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The 19th Symposium on Systems Analysis in Forest Resources

Estes Park, Colorado, USA

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Slack and Scarcity in Wildfire

Matthew Thompson

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ABSTRACT – Keynote on July 25, 2022

In this talk I will explore themes of slack and scarcity and how they relate to efficiency and risk in wildfire. I will first discuss slack and scarcity in the context of incident response and then scale up to the interagency system that prioritizes and allocates resources across incidents. Emphasis will be on how enhanced prioritization, logistics, operations, and proven fire analytics can support synergistic efficiency at fire incident and system scales. Lastly, I will discuss how the concepts slack and scarcity may apply to other contexts such as systemic wildfire risks in utilities and critical infrastructure.

Key words: efficiency, fire risk, systems, incident response

The DecisionES project: Decision Support for the Supply of Ecosystem Services under Global Change

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ABSTRACT – Keynote on July 27, 2022

Pressures on forest ecosystems are very likely to increase as a consequence of socioeconomic and demographic trends. A growing population will demand more products (e.g., wood) to be extracted from forest ecosystems. At the same time, these harvesting activities and their interactions with global change drivers will impact the sustainability of the supply of a wider range of non-provisioning services (e.g., wildfire protection, water, and biodiversity).

DecisionES is a 5-year project (2021-2026) funded by the Marie Skodowska-Curie Research and Innovation Staff Exchange (RISE) action under the European Union H2020 program. The DecisionES general objective is to enhance forest management planning and policy analysis by evolving an integrated and multifunctional ecosystem services supply approach thus effectively contributing to delivery of services under climate change. Different models and methods will be developed and encapsulated in computer-based tools designed to effectively address concerns with the sustainability of the provision of ecosystem services.

DecisionES plans to realize its strategic vision and general objective through the integration of complementary state-of-the-art multidisciplinary expertise available in its beneficiary and partner institutions. The consortium includes highly qualified research institutions in ten countries (i.e., Spain, Portugal, Finland, Sweden, Costa Rica, Chile, Brazil, Canada and USA) that share complementary interests in key scientific disciplines for an ecosystem services supply chain.

Key words: non-provisioning services, forest management, multidisciplinary, supply chain

Strengthening forest resilience, harmonising stakeholder interests and ensuring sustainable wood flows: ONEforest – a multi-criteria decision support system

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ABSTRACT #5

Worldwide forests are expected to contribute to climate protection as well as to fulfill a variety of functions, e.g., a steady supply of wood for the wood processing industry, retention of rainwater, protection against avalanches and erosion, place of recreation for tourists. But nowadays forests are facing major challenges due to climatic changes. Forests are increasingly prone to storms, insects and droughts. As a result, forest management decision making regarding the enhancement of forest functions is becoming more and more difficult and complex.

To support stakeholders to make optimal decisions in the forest and timber value chain, the ONEforest project aims to present a multi-criteria decision support system. A total of 19 partners from eight European countries, primarily universities and colleges, are involved in a three-year project: The ONEforest project. The researchers investigate how the forest as well as the forest and timber value chain should be holistically evaluated under economic, ecological, and social aspects in four biogeographical model regions (Mediterranean forests in Spain, Alpine forests in Switzerland, continental forests in Germany, and boreal forests in Estonia). As an outcome, different scenarios for the next 30 years are developed in order to map a future-oriented forest management and timber industry. This decision support system is based on different scientific methods: Besides policy and stakeholder analyses, forest growth models are updated and large databases of forest and timber statistics are generated. A newly developed multi-criteria decision support system, a dynamic value chain model as well as extensive life cycle assessments provide information for decision-making to stakeholders worldwide by assessing sustainable forest management, synergies and trade-offs of forest ecosystem services, reliable wood supply, and stakeholder interests through forest and timber value chain indicators.

Key words: multi-criteria decision support system, sustainable forest management, forest ecosystem services

System Analysis of Wildfire-Water Supply Risk in Colorado, USA with Monte Carlo Wildfire and Rainfall Simulation

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ABSTRACT #9

Water quality degradation from contaminant mobilization and transport after wildfire threatens communities that rely on surface water from fire-prone watersheds. We developed a Monte Carlo simulation method to estimate the likelihood of wildfire impairing water supplies by combining probabilistic sets of hypothetical future annual wildfire and rainfall activity. We considered water quality impaired if it exceeded turbidity limits for treatment by modeling wildfire burn severity, postfire erosion, sediment transport, and suspended sediment dilution in receiving waterbodies. System-level water supply disruption was then investigated by examining the impairment status of water supply components and their contributions to system performance. Our results for a multi-source water system in the Front Range Mountains of Colorado, USA indicate that wildfire may impair water quality in 15.7-19.4% of years for diversions from large watersheds, but water quality impairment in off-network reservoirs should be rare, especially for large reservoirs with small local watersheds. System redundancy nearly eliminated disruption risk for a pair of substitutable terminal sources (99.9% reduction) and meaningfully reduced it for alternative conveyance routes (4.3-25.0% reduction). Alternatively, disruption risk was almost doubled by the dependency between reservoirs on a conveyance route. Our results highlight the importance of considering water system characteristics when evaluating wildfire-water supply risks.

Key words: systems analysis, wildfire risk, Monte Carlo simulation, water quality

Retrospective analysis of fuel break effectiveness in two fire prone landscapes

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ABSTRACT #10

Growing wildfire damages in the western United States have renewed interest in the use of fuel breaks to reduce the negative impacts of large wildfires. Fuel breaks are conceptually appealing due to their potential to decrease wildfire exposure with limited fuels modifications intended to facilitate fire suppression at strategic containment locations. Understanding of fuel break effectiveness, or probability of success, is key to informing both pre-fire fuels management and the use of fuel breaks in fire response. We assembled a dataset of wildfire-fuel break interactions over the last decade in two landscapes with widespread use of fuel breaks – Southern California and the Northern Great Basin – to analyze landscape, weather, and fire response factors that influence probability of success. Preliminary results are that fuel breaks successfully held approximately one third of the time that they encounter wildfire in both landscapes. Statistical models of fuel break success developed using multivariate logistic regression, boosted regression, and random forests all show promise for use in planning, with overall accuracies and area under the receiver operator characteristic curve exceeding 0.8. Preliminary results suggest that suppression activities and weather are the dominant influences on probability of success.

