Every fire is unique as are the forest resources affected. Therefore, no rules can be established regarding the variables to include in the analysis of each fire. Each situation must be examined and decisions made on the relative values of resources affected. There is no doubt, however, that there are significant forest values other than timber and by excluding possible benefits of fire from fire management decision processes, there may be excessive levels of effort and expenditure on the control of some fires.

VI. Summary and Conclusions

The purpose of this thesis was to develop a method for the incorporation of non-market values into a framework for fire management decision making processes. Several objectives were identified pursuant to this purpose. These were to review the literature on non-market benefit valuation techniques that were theoretically acceptable and useful in fire evaluation procedures, and to review approaches aimed at using results from the application of these techniques in evaluating non-market net benefits of fire control. From these reviews, a suitable approach was chosen for this study. Data sources and deficiencies were to be identified during the course of the study.

The method chosen for non-market benefit valuation involved the determination of net value change in resource values due to fire. This marginal approach allowed the determination of relative value changes. Absolute resource values are difficult to measure since they depend, as described in Chapter II, on the circumstances of the evaluator. A conceptual model was derived from the literature that illustrated the entire process of the economic evaluation of fire. Figure IV.1 showed a conceptual model for fire management decision strategies. The process is interactive with management decisions influencing the three parts of the model; the fire behavior, fire effects and economic evaluation components. Information derived from the three part model in turn influences fire management decisions. Fire control activities affect both fire behavior and fire effects and costs of those activities are part of the economic evaluation as shown in Figure IV.1. A case study was used to illustrate the use of the model. An area of the Grande Prairie forest, namely the Wapiti map sheet area (83L), was chosen due to data availability. Each component of the model was considered separately. Fire behavior was researched in detail and output from the component was simplified by focusing on fire intensity information. That information was then used in the determination of biophysical fire effects on non-market resources. Output from the fire effects module was used in the economic evaluation module to derive the final net value changes due to fire. Timber value changes were similarly derived and compared with non-market value changes. Present values were calculated to compare value changes that occurred over time.

The results showed some interesting trends even though their derivation involved several limiting assumptions. Wildlife values, specifically those of moose, were derived to illustrate use of non-market valuation methods. There were difficulties involved in the fire effects component. Fire is extremely variable as are its effects on wildlife. Therefore, simplifying assumptions were made in some places to derive reasonable fire effects output. Fire behavior models are fairly well developed. However, it was beyond the scope of this study to actually model a series of fires. Instead, specific intensities were chosen and the effects of those intensities were evaluated. For wildlife, fire effects on habitat required evaluation. Succession following fire was found to be quite variable and again, specific successional patterns were chosen which may or may not occur after fire. Many factors affect succession following fire and although biological models have been developed for analyzing successional trends, use of a model of this type was not part of this study. Instead, the determination of wildlife population changes from successional patterns involved reliance on expert opinion of scientists from the Alberta Fish and Wildlife Division. Potential carrying capacities for moose were determined rather than actual populations which are influenced by many exogenous factors. Net value changes were determined by comparing post-fire values to pre-fire values. The results showed that net value changes for wildlife were zero or positive indicating benefits to the resource from varying levels of fire intensity. Timber values, conversely, were all zero or negative indicating a detrimental effect of fire on the timber values as would be expected. The greatest increases in values for moose were found in the aspen and mixedwood forest types. Both timber and wildlife value changes were of similar orders of magnitude as measured in value per square kilometre.

A. Conclusions

In general, the conceptual model used and the net value change concept used in this study was acceptable. Few problems were found with the economic evaluation portion of the study. The biophysical analysis was responsible for most of the technical problems encountered in trying to derive net value changes. Data deficiencies were outlined and sources of available data were identified. Costs of fire control and costs of developing and maintaining timber and wildlife resources were not considered in this study. Technically, net present values should be calculated with costs of protecting the resource subtracted from benefits gained. The purpose of this study was to derive non-market value changes due to fire with no reference to costs.

