INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Application of Operations Research in Forestry and Wildlife

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Abstract: Operations research is becoming increasingly prevalent in the natural resource sector, specifically, in agriculture, fisheries, forestry and wildlife. While there are similar research questions in these areas - how to extract and use the resources efficiently and how to account for environmental impacts, there are also differences - the length of time associated with a growth and harvesting or extraction cycle, and whether or not the resource is renewable.
In this paper, we review the most recent and seminal work in all four areas, considering modeling, algorithmic developments, and application in terms of operations research.
Keywords: Wildlife, Forestry, Fishery, Wildfire, optimization

I. INTRODUCTION

Record-breaking fires are ripping through the Amazon — an ecosystem on which the whole world depends. An unprecedented number of fires have raged throughout Brazil in 2019, intensifying in August. There have been more than 80,000 fires so far this year, the most ever recorded by the country's National Institute for Space Research (INPE). (Calma, 2019)

Amazon plays a huge role in pulling planet-warming greenhouse gases out of the atmosphere. Without it, climate change speeds up. As the trees and plants perish, they would release billions of tons of carbon that has been stored for decades — making it nearly impossible to escape a climate catastrophe.

"We don't have an adequate structure to prevent, to control, and to fight the forest fires," Barroso, says. He wants to establish a forest fire protection system in the Amazon that brings together government entities, indigenous peoples, local communities, the military, large companies, NGOs, and education and research centers. "We have to integrate everybody," Barroso says, adding, "we need money to do this, we have to receive a great investment." (News, 2019)

The best fire fighting technique in the Amazon is to prevent them in the first place — by controlling deforestation and managing agricultural activities. And this is where the application of Operation research comes in. Operations Research techniques in forestry are numerous. The most widely used mathematical models are: linear programming, integer programming. goal programming, dynamic programming, network analysis, and computer simulation. The demand for improved efficiency, combined with multiple-use requirements, and the availability of computers, will result in a continuing increase of the use of Operations Research in natural resources in wildlife, forestry and agriculture managerial decision-making.

Operations Research is the development and application of scientific optimization techniques for the management of organizations or systems. From early on, natural resource management has been recognized as an area extremely suitable for the implementation of Operation research. Five factors, which are common to most management problems in forestry, make it possible to use a wide range of Operation research solution procedures which have been developed to assist in managerial decision making. These five factors are: a complex environment; one or more specific objectives; doubt about the best course of action; decisions constrained by limited resources; and the possibility to quantify the problems. Fishermen are interested in predicting fish populations, allocating fleet effort, and avoiding fish depletion. Behavioral models are also relevant in this context. Decisions in forestry and wildlife are centered around the strategic, tactical and operational levels of managing plantations and public lands to meet demands while adhering to supply restrictions, which are coupled with events such as forest fires and policies. (Bjørndal, 2017) Each Operation research solution technique involves the construction of a mathematical model. This is a set of mathematical statements that collectively describe the workings of an organization or system. Mathematical programming, a sub-discipline of Operation research, involves the use of these mathematical models to solve managerial decision making in each case depends on the nature of the problem, and can be deterministic or probabilistic; analytical or numerical; linear or nonlinear. This paper describes a number of mathematical programming techniques and their application in forestry and wildlife. (Buford, 2014)

A. Research Objectives

Understand the application of Operation research in real life fields of wildlife and forestry.Find the importance of the Operation research mathematical models like linear programming, integer programming. goal programming, dynamic programming, network analysis, and computer simulation and elaborate its use in the wildlife industry. Furthermore, outline and analyse strategic approaches with reference to OR like optimality.

B. Research Methodology

The method used for conducting the research was a qualitative approach under which numerous research papers were studied and analyzed and the application of Operation research is seen whether it is evident or not in the industry and what modifications and changes could help in making the usage more applicable.