Key words: fuel breaks, wildfire risk, suppression effectiveness, performance measurement, machine learning

A new approach for transport cost agreements

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ABSTRACT #11

In practical routing and transports, it is important to find the contractual agreement for the payment between the owner of the transportation service company and the client who agrees to use the services provided by the transportation company. The most common agreement is based on distance. Typically, a linear function c(d)=a0+a1*d, where c(d) is the unit cost for each ton transported between two points with a distance d, and where a0 and a1 are negotiated parameter values between the organizations. This agreement covers all costs, including salary, fuel and maintenance. As the payment is only based on distance, it is well known that these agreements are good on average but when comparing two specific routes with the same start and end points, it typically is unfair. For example, one route may take a motorway for 120 km and another uses low quality private roads for 60 km. The time and fuel consumption may be similar but the payment very different (factor of two) as the same linear function is used. Today there exist standards to define the distance or best route used based on multiple objectives. The system Calibrated route finder is used as a standard in Swedish forestry. The weighted multi-objective provides information for finding the best route and distance. However, the quantitative measure from the weighted objective does not necessarily represent the actual cost of the route as there are parts, e.g., safety and stress, which are not cost drivers. Hence, the function c(d) is not suitable as it does not provide any description of the real "difficulty" (quantitative measure from weighted objective) of the individual route. We propose a new function that balances both the quantitative difficulty and distance to define a new agreement. Extensive tests from Sweden are used as a case study for the proposal. We present numerical results from these tests, both general and more specific with a few selected forest companies.

Key words: transport, routing, contracts

Innovating forest ecosystem management decision making methods

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ABSTRACT #12

This presentation will report research results from the BIOECOSYS project (https://www.bioecosys.com/). We provide information that may contribute a) to build and integrate resource capability models to estimate the impacts of stand-level management options on the provision of ecosystem services (e.g., wood, carbon, biodiversity, resilience to wildfires, protection against erosion, cultural services); b) to combine spatial optimization mixed integer programs with Pareto frontier approaches to provide information about the trade-offs between ecosystem services; and c) to integrate the spatial optimization Pareto frontier approach with a web based platform to implement a procurement auction approach and thus attract monetary commitments for increased supply of ecosystem services. We discuss results from the application of methods and tools developed to address a) to c) to the project case study area, the Sousa Valley, located in Northwest Portugal. It is currently dominated by eucalypt (Eucalyptus globulus Labill) pure stands and mixed stands of eucalypt and maritime pine (Pinus pinaster Ait). Associação Florestal de Vale do Sousa (AFVS) is responsible for the development of the ZIF joint management plan for over 300 forest owners. Stakeholders aim at promoting active forest management and at targeting the supply of a wide range of ecosystem services.

Key words: forest management and planning, ecosystem services, multi-criteria methods

Detection of fire ignitions from lightnings: integration of helicopter flight route planning and lightning classification using optimization and machine learning techniques

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ABSTRACT #13

Lightnings are the major natural cause of wildfires. In Catalonia, located in the Mediterranean basin, firefighting teams try to detect unspotted fire ignitions caused by lightnings after electrical storm events. Firefighters fly with a helicopter using lightning reports provided by the meteorological agency without any other tool than a GPS. The aim of this research project is to automate the data collection process and provide a tool to support the detection process. The research is divided in two parts, the first part is a binary lightning classification tool and the second part is a tool to calculate flight route plans.

The lightning classification tool is an experimental classifier with the objective to identify lightning with a high probability of igniting a forest fire. The classifier uses historical lightning information and meteorological data, such as rainfall, temperature, humidity, etc. and other processed sources of data are added to the classification tool, such as the land cover information, the NVDI index or the standard precipitation index. Several machine learning (ML) tools and algorithms have been tested: Decision trees, Random Forests and Neural Networks. The ML techniques have been tested with different datasets as the available data change during the analyzed period and they also have been tested with different meta-parameters. The classification tool implements only a binary classifier, it does not intend to be a lightning predictor nor a lightning modeler. This classification tool is integrated as a plugin in the QGIS software to provide a common interface with the advantages on visualization or geo-spatial processing that a GIS capable tool can provide

The route planning tool is a flight route planner with the goal to provide a flight route to the selected lightning locations. It considers the lightning hit locations, the field of view from the helicopter, the helicopter flight range and the helicopter base location. Lightning hit locations to be seen from the helicopter are clustered using the previous listed information and the tool computes an optimal route along all lightning groups. The tool is able to deal with all the recorded lightnings or it can narrow the search filtering the lightnings with the result of the classification tool or different logical and spatial filters. This tool is also implemented in the mentioned plugin that integrates in the open source platform QGIS.

Key words: lightning, wildfire, machine learning, classification, optimization, flight route plan

An ecological-economic approach to assess impacts of Eucalyptus Woodlot Expansion in Agroforest Landscapes of Northern Ethiopia

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ABSTRACT #14

The conversion of fertile croplands to Eucalypt woodlots in Ethiopian highlands, as a consequence of its business attractiveness to smallholders raises concerns related to food production, water resources, carbon and other ecosystem services. This study was therefore designed to examine land allocation and plantation management decisions. The emphasis is in the analysis of tradeoffs between economic gains from harvesting Eucalyptus timber, food production, carbon and water use. For that purpose, we consider a 1987 ha agroforest landscape in the Amhara region, Northern Ethiopia. With a nine 1-year periods planning horizon, the study developed and used nine Model I single objective LP models, and analyzed tradeoffs between objectives (LEV, Carbon, VolEI, Crop production, Water use) using an LP based Pareto frontier approach. The study revealed that the objective of maximizing the total economic gain from the sale of Eucalyptus wood poles favored a complete conversion of the available crop land into Eucalyptus woodlot. To meet the minimum annual crop production /consumption/ requirements of households in the study area, the land under Eucalyptus should be limited to 1772 ha, with a sequestration potential of 1.5 to 1.57 X 10^7 kg yr^{-1} of carbon in the above ground biomass. However, this land cover limit should be decreased to 921 ha so as to limit the total annual water use (for biomass production) below the amount available from rainfall (11,000 m^3 ha^{-1} yr^{-1}). Moreover, the study highlighted that maximizing the harvested wood volume or LEV would come at the cost of decreased aboveground carbon stock and volume of ending inventory and higher total water use. It also provided alternative optimal pareto-front points among which decision makers will be able to select their preferred targets. The current study also showed the potential for the application of Pareto Frontier approaches to support the development of effective ecological-economic management strategies and the design of land use policies in an Ethiopian context.