There are several major conclusions that can be drawn from the results of this study. Probably the most important of these is that non-market values are significantly affected by fire and the changes in value induced by fire are not necessarily in the same direction as timber values. This study only looked specifically at moose value changes which were found to be mostly positive. Other wildlife species may not exhibit the same direction of change in value or the same magnitude of change. Furbearers tend to require mature forest for habitat and would likely be adversely affected by fire. Determining value changes for furbearers would be relatively straightforward given the existence of a defined market for them. Caribou also rely on mature forests for habitat and negative value changes due to fire for caribou would be expected. Other non-market values such as wildlife viewing and photography are affected by fire, however the direction of change in value is less predictable. Burned areas may, however, improve wildlife species diversity and numbers resulting in improved viewing values. Thus, fire affects many forest values besides timber and often in a significant manner. Improvements in the derivation of non-timber value changes due to fire can only improve the management of forests and forest fire by making management practices more economically efficient. At the same time, public welfare would be better served by more efficient fire management.

The second major conclusion from this study is that in order to include possibly significant non-market values in fire management decisions in the prairie provinces, major improvements in data are needed. More work is required to refine fire models. To date, only three of the fourteen fuel types identified by the Canadian Forest Service have been modelled in the Fire Behavior Prediction System. More fire behavior information would contribute to the ability to determine valid fire effects information. Improvements are required as well, in fire effects determination under prairie conditions. The ecological mapping work by Pedocan and the Alberta Fish and Wildlife Division was invaluable to this study. Their mapping, however only covers the Wapiti map sheet area. That area covers only a portion of the ecological forest zones found in the prairie provinces. More extensive mapping would contribute significantly to the data base for all three provinces. There is a need for more study in the area of fire ecology specific to Boreal forests. More extensive and long term monitoring of burns would help to quantify some of the fire effects information that was derived from the literature for this study. Successional sequences and wildlife population dynamics due to fire need further study at least to make data more readily available for the evaluations performed in this study. Not only does the biophysical fire effects data base need to be expanded, but the economic valuation studies that deal with non-market values require more research specific to the prairie provinces. Research in this area was begun in Manitoba and Saskatchewan in the mid seventies (Ross, 1975; Ross and Paul, 1976; Capel and Pandey, 1973; Capel and Ross, 1973; Capel and Teskey, 1976) and in Alberta in the late sixties (Phillips and Pattison, 1972). Local data are available for some non-market values but the need for more research has been illustrated in this study. Better acceptance and use of non-market values in fire management is indicated and as information in this area becomes more available, its use will hopefully improve.

B. Policy Implications

Positive value changes resulting from fire suggest that in some situations fire management might be best oriented to a controlled burn policy. There may be some areas within the three provinces where net benefits - all gains less losses due to fire - are positive. Obviously a great deal of work still needs to be done to identify such areas. Costs of fire control need to be weighed against net benefits where there are losses to timber and non-market resources and gains to other non-market resources. Priorities of resource use are established in some areas that do not necessarily reflect measured values and these situations need to be accounted for in evaluations. This study ultimately shows that fire management is changing with improvements in data and evaluation techniques and new information needs to be incorporated to make fire management decision processes more economically efficient.