II.   LITERATURE REVIEW
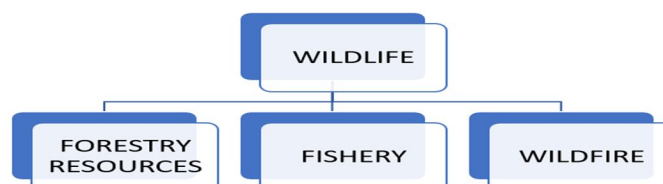
A. Forestry Resource

Forestry includes creating, managing, conserving forests and resources associated with it, for human and environmental benefits. Forest ecosystem is one of the most important components of the biosphere. In early ages, Forests were mainly used for timber production, but now, uses of forests include recreational activities. Urbanization and expansion has led to deforestation and extinction of various species of trees and wildlife. Hence, we need to optimize the methods of sustainably obtaining forestry resources using Operations research to conserve forests.

B. Classic Optimization Techniques

Linear Programming is often used in forest management for strategic planning situations, as well as for timber harvesting schedules. Other situations are the presentation of non-linear objective functions and constraints, which led to the use of Non-linear Programming. Unlike LP and NLP, problems involving discrete decision variables are included in these models, with the integer variables mostly used being the binary ones. When the problem includes several interrelated decisions, linear programming may not be the most efficient method. Instead, Dynamic Programming provides an efficient procedure to solve this kind of problem (Ezquerro, Pardos, & Diaz-Balteiro, 2016).

C. Metaheuristics Methods

Sometimes it is difficult to solve different optimization problems, thus some iterative procedures have been developed. These so-called Heuristics , although later they were denominated Metaheuristics . Under these names different techniques have been encompassed and they are frequently applied in problems associated with forest management, but do not ensure the attainment of a global solution. One of the most popular ones is Simulated Annealing, while other metaheuristics techniques often applied to forest management problems are Tabu Search, Genetic Algorithms, and a Heuristic optimization technique created for tactical forest planning (Pukkala & Kurttila, 2004).

D. Multiple-Criteria Decision Making Approaches

The main Multi-Criteria Decision Making methods (MCDM) are used when the Decision Maker is faced with problems in which several criteria show conflict between each other. These MCDM methods have initially been assembled into two broad groups according to whether the problem is of a continuous or discrete type, although this does not mean that some methods habitually employed for continuous problems cannot be applied when a selection between a finite set of solutions has to be made. Some reviews of the application of these techniques to solve diverse forest management problems are Multi-Objective Programming, Goal Programming, Compromise Programming, Multi-Attribute Utility Theory, with Simple Additive Weighting Method, Analytic

Hierarchical Process, ELECTRE, and Preference Ranking Organization Method for Enrichment Evaluations to be used when the problems are of a discrete nature. Moreover, it should be noted that, on many occasions, there are hybrid methods which combine not only various MCDM methodologies but also techniques like MH ones with MCDMs. In a recent review on applications of MCDM methods to forest management, it was coined the term "hybrid approaches" to integrate an MCDM technique and other decision making ones.

E. Other Techniques

Sometimes these OR techniques have been used to aggregate individual preferences. These aggregations belong to the group decision-making techniques which do not exclusively use OR methods, although there are many examples where, for instance, MCDM and GDM methods have been merged (Ezquerro, Pardos, & Diaz-Balteiro, 2016).

F. Multiple-Objective LP in Forest Management

The paper presents the applications of operations research in forest management. In this paper, multiple-objective linear programming (MOLP) has been attempted. The problem faced here is of resource allocation by an operating subunit of Mark Twain National Forest in Missouri. Forests used to be managed with the primary purposes of timber production and disease and fire prevention in mind. (Ralph E Steuer, 1978) Today, the Multiple Use and Sustained Yield Act and modern trends toward outdoor recreation have resulted in more being expected from national forest properties than their limited resources can supply. To allocate optimal amount of two methods were used-

1) *The Weighing Vectors:* In this method, weights were assigned to five considerations, which corresponded well with intentions of forest planners' but gave poor results. Those considerations which were different from those of forest-planners' purposes led to much better results. The multiple- objective linear programming method with interval criterion weights was also tried which gave results in favor of unrealistic criteria.