Key words: carbon stock, crop production, Eucalyptus woodlot, linear programming, Pareto Frontier, tradeoff, water use

Review of recent frameworks to assess the relationships between wildfire and ecosystem services and identification of innovation opportunities

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ABSTRACT #15

Ecosystem services provided by natural systems contribute to ecological, economic and social sustainability. The valuation of different ecosystem services over time and place creates a feedback loop that influences governance, resource management, and markets, and in turn affects ecological systems. For this reason, different frameworks are used to assess the relationships and trade-offs between ecosystem services. Forest ecosystems, even when managed, are prone to wildfires. The human-environmental dimensions of a wildfire in forest areas are strongly related to the landscape mosaic and the corresponding ecosystem services. Thus, understanding these relationships contributes to devising viable management strategies that optimize the provision of ecosystem services while minimizing the occurrence or the severity of wildfires.

The impacts of escalating wildfires in many regions suggest a more sustainable coexistence with wildfires. Climate change and overexploitation of ecosystem services on fire-prone landscapes will only compound current problems. Emerging strategies for managing ecosystems and mitigating risks to human communities are a focus of scientific and governmental interest, although greater recognition of the inherent variation of tradeoffs and links between wildfires and ecosystem services is important. Contrarily to earlier simplistic approaches targeting total fire exclusion, these new strategies perceive fire as a natural ecosystem process to be integrated into new frameworks. A more coordinated approach to risk management and land-use planning in these coupled systems is needed. As the scientific literature connecting fire to ecosystem services is evolving and disparate, relevant research often has not explicitly identified the impacts that fire has on landscape ecological functioning and on the corresponding provision of "ecosystem services". Only when the whole spectrum of services under interest is considered will land managers and stakeholders be able to assess the implicit impacts and trade-offs.

It is recognized that there have been growing developments in both forest ecosystem management and wildfire management. However, the assessment methods to evaluate the connections between them must be constantly evolving. The results obtained are well suited to contribute to decision-making and policy development. The objective of this work is to assess the conceptual frameworks that are recently being used to evaluate the underlying mechanisms of the relationship between wildfires and ecosystem services. The motivation of this work is to both contribute to the understanding of current developments and identify innovation opportunities as well as future research prospects.

Key words: wildfires, ecosystem Services, review

Sapling height increment tipping points in beech-dominated forests reflect overbrowsing, which can be reduced by raising the deer harvest

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ABSTRACT #16

Overbrowsing by ungulates significantly impacts forests worldwide. However, it is usually not the single browsing event that leads to sapling mortality, but the little-researched interactions of browsed saplings with their biotic and abiotic environment. As height increment of saplings is a vitality indicator reflecting their status, we aimed to I) determine the importance of individual parameters influencing height growth, II) observe the effects of ungulate browsing in the environmental interaction framework of young saplings, and III) evaluate parameters influencing local ungulate browsing.

We analyzed an extensive dataset of 248 monitoring areas distributed across Germany in beech-dominated forests. Each monitoring area contains a 100m^2 ungulate exclusion and control plot, which were assessed annually from 2016-20. The species-specific mean annual height increment for every plot for all saplings in a 50-500 cm height range, was used as a response variable in a random forest model to investigate aspects I) and II). Browsing probability, as a measure of ungulate impact, and over 25 site and climate variables were integrated as explanatory variables. For aspect III) we used the local browsing probability of the plots with ungulate impact as response variable and extended the explanatory variables with forest fragmentation and local hunting variables.

I) Browsing probability and light availably were the most influential parameters for selectively browsed, admixed tree species (e.g., sycamore maple). II) Height increment showed tipping points, which, when browsing exceeded a certain level, caused a permanent collapse of growth. However, light availability enhanced height increment. III) An increase in deer harvest reduced the browsing probability of selectively browsed species considerably. We conclude that the growth-inhibiting effect of ungulate browsing is a multifactorial phenomenon, which can be mitigated by silvicultural management and efficient hunting strategies.

Key words: height increment, regeneration, tipping points, ungulates, browsing, random forest, light, forest management, deer harvest

An optimization approach to address carbon sequestration in forested landscapes' management planning - an application in Northwest Portugal

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ABSTRACT #17

Forests are key sinks of carbon, as they can uptake and sequester important amounts of CO_2 as well as regulate other greenhouse gas exchanges with the atmosphere. Management decisions and resultant silvicultural practices can largely influence these ecosystems' carbon balance. This research presents an approach to help land managers cope with the need to ensure the provision of multiple forest products and services while contributing to mitigate climate change by carbon sequestration. The emphasis is on combining a landscape-level resource capability model with a mathematical programming optimization method to model and solve a land management problem involving timber production, carbon sequestration and resistance to wildfire targets. Results of an application on a forested landscape in Northwest Portugal show that this approach may contribute to analyze and discuss synergies and trade-offs between these targets. They revealed important trade-offs between carbon sequestration and, both, timber production and fire resistance.

Key words: carbon sequestration, forest management planning, mathematical programming, optimization, trade-offs

Discounting ecosystem services in robust multi-objective optimization – an application to a forestry-avocado land-use portfolio

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ABSTRACT #18

Research about ideal land-use distribution is necessary to best meet the needs of present and future generations. As Earth's land area is limited, allocating scarce land while accounting for uncertainty is one way to meet multiple, sometimes competing interests in a sustainable way. Compromises in land-use are necessary for simultaneously offering regulating, provisioning, supporting as well as cultural ecosystem services. To consider time preferences of people and account for future service provisioning changes, discounting is standard in economics. However, so far discounting has mainly been applied to monetary flows and ignored for many ecosystem services. In multi-objective optimization, selectively disregarding time preference for non-monetary services create bias. We study how discounting a range of ecosystem service indicators influences a public planner's optimal land allocation.