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Appendix A

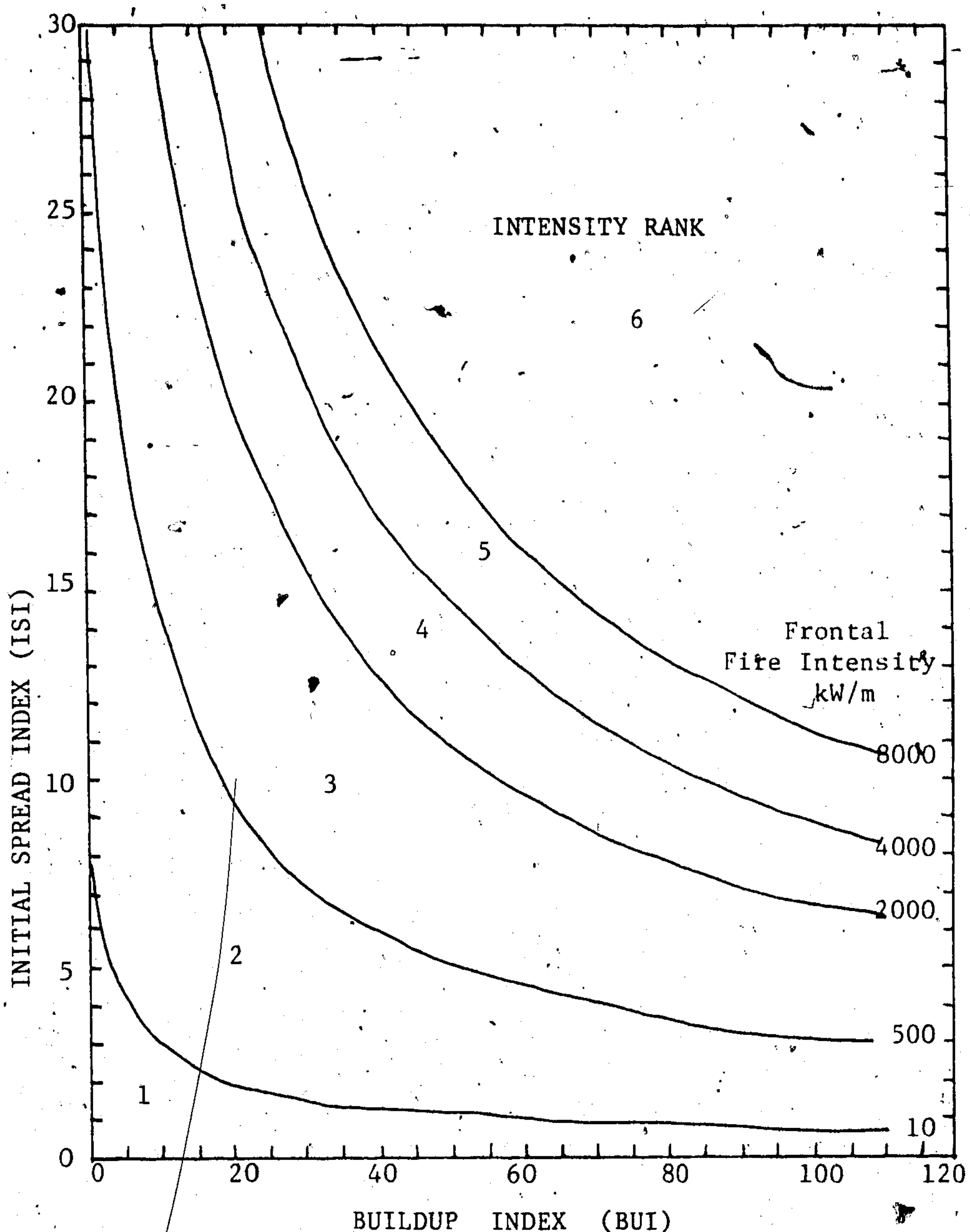
Fuel Types Used in the Fire Behavior Prediction System

Group	Identifier	Descriptive Name
Coniferous	C-1	Spruce - Lichen Woodland
	C-2	Boreal Spruce
	C-3	Mature Jack or Lodgepole Pine
	C-4	Immature Jack or Lodgepole Pine
	C-5	Red and White Pine
	C-6	Red Pine Plantation
	C-7	Ponderosa Pine - Douglas-fir
Deciduous	D-1	Leafless Aspen
Mixedwood	M-1	Boreal Mixedwood - leafless
	M-2	Boreal Mixedwood - summer
Slash	S-1	Jack or Lodgepole Pine Slash
	S-2	Spruce - Balsam Slash
	S-3	Coastal Cedar - Hemlock - Douglas-fir Slash
Open	O-1	Grass