2) *The Interactive Approach:* This method did not include any weighing of consideration and resulted in objectives with algorithmic procedure. The procedure generates a small group of solutions, rather than one solution at each iteration for presentation to the decision maker. A one-two-week time around is taken in order give performers adequate time to perform and reflect upon each other's input. The algorithm is built to work within a predetermined number of iterations. By maintaining a record of each iteration, the decision maker can change in the early decision itself if he feels an error might have been made. (Ralph E Steuer, 1978)

G. Operations Research Models and the Management of Agricultural and Forestry Resources

This research paper helps in comparing the operations research in agricultural and forestry resources. we must consider the sustainability of the underlying natural system. For agricultural and forestry resources, sustainability implies imposing constraints on the model to ensure that the harvest rate of the resource does not surpass its natural regenerative capacity and that we maintain the financial rate of growth. Second, we must consider the relationship between production processes and general environmental, economic and social issues. (Andres Weintraub, 2006)

1) *Agriculture:* There are two levels of planning: farm level and regional-sector level. Researchers have used LP models at the farm level to assess and to simulate the economic impact of agricultural policies on farmers' incomes and production patterns. In regional sector, objectives used in farm level are economically unjustifiable due to changes in supply of outputs. The objective function is to maximize social welfare, measured by the sum of consumer and producer surpluses. The purpose is to find a pure or mixed strategy that optimizes the decisions of the decision maker. (Andres Weintraub, 2006)

2) *Forestry:* LP model is used for long range harvest planning. In developed countries where ecological issues, biodiversity, and preservation took precedence over timber productions, where preservation of original species is the goal. The decision making in forestry is divided into strategic or long term, tactical or medium term, and operational or short term. (Andres Weintraub, 2006)

H. Comparative Analysis

In both the fields, the decision makers are agencies and managers. The common problems are faced by both industries, such as scarcity, concern for the environmental effects of production, and the need for efficient production processes. The two areas differ in the nature of the resources and the way they are handled, time horizons considered, planning and operational processes, and environmental impacts.

In agriculture, most decisions are operational for which manager needs data on prices, yields, and costs. In forestry, Analysts have collected data concerning the environmental impacts of forest managers' decisions. Environmental issues are increasing due to increase done environmental damage. In forestry, environmental issues play a major role, while in agriculture, managers are concerned with protecting soil.

In agriculture, use OR is increasing with technological advancements. The most common type of OR models used are LP, simulation risk programming. In forestry, the use of OR models is broad for problems ranging from strategic forest planning to operational harvesting and transportation decisions. The OR techniques used are LP and mixed integer LP models.
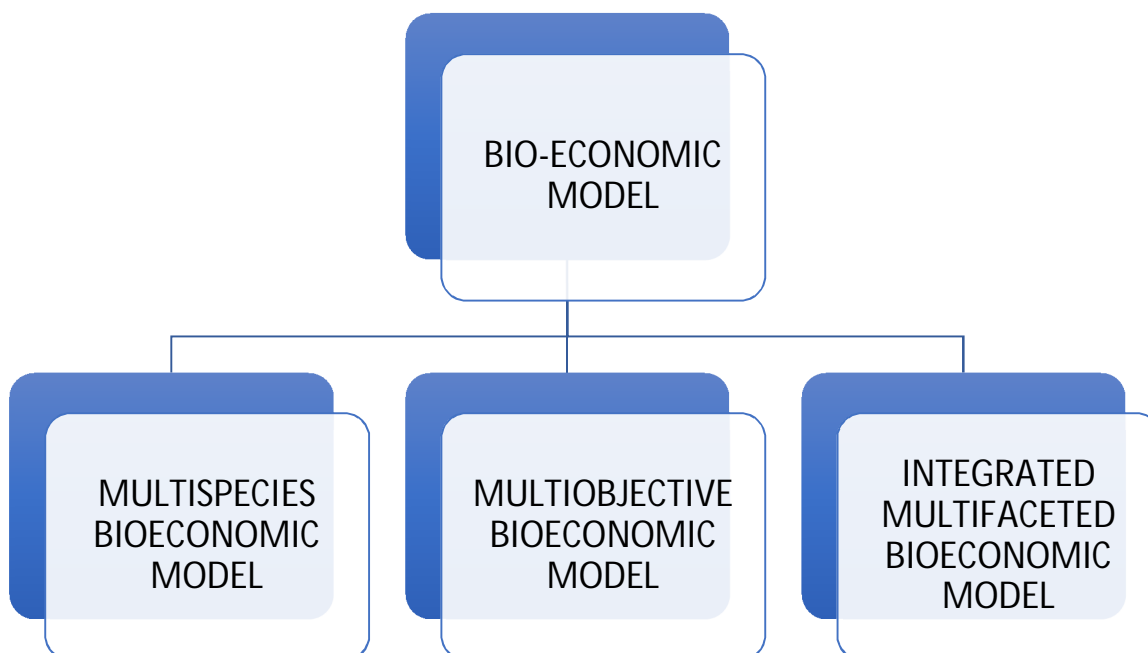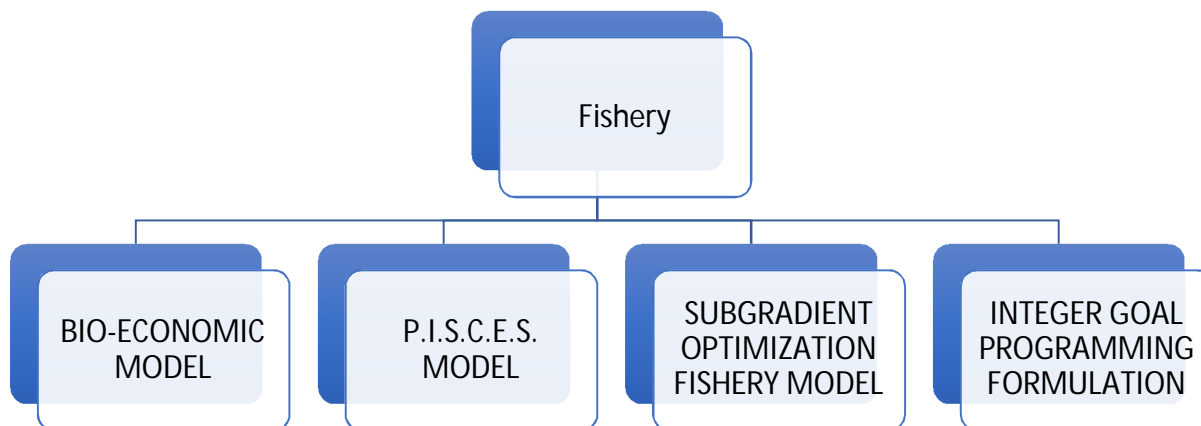
I. Fishery Industry