We used a robust multi-objective optimization approach to model a mixed forestry-avocado farm portfolio in South Africa, balancing the provisioning of four ecosystem services, represented by the following indicators: net present value, payback period, carbon sequestration and fertilizer use. For several levels of risk preference, we optimized the land-use shares and analyzed the indicator performance. The objectives for optimization were the provisioning of the four ecosystem services and disservices. Our study included monocultures of pine and eucalyptus, as well as irrigated and dryland avocado orchards. To account for time preferences concerning indicator flows, we applied specific discount rates to each ecosystem service indicator, depending on its character (non-monetary or monetary indicators). We demonstrate that discounting reduces the standard deviations of the discounted sum of the indicators, which leads to less diversified land-use portfolios. To account for discount rate uncertainty, we introduced three indicator sets, each using a different discount rate, which offset the effect of decreasing diversification. Directly discounting non-monetary indicators could offer a promising strategy in land-use planning to face uncertain future provisioning of ecosystem services.

Key words: ecosystem services, social discounting, dual discounting, robust optimization, multi-objective decision-making, land-use planning, ecological discounting

Optimal ordering policy for storage and delivery of forest residues and willow biomass for continuous industrial supply

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ABSTRACT #19

Given the abundance of biomass available in the forest and agricultural sectors, biomass has been demonstrated to be a vital source of feedstock for renewable energy and bioproducts, and a sustainable alternative to fossil fuels. The development of biomass energy projects and other bio-based businesses depends on effective and efficient biomass logistics and supply from forestry and agricultural operations. However, due to a variety of factors such as resource variability, dispersed location, seasonality of harvest, and other characteristics fulfillment on demand requires a systems approach to inventory policy. Improved inventory management practices can contribute to increased competitive advantage and improved organizational performance in every industrial sector. Despite the potential direct and favorable influence of optimized inventory management on biomass supply chain efficiency, inventory management methods are often disregarded or only lightly investigated in the literature of biomass supply chain management. The goal of this study is to establish an optimal inventory ordering policy for sustainable biomass supply chain management in the Mid-Atlantic region of the United States in order to improve biomass logistics and reduce risk to investment. In our proposed ordering policy, an order/procurement is placed at a specific level with a specific volume to meet demand at the lowest possible cost. For a given inventory policy, a sensitivity analysis is conducted to assess the impact of procurement location, warehouse capacity, inventory holding cost, penalty cost, feedstock availability, and demand and supply on the final cost.

Key words: biomass supply chain management, biomass inventory management, optimal policies, forest residues, sensitivity analysis

A systems approach to regional multi-feedstock biomass supply chain models

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ABSTRACT #20

Optimization, simulation and systems modeling are the backbone of biomass supply chain management. This presentation is focused on the development of advanced models for a new biomass supply system in the mid-Atlantic region of the United States that strategically leverages biomass from three complementary and underused sources: logging residues, coppicing willow, and switchgrass. Willow and switchgrass are suitable for cultivation on over 4 million hectares of restored and reclaimed surface mined lands in the study region, as well as on marginal agricultural sites. In addition to these purpose-grown feedstocks, 8 million metric tonnes of forest residues are available annually from timber harvest and other forest management activities in the region. These materials can be used as feedstock for a wide range of bioproducts, including liquid fuels and chemicals, adhesives, 3D printing resins, bicarbonate nanomaterials, and biochar. Achieving the benefits of an expanding bioeconomy in this region will require next-generation supply chain models that facilitate multi-feedstock, multi-process procurement planning to manage biomass supply risk as measured by cost, quality, timing, energy balance, greenhouse gas emissions and other metrics. We present a framework for feedstock supply modeling that includes the use of new heuristics and inventory control methods to solve large, complex problems using empirical production, logistics and procurement data from existing and new conversion facilities. These models explicitly incorporate uncertainty as well as spatial and temporal variability that can intensify risk, with the purpose of improving the design, performance, and efficiency of biomass supply systems to de-risk bioeconomy investment by minimizing time and cost, while simultaneously addressing other constraints.

Key words: optimization, inventory, modeling, supply chain management, biomass, bioeconomy

Optimization, asymmetric information, and ecosystem services auctions: a tour of possible synergies

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ABSTRACT #21

In 2020, Robert Wilson and Paul Milgrom received the Nobel Prize for contributions to auction theory that (among other things) laid the foundation for multibillion dollar markets for a common pool resource: broadcast spectra. Over the previous two decades, agricultural, environmental, and natural resource economists have extended this work, vigorously pursuing innovations in auction theory and constructing a diverse set of techniques aimed at overcoming the unique informational challenges and market failures that can impede efficient, sustainable management. However, uptake of these tools has been halting and inconsistent. Drawing from (1) a pair of systematic literature reviews, (2) an international Delphi study with auction experts from 27 universities and research bodies like USDA ERS, CSIRO, EFI, and INRAE, and (3) experiences from a Europe-wide innovation action, this presentation introduces a selection of emerging auction techniques with close connections to mixed-integer programming, dynamic programming, and multi-objective Pareto methods. It highlights key knowledge gaps, data needs, and suggests possible directions for future research.

Key words: payments for ecosystem services, auctions, subscription games, optimization

Suitable tract bank size: exploration & estimation

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ABSTRACT #23

There are established norms in Swedish forestry as to how many stands should be kept planned and ready for harvest. These ready for harvest stands, also called the tract bank, gives the harvest manager a selection of stands to choose from while scheduling harvests. Too few and the harvest manager might be forced to make bad decisions, too many brings additional unnecessary cost. However, there is little research done quantifying how many stands should be in the tract bank and how that amount changes depending on conditions such as geographic location or what sources are used – source such as contracted harvests or harvests on company owned land.

The purpose of this study was to further our understanding of how uncertainty may affect suitable size of the tract bank. In the first step, how much volume a Swedish forest company has in the tract bank each month over an eight-year period was compared with the industry norm. The second step was to look at how uncertainty in seasonality affects harvest management and defining it as its variation between years. As well as looking at how much variation there is in the difference between the planned volume and the actual volume delivered to the industry. The last step was to develop an inventory model for the tract bank with two sources, based on the variation calculated in step two.