Source: Adapted from Alexander et al. (1984)

FIRE BEHAVIOR CHARACTERISTICS/SUPPRESSION INTERPRETATIONS CHART

(Upland Jackpine Fuel Type)



Source: Adapted from Alexander et al. (1984)

Appendix B Cont'd

Fire Intensity Table with Descriptions of Intensity Ranks

Chart Rank	Frontal Fire Intensity (kW/m)	Description of Fire Behavior Characteristics and Fire Supression Interpretations	Fire Weather Index[1] (FWI)
1	< 10	Smouldering or creeping surface fire. Firebrands and going fires tend to be virtually self-extinguishing unless high Drought Code (DC) and/or Buildup Index (BUI) values[2] pervail, in which case extensive mop-up is generally required.	0-3
2	10-500	Low vigour surface fire. Direct manual attack at fire's head or flanks by fire-fighters with hand tools and water possible. Constructed fire guard should hold.	4-13
3	500-2000	Moderately vigorous surface fire. Hand-constructed fire guards likely to be challenged. Heavy equipment (bulldozers, pumpers, retardant air-craft, skimmers, helicopters w/bucket) generally successful in controlling fire.	14-23
4	2000-4000	Highly vigorous surface fire or passive crown fire (torching). Control efforts at fire's head may fail.	24-28
5	4000-8000	Extremely vigorous surface fire or active crown fire. Very difficult to control. Suppression action must be restricted to fire's flanks. Indirect attack with aerial ignition (i.e., helitorch and/or AID dispenser) may be effective.	29-33
6	> 8000	"Blow-up" or conflagration" type fire run; violent physical behavior probable. Supression actions should not be attempted until burning conditions ameliorate.	34

[1]Applicable to mature jack pine stands on level ground.
[2]DC 300 and/or BUI 40.

Prepared by: Martin E. Alexander,
CFS-NoFC, Edmonton, Alberta

Appendix C

Fire Intensity Effects on the Jackpine Fuel Type

Intensity Rank	Frontal Fire Intensity (kW/m)	Description of Impact and Direct Effects of Fire on Forest Vegetation
1	<10	None to minimal provided there is no persistent ground fire activity. (The subsurface impacts and effects of fire are largely dependent on the 'Depth of Burn' and woody fuel consumption which are a function of the Buildup Index (BUI) or Duff Moisture Code (DMC), depending on the fuel type.
2	10-500	Fires are so gentle that the overstory canopy sustains very little or no visible damage. However, advanced regeneration is generally killed and a portion or all of the aboveground component of lesser plants are normally consumed in the flaming front.
3	500-2000	Fires are vigorous enough to induce stem bole scarring and some tree mortality.
4	2000-4000	Fires are sufficiently intense enough to cause complete tree mortality.
5	4000-8000	Represents a level of fire intensity that very little of the Canadian forest could survive.
6	>8000	Same as Intensity Rank 5.