Fishery Industry is the taking of fish and other seafood and resources from oceans, rivers, and lakes for the purpose of marketing them. In the early 21st century about 250 million people were directly employed by the commercial fishing industry, and an estimated one billion people depend on fish as their primary source of animal protein.

Operations Research can be applied in the fishing industry with various models for integrating the various biological, economic and social factors.

1) *Bio-economic Model:* This is a quantitative model characterized by the fact for integrating the human and the natural sides of fisheries equation to economic elements. This linking may be considered a quantum leap in Fisheries analysis. (Charles, 1994) It is based on the behavioral and optimization models.

The various bio-economic models are as follows:

a) *Multispecies Bioeconomic Model:* This model talks about the multiple species that are available in the tropical region and the use of a single species model would have inaccurate conclusions. The diverse components are rarely given attention and emphasis is only on biological or economic aspects.

b) *Multi Objective Bio-economic Model:* The objective by the management includes a lot of objectives, which can be resource conservation, economic performance, maintenance of the fishing community and their habitat and viability (Charles, 1994). These objectives are usually not complementary, hence balancing and finding optimality is very difficult with these conflicts present. Dynamic Programming is one of the examples. Here a weighted sum of the objectives is taken to form a function for solving.

c) *Integrated Multifaceted Bio-economic Model*: This is an extension to Bio-economic modeling and incorporates the social, political factors as variables too. This is a complex methodology and hence requires highly qualified researchers. This is difficult but crucial in achieving accuracy in developing nations such as India wherein fisheries management is impossible without considering the socioeconomic consequences.

2) *P.I.S.C.E.S. Model:* Participatory Institutional Survey and Conflict Evaluation Solving is a machine-processed model. It uses the Simulator output, which gives the output, which is the prediction of number of angler days, and helps the resource allocation and management policy. The cost of implementing can be discerned by the input too. The model is designed to use techniques of *Statistics* and *Monte Carlo Simulation* (Lackey, 1974). The MCS is gives out expected values, which are actual predictions while standard deviations here give the measure of risk associated with fishing. This engages 50 iterations for producing each prediction. The Minimum crowding and maximum angler days relationship helps widely in the conservation of fish and at the same time keeping the industry profitable.