The results show how the studied company generally has less than half of the norm in its tract bank. The initial results from the inventory model also show that the norm might be overestimating the needed amount for the tract bank. But some more validation is needed before presenting the results from the model and drawing conclusions – which will be finished prior to the SSAFR conference and presented.

Key words: harvest planning, harvest management, forestry, inventory modelling, logistics

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A decision support tool for forwarding operations with sequence-dependent loading

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ABSTRACT #24

High productivity in forest harvesting requires efficient forwarding. Planning is complicated by multiple choices of routes and their order, the number and types of assortments, the loading sequence, and pile organization at the landing. This study develops and tests a decision support tool for forwarder routing with sequential co-loading of assortments. Input data is the harvester production file (including GNSS-tracking), placement of landing, and technical data from the harvester. The trail network is generated from the harvester data when devising routes to pick up all log piles, including specific assortments and volumes. Multiple assortments can be loaded along each route, and a certain loading sequence of assortments is preferred and/or required. Sorting time during co-loading varies, depending on the assortment combinations. Route planning is modeled using a set partitioning problem, and the solution method is a metaheuristic based on repeated matching. In addition to routes and loading sequences, solutions include the organization of assortment piles at the landing, depending on the total volume of each assortment. The tool was tested with good results on five clearcuts (3-11 ha) in northern Sweden, by comparing the results with data from actual forwarder production files.

Key words: forest operations, forwarding, routing, skid trails, machine operating trails, sequencing, trail network

Pathfinder – A tool for operational planning of forest regeneration on clearcuts

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ABSTRACT #25

Sustainable forestry requires efficient regeneration methods. In Sweden, 99% of the planting is manual, but finding labor for the arduous work is difficult. An autonomous scarifying and planting machine with high precision, low environmental impact, and a good working environment would meet the needs of the forest industry. Within the work of developing this machine (Autoplant), a tool for creating a global driving plan on the regeneration area is needed. The tool, Pathfinder, plans the routes based on digital elevation models (DEM), depth-to-water (DTW) maps, no-go areas (for culture or nature conservation), machine data (e.g. working width, maximum slope, time for U-turns), and the harvester production (hpr) file. An optional layer with boulders, ditches and windthrown trees could also be used if such data is available (derived from LiDAR or RGB scans). The boundaries of the working area are derived from the hpr file. DEM and DTM are used to calculate slope and sensitive areas, respectively. Route efficiency involves many aspects, but most important is to avoid U-turns. A four-phase approach is used to find the routes. The first uses the DTM to identify larger areas of smaller discretized squares (say 5 by 5 m) with similar slope characteristics. The second phase combines the directions in the squares to form longer paths where the costs of turning can be modeled. The third phase is to generalize the paths in such a way that the width of the specific machine is considered. The fourth phase is to identify a vehicle routing solution where each route satisfies planting capacity (number of plants) and/or fuel capacity of the machine. The set of routes provides the overall planting solution. The decision support tool could be used for any planting machine, but also for traditional scarifiers.

Key words: forest operations, route planning, autonomous vehicles, regeneration, planting, site preparation, soil scarification

Integrated Wildlife and Timber Management for Multiple Objective Models: Establishing Matrices for Assessment of Wildlife Habitat Quality in Managed Timber Stands

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ABSTRACT #26

Wildlife management is intimately related to forest management. Forest management has a long history of using of growth and yield models to predict future yields and wildlife management has a long history of using habitat suitability models to estimate habitat quality for individual species. Often, forest planning and habitat suitability models do not use the same metrics that growth and yield models predict. Creating, maintaining, and improving wildlife habitat is basically manipulating the forest by harvesting, fire, and other treatments. Integrating wildlife habitat into forest management requires the resulting forest conditions to be linked quantitatively to specific focal wildlife species. We relate the structure and composition of forest stands to their potential to provide habitat for 16 focal species important to the forest planning goals of the North Carolina Wildlife Resources Commission (NCWRC). Based on wildlife literature, we identified 11 forest condition metrics (e.g., basal area [BA], % canopy cover) related to habitat quality for the focal species, which could be predicted and tracked periodically using growth and yield models. Multiple forest condition metrics were identified for each focal species, or guild, in order to capture a meaningful summary of conditions in a stand.

We parameterized each metric (e.g., BA 10 – 20 m^2/ha) and qualified those ranges into Best, Good and Poor categories, based on the potential of a stand in that condition to provide habitat for the relevant species, or guild. The determination of the parameter values and quality assignments were based on the values reported in the literature, followed by review and refinement from NCWRC biologists and wildlife researchers. This resulted in a group of matrices relating the potential (Best, Good, or Poor) of a stand to offer habitat to a focal species or guild. Assigning 0.0 – 1.0 values to the Best, Good, and Poor qualifications allows for quantification of habitat values, which synthesizes all condition metric values into a single index and represents the potential for habitat in a given stand based on its structure and composition at a given point in time. This provides areal estimate of wildlife habitat, which can be used as a covariate in linear programming planning models. The lack of reported values for basic condition metrics such as basal area and % canopy cover for several otherwise appropriate focal species indicated knowledge gaps. Additionally, efforts should be made to develop areal based prediction models for important condition metrics like % shrub cover and % native herbaceous groundcover, which are needed to refine habitat quality for numerous potential focal species. Finally, identifying focal species and appropriate targets for forest condition metrics useful in quantitative models during the development of management plans on public lands should efficiently incorporate input from species experts, land managers, and public stakeholders in an established process.