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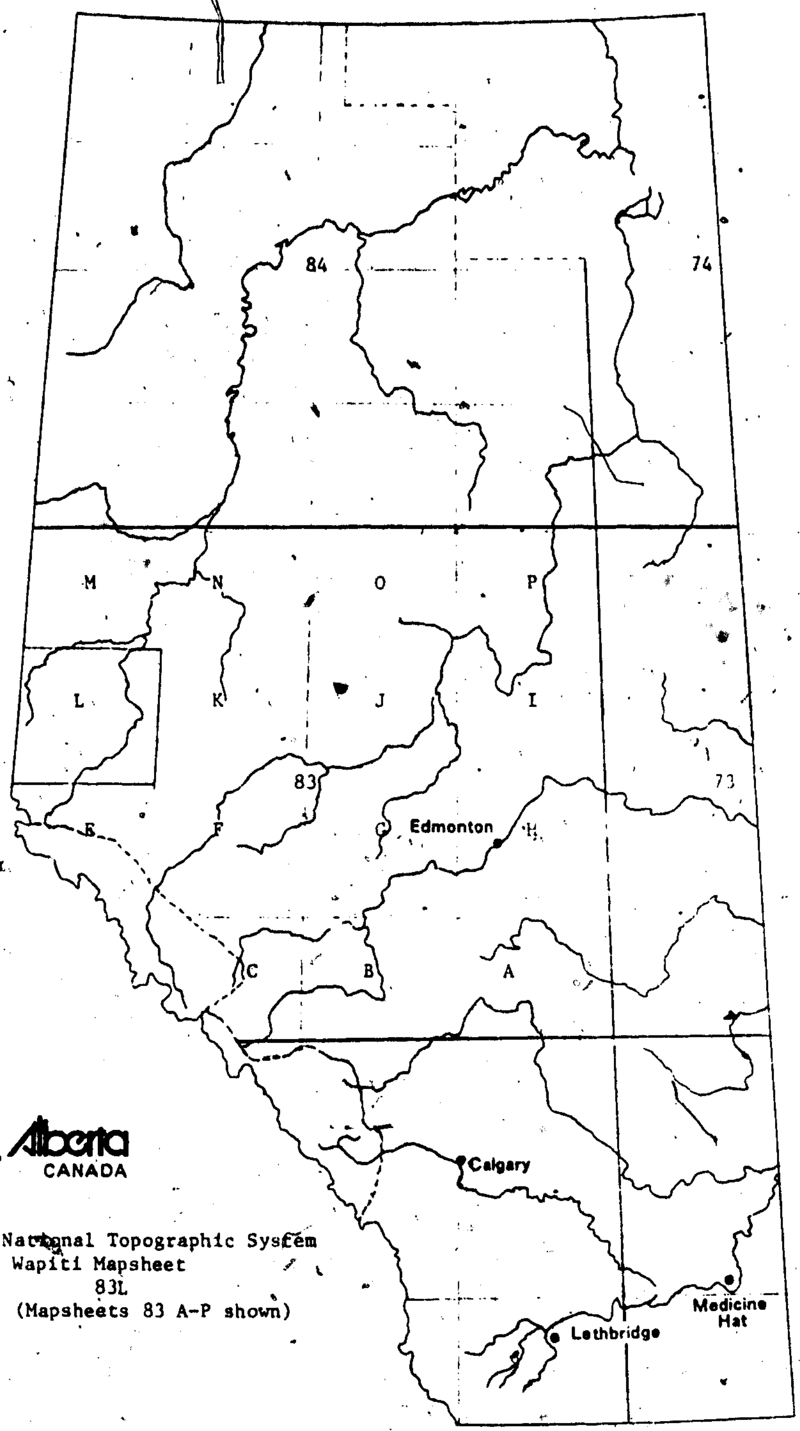
Appendix D



National Topographic System
Wapiti Mapsheet
83L
(Mapsheets 83 A-P shown)

Appendix E

Vegetation Type Descriptions

FUEL TYPE: Mature Jack or Lodgepole Pine (C-3)

Northern Boreal Mixedwood - Vegetation type 1 (Russell et al. 1984)
Lodgepole/Jackpine/Arctostaphylos uva-ursi/lichen
Associated species: Populus tremuloides, Picea mariana, Alnus crispa, Rosa sp., Ledum groenlandicum, Shepherdia canadensis, Vaccinium myrtilloides, V. vitis-idaea, Linnaea borealis, Cornus canadensis, Maianthemum canadense, Cladina mites, C. alpestris, Cladonia sp., Pleurozium schreberi, Hylocomium splendens.