3) *Sub gradient Optimization Fishery Model:* This is the model, which uses decomposed pricing method for determining the optimum catch of fish and not harming the aquatic life by over harvesting fish and creating an inventory which may or may not be used. This method is done by dualizing the constraints and then solving. It needs more scrutiny to understand the feasible solution. (Geoffery A. Meester, 2004)

4) *Integer Goal Programming Formulation:* Integer goal programming formulation is a mathematical approach in reserve siting and conservation problems. It helps in forming a network of reserves of fish. It uses Linear Programming as a part for calculations. It looks for reducing cost of the reserve and inventory holding. The weights are assigned on the type of fish and the rarity and demand and importance in the market and to the ecology. (Marius Radulescu, 2010)

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J. Wildfire

A wildfire is an uncontrolled fire in an area of combustible vegetation occurring in rural areas. Depending on the type of vegetation present, a wildfire can also be classified more specifically as a brush fire, bushfire etc. (wil1). Operation research involves the use of various tools such as Mathematical programming, Integer programming etc. in order to assist bushfire manager to analyze and interpret various alternatives and make decisions in the challenging environment. It also uses analytical approach to aid decision making in the challenging environment moreover operation research helps in making plans and doing budgeting to stop wildfires it further helps in purchase of equipment, deployment of resources etc. (Minas J, 2012).

III. METHODS FOR HANDLING COMPLEXITY

A. Mathematical Programming

It helps to solve complex problems consisting of a large number of interrelated decisions together with resourcing and other operational constraints,

There are various categories of Mathematical programming are-

1) *Linear Programming:* It can be formulated as a linear combination of the decision variables. Linear programming model helps in fuel-reduction treatments, which helps to mitigate the effects of a particular "target fire" with a known origin and spread behavior.

2) *Integer Programming:* This models feature inputs or outputs that are required to take on discrete whole number values, In case of wildfire Donovan and Rideout (2003) helps to determine the optimal mix of fire fighting resources to dispatch to a given fire to achieve containment with minimal resultant costs and damages it further helps to tackle the problem of scheduling multiple fire-fighting resources

3) *Dynamic Programming:* This model helps to determine the most efficient mix of available initial attack resources to dispatch to a fire. Paper offers a powerful computational tool for finding the most efficient dispatch of available suppression resources to a fire. It also can provide a significant amount of information on economic trade-offs of alternative suppression strategies. This information can be very important to dispatchers when faced with the uncertainty of additional fires and a need to allocate resources between fires (R.Wiitala, 1999).

4) *Problem Structuring Methods:* Problem structuring is a technique that helps to map the nature or structure of a situation that some people want to change. It has two parts decision conferencing and expert judgement elicitation.

Decision conference is used in major wildfires to facilitate dialogue between stakeholders and aid recovery-phase planning. Whereas expert judgement elicitation methods have been used to estimate fire containment probabilities and fire-line construction rates.

B. Methods For Handling Multiple Conflicting Objectives

1) *Multi-objective Optimization:* Wildfire management involves various agencies and groups which have different priorities and objectives which conflict with one another, for example frequent planned burning can provide additional protection to build assets but may have a negative impact on biodiversity. Wildfire managers are required to consider potential impacts on non-market values such as: ecosystem health, conservation of flora and fauna, water quality and cultural heritage. Ascertaining a monetary value to these items would be an expensive, time-consuming and uncertain exercise. This lack of a common currency makes it difficult to evaluate and compare the outcomes of decisions or strategies. Multi-objective optimization is a technique that is suited to these types of problems.

C. Methods for Handling Uncertainty

1) *Simulation:* Simulation is an approach used to model real-life stochastic systems that evolve probabilistically over time. Wildfire managers are required to make difficult decisions in conditions of uncertainty. Simulation is one of the most robust and easily applied methods for consideration of uncertainty in decision support systems.

IV. RESEARCH FINDINGS

The findings concluded from the above research are as follows:

1) Classic optimization techniques like linear programming and non-linear programming although extensively used cannot be efficiently used when the problem includes several interrelated decisions. Dynamic programming is a more efficient method to solve such problems.