Key words: land management, linear programing, optimization model, forest structure, habitat quality

Optimizing individual-tree harvest decisions in structurally complex, heterogenous-quality stands

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ABSTRACT #27

Foresters, landowners, and land management agencies are increasingly interested in silviculture that maintains or creates complex stand structures. While largely motivated by consideration of biodiversity or other non-timber values associated with complex forests, thoughtfully executed neighborhood-scale silviculture can also increase economic returns from timber production. This study develops a simulation-based tool for modeling financially optimized tree-by-tree harvesting schedules for complex stands in the Northern Forest region of the northeast United States. These stands are often compositionally diverse and heterogeneously arranged, and the value of the products they produce are strongly differentiated by quality. We work within the gap model framework from forest ecology, conditioning each individual tree's growth and its probability of natural mortality on the evolving neighborhood-scale competitive environment it resides in. We develop size-, species-, and grade-specific price functions to assign harvest values to discrete bole sections, and we use a genetic algorithm to specify the financially optimal timing of individual-tree harvesting decisions. We apply this approach to sample data from a northern hardwood forest in northern New York, specifying the harvest schedule and simulating the resulting stand development that maximizes financial returns over a 100-year period. We contrast our results to those obtained from a harvest strategy "optimized" for the same forest using conventional stand-level modeling, where harvesting is specified by percentage of each species/size-class combination, based on averaged quality, and where growth and mortality of each class is a function of aggregate stand-level stocking. We simulate the implementation of this prescription back down at the plot level, constraining optimization so as to keep harvesting consistent with the targets for percentage removals from each size-and-species class and for stand-wide residual stocking. We compare the projected financial performance of the aggregated and plot-level simulations of the stand-level prescription and compare each to the optimized tree-by-tree harvesting schedule.

Key words: optimal harvesting, complex silviculture, neighborhood dynamics, gap model

Updating of forest road networks using Single Photon LiDAR to classify road conditions and identify significant metrics for determining road state in Ontario's Boreal Forest, Canada

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ABSTRACT #28

Knowledge about the impact of roads on forest landscapes is essential for sustainable forest management. Identifying abandoned or decommissioned roads and quantifying their impacts on forest ecosystems is vital for informing landscape management. In Canada, vectorial maps of forestry road networks are available provincially, however often contain inaccuracies. The limited availability of accurate road network data inhibits road impact assessments that use conditions to categorize road state. In this study, we apply a novel approach for updating existing forest road networks and characterize road conditions in forested landscapes in Ontario's Boreal Forest. To do so, we use Airborne laser scanning (ALS), a well-demonstrated tool for characterizing the three-dimensional structure of vegetation and terrain. Assuming that structural descriptions of vegetation cover paired with terrain surface conditions facilitate the accurate identification of landscape features, including forest roads across densely forested landscapes, we classified roads into four states based on drivable width, edge vegetation, as well as surface and edge degradation using high-density Single Photon Lidar (SPL). We investigate the potential for combining updated road networks with random forest modelling to assess the importance of forest structure, topographic variables, and road attributes in predicting road conditions and state. Results show that high-quality roads are easier to locate using SPL data and that the position of these roads correlates with the existing network. The random forest models demonstrate the suitability of SPL metrics for classifying forest roads and that variables driving classification are elevation, forest density, and canopy cover. The relationships observed between road state and forest characteristics inform ongoing regional-scale forest management. The provision of accurate road location data, including the mapping of new unmapped roads as well as pairing information on road state is critical for assessing the cumulative impact of roads over the landscape, on essential forest services, such as biodiversity.

Key words: LiDAR, airborne laser scanning (ALS), single photon Lidar, forestry

Coefficient development using fuzzy sets for wildlife management planning under uncertainty

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ABSTRACT #29

Habitat Suitability Models (HSM) are the standard way to estimate quality of an environment for wildlife species. These models are based on a combination of expert knowledge and field observations, and are naturally uncertain. The resulting information from HSMs are appropriate for filtering through Fuzzy Set models. This paper explores an unconventional methodology for modeling habitat using Bachman's Sparrow as an example to account for uncertainty in HSM estimation. The data set studied used absence/presence (a binary set) of Bachman's Sparrow. The binary set was assumed be a function of landform, cover type, successional age class, forest patch size, canopy cover, and connectivity, which were collected. To account for uncertainty, an Adapted Fuzzy Inference System (AFIS) was adopted. AFIS takes rules based on expert knowledge to make inference about the final HSM score. Fuzzy rules were made following published studies addressing the same data set and traditional HSM for Bachman's Sparrow. We defined 3 fuzzy classes of HSM scores along with numeric intervals accounting uncertainty ("Poor" - [0.0, 0.4], "Good" - [0.4, 0.7], "Best" - [0.7, 1.0]). Two models were compared, the traditional model taken from USDA technical report NRS-49 for landbirds, and the AFIS model. Three states were considered for the uncertainty analysis, the first is pessimistic, second represents the average, and the last is optimistic according to 3 different defuzification techniques. The fuzzy model, although not developed for that particular species, has the required generality to approximate nonlinear behavior characteristic of traditional HSM for Bachman's Sparrow. The AFIS model showed, in scenario 2 - average, agreement with the traditional model. Scenarios 1 and 3 give flexibility to the manager to choose the most accurate status of each stand, which might not be yielded by only the sample, but also by the point of view of the decision-maker.

Key words: fuzzy sets, decision support, habitat suitability, Bachman's Sparrow, Mamdani system

A bi-level model for state and county aquatic invasive species prevention decisions

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ABSTRACT #30

Accidental transport of aquatic invasive species (AIS) on recreational watercraft facilitates AIS movement among waterbodies of the United States. In response, state and county agencies fund watercraft inspection and decontamination at access points at popular lakes. We present a bi-level model for determining how a state planner can efficiently allocate inspection resources to county managers, who independently decide where to locate inspection stations. The bi-level model assumes that each county determines a set of optimal plans, where each plan identifies lakes for inspection stations that maximize the number of risky boats inspected within the county under a different budget constraint. Then, the state planner selects the set of county plans that maximizes the number of risky boats inspected throughout the state subject to an upper bound on the number of lakes that may be selected for inspection stations statewide. We apply the model using information from Minnesota, USA, including the infestation status of 9,182 lakes and estimates of annual numbers of risky boat movements from infested to uninfested lakes. Comparison of solutions of the bi-level model with solutions of a state-level model where a central planner selects lakes for inspection stations shows that when state and local objectives are not aligned, the loss in efficiency at the state-level can be substantial.