The vegetation type has a high species diversity, however, cover values of shrubs and herbs are low with mature pine dominating the canopy.

FUEL TYPE: Boreal Spruce (C-2)

Northern Boreal Mixedwood - Vegetation type 2a (Russell et al. 1984)
Black spruce/Ledum groenlandicum/Feathermoss
Associated species: Pinus banksiana, P. contorta, Ledum sp., Cornus canadensis, Vaccinium vitis-idaea, Pleurozium schreberi, Hylocomium splendens, Ptilium crista-castrenis, Peltigera aphthosa, Alnus crispa often a dominant shrub.

Usually low species diversity in poorly developed herb layer ; Black spruce forms a closed canopy with branches to the ground.

FUEL TYPE: Boreal Mixedwood (M-2)

Southern Boreal Mixedwood - Vegetation type 3b (Russell et al. 1984)
White spruce/Viburnum edule/Rubus pubescens
Associated species: Populus tremuloides, Pinus banksiana, Alnus crispa, Rosa sp., Ledum groenlandicum, Linnaea borealis, Vaccinium myrtilloides, Cornus canadensis, Vaccinium vitis-idaea, Maianthemum canadense, Epilobium angustifolium, Elymus innovatus, Fragaria virginiana, Aster cilialatus, Pleurozium schreberi, Polytrichum juniperinum.

Boreal mixedwood types are highly variable in terms of species diversity and dominance.

Appendix E Cont'd

FUEL TYPE: Leafless Aspen (D-1)

Aspen Parkland → Vegetation type 4 (Russell et al. 1984)
Trempling aspen/shrub/herb
Associated species: Populus balsamifera, Symphoricarpos occidentalis, Rosa sp., Galium boreale, Salix sp., Calamagrostis inexpansa, Vicia americana, Carex sp., Aster ciliolatus, Fragaria virginiana, Amelanchier alnifolia, Corylus cornuta, Prunus sp., Viburnum edule, Rubus strigosus, Agropyron sp. Aralia nudicaulis, Cornus canadensis, Pyrola asarifolia, Maianthemum canadense, Schizachne purpurascens, Bromus ciliatus, Calamagrostis canadensis, Epilobium angustifolium, Lathyrus ochroleucus, Mertensia paniculata, Rubus pubescens, Viola sp.

Predominant upland vegetation on the northern fringe of Parkland bordering on Boreal forest. Islands of aspen stands are found within the coniferous Boreal forest as well.

Source: Adapted from Russell et al. (1984)

Appendix F

Table F.1: Present Values for Wildlife in the Boreal Spruce Vegetation Type

Discount Rate	Fire Intensity	Time Since Fire (years) 15	30	60
	NO FIRE	155.9	100.1	41.3
r=3%	LOW	155.9	100.1	41.3
	MEDIUM	467.3	299.9	41.3
	HIGH	467.3	599.9	41.3
	NO FIRE	116.9	56.2	13.0
r=5%	LOW	116.9	56.2	13.0
	MEDIUM	350.2	168.4	13.0
	HIGH	350.2	336.9	13.0
	NO FIRE	88.1	31.9	4.2
r=7%	LOW	88.1	31.9	4.2
	MEDIUM	263.9	95.6	4.2
	HIGH	263.9	191.3	4.2

Table F.2: **Present Values for Wildlife in the Pine Vegetation Type**

Discount Rate	Fire Intensity	Time Since Fire (years) 15	30	60
r=3%	NO FIRE	155.9	100.1	41.3
	LOW	467.3	100.1	41.3
	MEDIUM	467.3	299.9	41.3
	HIGH	467.3	299.9	41.3
r=5%	NO FIRE	116.9	56.2	13.0
	LOW	350.2	56.2	13.0
	MEDIUM	350.2	168.4	13.0
	HIGH	350.2	168.4	13.0
r=7%	NO FIRE	88.1	31.9	4.2
	LOW	263.9	31.9	4.2
	MEDIUM	263.9	95.6	4.2
	HIGH	263.9	95.6	4.2