2) Metaheuristics methods are frequently applied in problems associated with forest management, but do not ensure the attainment of a global solution. Simulated Annealing (SA) is one of the most popular metaheuristic methods used.

3) Multiple-Criteria Decision Making Approaches (MCDM) are used when the Decision Maker (DM) is faced with problems in which several criteria show conflict between each other. On many occasions, there are hybrid methods which combine not only various MCDM methodologies but also techniques like MH ones with MCDMs. In a recent review on applications of MCDM methods to forest management, it was coined the term "hybrid approaches".

4) There are many applications in which the random or uncertain future is considered, including stochastic techniques. Sometimes these OR techniques have been used to aggregate individual preferences which do not independently use OR methods.

With the increasing importance of environmental issues, the OR tools, especially the mathematical programs, are suitable for dealing with environmental externalities in decision making. The new uses of forest such as recreation activities, there are now multiple objectives to consider. The multiple objective linear programming method provides versatile approach to allocate resources. One of the most commonly faced environmental issues is climate change. In one of the latest articles published by Hokkaido University, climate change can alter tree demography in northern forests. As per the study, the rise in temperature and precipitation levels has negatively affected the growth of coniferous trees, proving the need to focus on environmental issues. (University, 2019)

The Bio-economic model is made for data sparse fisheries but its application has been limited and are currently also not been utilized properly for management of fishes and the reason for its minimal use can be the high cost for implementation.

The PISCES model has a lot of potential to help in the management but the expertise required and the collection of data of variables can be very hectic and if any variable is not considered then the preciseness of the analysis is lost and it would become unserviceable.

Sub gradient optimization fishery model uses decomposition pricing which is a factor that is effective but is still under experimental stage and its application for now cannot be commercial and be very useful for determining the desired solution. Once it is established appropriately then it will become a huge asset to the sector.

Integer Goal programming formulation is a very ambitious model which will not only give the profitability and conservation of fish but will help in defining the boundaries for marine reserves ultimately help in conserving marine biodiversity. It can be applied and would help in finding long-term solutions for the national parks and sanctuaries. (Thompson, 1995)

Operation research is widely used to address some of the major challenges in wildfire management, which includes complex conflicting goals or objective and uncertainty etc. Many of these methods complement each other and can be used in place of each other. In order to handle complexity we have various operation research models like mathematical programming Integer programming etc. which help in finding optimal mixture of resources to fight fire , than we use Multi-objective optimization which helps to solve the problem of conflicting objectives and after this we have various model to solve the problem of uncertainty as most of the wildfire managers are required to make difficult decisions in conditions of uncertainty or ever changing environment thus helping to reduce the social, environmental cost of wildfire.

In the recent article by Colorado State University, it has been stressed to reduce wildfires as Colorado State University scientists have said that Wildfire smoke seems to elevate levels of ozone, a nasty air pollutant with proven adverse health effects such as skin cancer, asthma etc. The ozone layer of Earth's atmosphere Good up high as it protects us from UV radiation from space but bad down where we breathe, it damages lungs and destroys crops and ecosystems. With climate change predicted to increase overall temperatures and thus the intensity and frequency and wildfires which would ultimately cause ozone depletion. This is one of the major reasons we should reduce wildfires. (Manning, 2016)

V.   LIMITATIONS

Facing lack of resources like information and comprehension, complete understanding of the models wasn't effective and hence we could not develop a statistical analysis for the same.

VI.   CONCLUSIONS

Wildlife is an integral part of the ecology and has been contributing in many ways to the environment and to mankind. Fisheries are an industry, which is very ancient and has been a source of income and food to many.

Application of OR in this industry is very scarce and minimal and hence the sector is not at optimality and the conservation of the species is not happening to its fullest. The models mentioned can be used more often but due to its high cost for implementation and high time costs make it difficult to apply.

The forestry resources with multiple objectives and uncertainties of environmental issues, Operation research is needed to conserve forest by optimal allocation of resources. Wildfire management is a subset of disaster management and it is necessary to minimize the loss for conservation of resources, lives and habitats.

The application of OR in wildfire has helped to a optimal mix of resources to put out the fire and complex decision making. It is used but has a scope of more application in case of such emergencies.

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