Key words: invasive species prevention, bi-level model, integer programming, optimization, tradeoff analysis, Eurasian watermilfoil, Starry stonewort, Zebra mussel

PRISM: A new management scheduling model for United States National Forest planning

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ABSTRACT #31

A management scheduling model is presented for use in United States National Forest planning. PRISM (plan-level forest activity scheduling model) is a linear-programming based tool that responds specifically to the 2012 Planning Rule that directs land management planning on National Forests. PRISM is a goal-programming based model that accounts for disturbances and considers a flexible number of user-generated attributes. The model incorporates a hybrid Model 1 and Model 2 structure. Case studies are provided for the Helena-Lewis and Clark, Custer-Gallatin, and Nez Perce-Clearwater National Forests. Model size, complexity, and solution times are compared as well as applications to evaluate plan Alternatives and the interaction of model solutions with a stochastic state-transition model. Future developments are discussed, including stochasticity of disturbances and additional state-transition complexity.

Key words: US National Forest Planning, management scheduling, goal programming, model application

An integer program to support reorganization of the wildland fire dispatching system in Colorado

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ABSTRACT #33

In 2019, the Rocky Mountain Coordinating Group and the Rocky Mountain Area Fire Executive Council embarked on a project to reorganize the dispatching system in Colorado. Potential changes to the dispatching system included dispatching zone boundaries, the number and location of dispatching centers throughout the state, organizational structure of the staffing at the dispatching centers, the design of the centers themselves (space available, office layout and communications infrastructure), and standardization of operating procedures. During the decision-making process, decision makers identified four key objective areas they hoped to address during the reorganization process: providing high and consistent levels of customer service, fostering resiliency and adaptability of the system to current and future needs, providing for the health and well-being of employees, and stewarding taxpayer dollars wisely. These objective areas each have several specific objectives within them. Because the set of alternatives associated with the potential changes is quite large (i.e., the combination of zone boundaries and cities makes for a large set of alternatives), an integer programming model was developed to identify an initial set of efficient solutions for decision makers based upon quantifiable metrics reflecting their key objectives. In this presentation we will discuss the context in which the need for the integer program was identified, we will present the integer program and results, and we will discuss how the results were presented to and used by decision makers.

Key words: wildland fire, dispatching, integer programming

End-user satisfaction and digital technology needs assessment of a sample of registered foresters in the eastern United States

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ABSTRACT #34

A survey of registered foresters in five eastern states of the United States was conducted in January 2022 to understand their use of digital technologies when managing woodlands. This survey was expected to provide a broad spectrum of opinion on the value of digital technologies to the work processes of registered foresters. Survey respondents were asked about the perceived usefulness of GIS, growth and yield models, inventory systems, databases, and other technologies. They were also asked about their past and current use of digital technologies. If respondents stopped using technologies at some point in the management of their woodlands, the reasons for these decisions were ascertained. If respondents indicated that none of the technologies are currently (or ever have been) of value in managing their woodlands, they were prompted to indicate reasons why, which ranged from applicability to cost and training issues. Results from this survey provide a snapshot of the perceived usefulness of digital technologies in the management of eastern United States forests in the early part of the twenty-first century.

Key words: GIS, forest, survey, decision-making software

Detecting critical nodes in forest landscape networks to reduce wildfire spread

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ABSTRACT #35

Although wildfires are an important ecological process in forested regions worldwide, they can cause significant economic damage and frequently create widespread health impacts. Preventive fuel treatments, such as prescribed burns or strategic thinning of forest stands, are intended to decrease the probability of wildfire spread and reduce the damage to human infrastructure. However, fuel treatments can be difficult to plan effectively in complex landscapes. Limited resources and personnel, as well as imperfect understanding of fire behavior, necessitate careful planning of fuel treatments to maximize their effectiveness.

We present a network optimization model to plan wildfire fuel treatments that minimize the risk of fire spread in forested landscapes. We used a stochastic fire behavior simulation model to estimate the probabilities of fire spread between pairs of forest sites in the area of concern and formulated a Critical Node Detection (CND) model that uses these estimated probabilities to find a pattern of fuel reduction treatments that minimizes the likely spread of fires across a landscape. The use of sophisticated fire behavior simulators helps account for a multitude of factors influencing the spread of fires in heterogeneous landscapes. We also present a model that includes control of the spatial contiguity of fuel treatments.

We demonstrate the approach with a case study in Kootenay National Park, British Columbia, Canada, where we investigated prescribed burn options for reducing the risk of wildfire spread in the park area. Our results provide new insights into cost-effective planning to mitigate wildfire risk in forest landscapes. The model can be reformulated to examine strategies for protecting human infrastructure from wildfires in forested regions. The approach should be applicable to other ecosystems with frequent wildfires.

Key words: forest, network model, wildfire spread, optimization

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Comparing Landscape Partitioning Approaches to Protect Wildlife Habitat in Managed Forest

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ABSTRACT #36

Industrial forestry activities can increase landscape fragmentation, impacting some wildlife populations, particularly Canada's woodland caribou, Rangifer tarandus caribou. To protect caribou in areas with forestry activities, the province of Ontario, Canada, implemented a Dynamic Caribou Harvest Schedule (DCHS). The DCHS spatially aggregates harvest disturbance into regions and distributes them across the landscape to maintain forest patch size-age distributions consistent with a natural variation range. However, the DCHS negatively impacts the cost and availability of timber supply. We compared the DCHS with an alternative zoning approach that assigned the harvest deferral and operational management zones within a large forest area. We compared these approaches using a linear programming model that combined harvest scheduling, forest road construction and caribou protection sub-problems. We formulated the protection of caribou habitat and forest road construction as network flow sub-problems and the harvest scheduling problem incorporated the ecological constraints prescribed by the forest management plan approved by the Province of Ontario. We compared the DCHS and zoning approaches in the Wabadowgang Noopming Forest of northwestern Ontario, a boreal area within caribou distribution zone. For the same volume of sustainable harvest, the zoning approach protected less area but more habitat and old-growth stands over the long term and yielded lower timber supply costs by 1.2-2.2$-m-3 than the DCHS.