Table F.3: Present Values for Wildlife in the Aspen Vegetation Type

Discount Rate	Fire Intensity	Time Since Fire (years) 15	30	60
	NO FIRE	467.3	299.9	123.6
r=3%	LOW	467.3	599.9	123.6
	MEDIUM	934.6	999.9	123.6
	HIGH	934.6	599.9	123.6
	NO FIRE	350.2	168.4	39.0
r=5%	LOW	350.2	336.9	39.0
	MEDIUM	700.4	561.6	39.0
	HIGH	700.4	336.9	39.0
	NO FIRE	263.9	95.6	12.6
r=7%	LOW	263.9	191.3	12.6
	MEDIUM	527.7	318.8	12.6
	HIGH	527.7	191.3	12.6

Table F.4: Present Values for Wildlife in the Mixedwood Vegetation Type

Discount Rate	Fire Intensity	Time Since Fire (years) 15	30	60
r=3%	NO FIRE	467.3	299.9	123.6
	LOW	934.6	299.9	123.6
	MEDIUM	1557.8	599.9	123.6
	HIGH	467.3	999.9	123.6
r=5%	NO FIRE	350.2	168.4	39.0
	LOW	700.4	168.4	39.0
	MEDIUM	1167.4	336.9	39.0
	HIGH	350.2	561.6	39.0
r=7%	NO FIRE	263.9	95.6	12.6
	LOW	527.7	95.6	12.6
	MEDIUM	879.7	191.3	12.6
	HIGH	263.9	318.8	12.6

Appendix G

Table G.1: Present Values for Timber in the Coniferous Vegetation Types

Discount Rate	Fire Intensity	Time Since Fire (years) 15	30	60
	NO FIRE	263.2	297.3	122.5
r=3%	LOW	463.2	297.3	122.5
	MEDIUM	231.6	148.6	122.5
	HIGH	0.0	0.0	122.5
	NO FIRE	347.1	167.0	38.6
r=5%	LOW	347.1	167.0	38.6
	MEDIUM	173.6	83.5	38.6
	HIGH	0.0	0.0	38.6
	NO FIRE	261.5	94.8	12.5
r=7%	LOW	261.5	94.8	12.5
	MEDIUM	130.8	47.4	12.5
	HIGH	0.0	0.0	12.5

Table G.2: Present Values for Timber in the Aspen Vegetation Type

Discount Rate	Fire Intensity	Time Since Fire (years) 15	30	60
r=3%	NO FIRE	473.0	303.6	125.1
	LOW	473.0	303.6	125.1
	MEDIUM	236.5	151.8	125.1
	HIGH	0.0	0.0	125.1
r=5%	NO FIRE	354.5	170.5	39.[illegible]
	LOW	354.5	170.5	39.5
	MEDIUM	177.2	85.3	39.5
	HIGH	0.0	0.0	39.5
r=7%	NO FIRE	267.1	96.8	12.7
	LOW	267.1	96.8	12.7
	MEDIUM	133.5	48.4	12.7
	HIGH	0.0	0.0	12.7

Table G.3: Present Values for Timber in the Mixedwood Vegetation Type

Discount Rate	Fire Intensity	Time Since Fire (years) 15	30	60
	NO FIRE	468.1	300.4	123.8
r=3%	LOW	468.1	300.4	123.8
	MEDIUM	234.0	150.2	123.8
	HIGH	0.0	0.0	123.8
	NO FIRE	350.8	168.7	39.0
r=5%	LOW	350.8	168.7	39.0
	MEDIUM	175.4	84.4	39.0
	HIGH	0.0	0.0	39.0
	NO FIRE	264.3	95.8	12.6
r=7%	LOW	264.3	95.8	12.6
	MEDIUM	132.2	47.9	12.6
	HIGH	0.0	0.0	12.6