Key words: industrial forestry, caribou, optimization, harvest scheduling

Hierarchical governance in pest survey campaigns

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ABSTRACT #37

Large-scale delimiting surveys are critical for detecting the extent of novel pest invasions and often undertaken at different governance levels. In this study, we consider a two-level hierarchical planning of spatial pest surveys – the central government agency with a mandate to report the spatial extent of pest invasion, and regional governments concerned about the possible threat of an outbreak. Central agency plans delimiting pest surveys across multiple administrative subdivisions (counties) in which regional governments could participate in conducting the pest surveys if funds become available. Our goal is to find the optimal levels of cooperation between the central agency and regional governments when the central agency may allocate a portion of the funds to regional governments to reduce the survey cost. We present a bi-level Stackelberg game model that finds optimal levels of cooperation between two levels of government in a large-scale pest survey campaign. The model finds the budget portion and regions where it is optimal to devolve a portion of survey funds to regional governments to improve the survey efficiency.

We apply the model to surveillance of hemlock woolly adelgid, a harmful pest of hemlock trees in Ontario, Canada. Our bi-level model solutions help anticipate the underperformance of pest inspections conducted by regional governments because their goals do not fully align with the central agency's survey objective. The bi-level approach offers a realistic assessment of the governance hierarchies in large-scale delimiting pest surveys because it helps the central agency to account for the utility preferences of the regional governments and endogenize their survey decisions concerning their preferences. The methodology can be adapted to explore cost-sharing strategies in governance hierarchies in other regions and administrative jurisdictions.

Key words: survey, hierarchical planning, optimization, cost-sharing

Retention in wildland firefighters

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ABSTRACT #38

In the past several years, the United States Forest Service has struggled to retain and fill wildland fire positions across the country. This results in a loss of workforce capacity for the Forest Service, which fields the largest firefighting workforce in the United States; the personnel provided by the Forest Service are critical to the multiagency wildfire response system in the United States. A loss of workforce capacity at the Forest Service is particularly concerning as the wildland fire suppression resource dispatching system has struggled in recent years with suppression resource shortages and had to turn down many suppression resource requests for wildland firefighting resources from local fire managers. In this presentation we use fire assignment data, data from the Quarterly Census of Employment and Wages and wage data from CalFire (one of the Forest Service's main competitors for firefighters) to explore the impact that alternative employment opportunities have on retention of federal firefighters. We delve more deeply into retention of Interagency Hotshots, as retention challenges in that specific program have led to some of these critically important crews being unable to retain their Type 1 qualification status.

Key words: wildland fire, workforce capacity, retention

Modelling potential control locations: development and adoption of data-driven analytics to support strategic and tactical wildfire containment decisions

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ABSTRACT #39

Wildfire management has long been driven by a cadre of experienced professionals that rely heavily on their personal experience and judgement to determine the best available holding features to contain actively growing wildfires. In the western United States, the number of large high-severity wildfires has increased dramatically over the past decade, pushing the limits of the fire management system, and highlighting the need for more strategic, data-driven approaches to incident response. Here we present work that builds from an original methods paper published in 2017 that outlined a gradient boosting approach to predict potential fire control locations.

Over the past four years, a series of significant model improvements, informed by its application on more than 200 large wildfires in the western US, has led to widespread adoption of the Potential Control Locations (PCL) model as an important decision support tool for large wildfire management and strategic fire planning across ownerships. With wall-to-wall models developed for most of the western United States, the PCL Atlas can be pre-positioned and easily shared among incident command teams, fuel and fire managers, line officers, and the public to communicate response options and intentions.

Here we detail improvements to the updated model framework, assess its effectiveness as a decision support tool under a range of real-world applications, and outline future research directions to improve the accuracy of model projections. Specific ongoing research topics address improvements to generalized landscape-scale PCL models and development of custom short-term PCL forecasts that account for variability in seasonal fuel loading, daily fire weather, and topographically driven fuel moisture gradients. We also address the underlying data infrastructure needed for PCL modeling and potential for international applications.

Key words: risk management, strategic planning, decision support, containment likelihood, wildfire Response

GreenLane supply chain training laboratory – prototype and test results

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ABSTRACT #40

Nordic wood supply management requires coordination between purchase, production and transport. Improved coordination of production and transport reduces lead-times, degrading and value-loss. The Era-Net GreenLane project (2019-2021) aimed to develop and test supply chain training laboratory environments for reduced value loss in three regions (Sweden, Austria and Norway). This paper presents the prototype and initial test results for the Norwegian coastal case.

The Norwegian case data consists of three years of production and transport reporting from a forest owners association (1100 contracts, 3 assortments from 34 supply areas). Each contract was matched with its surface deposit type and road class to indicate the relative bearing capacity and availability during different seasons.

Three-month training scenarios were selected from a 52-week time series of weather data where temperature, precipitation and snow-depths drive weekly variation in soil and road moisture states. The training includes monthly planning of common goals, followed by weekly decision-making (select contracts for purchase, schedule contracts for harvesting, allocate road-side stocks for transport). The training environment is based on an Excel-document (shared between participants via Teams) which provides maps, decision tables, stock status and KPI-graphics.

The initial test results come from a competition between five two-person teams. The competition score was defined as sum delivery bonus (for meeting monthly mill delivery plans) minus value-loss (for exceeding lead-time limits). The final scores ranged widely (222 to 1,012 NOK). Three of five teams reached a bonus over 1,000,000 NOK. Two teams achieved a value loss below 100,000 NOK. The team with the highest score delivered 97-98% of sawlog and prime pulpwood volumes with 2 weeks of completed harvesting. The team-work was time consuming (6-8 effective hrs per scenario) but gave a realistic reflection of regional operating conditions for training purposes.

Key words: wood supply, seasonal weather, supply chain laboratory, roadside stocks, lead times, value-tracking

Large-scale wildfire mitigation through deep reinforcement learning

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ABSTRACT #41

Forest management can be seen as a sequential decision-making problem to determine an optimal scheduling policy, e.g., harvest, thinning, or do-nothing, that can mitigate the risks of wildfire. Markov Decision Processes (MDPs) offer an efficient mathematical framework for optimizing forest management policies. However, computing optimal MDP solutions is practically computationally challenging for large-scale forests due to the curse of dimensionality, and the computational complexity grows exponentially with the numbers of stands. In this work, we propose a Deep Reinforcement Learning (DRL) approach to improve forest management plans that track the forest dynamics in a large area. The approach emphasizes on prevention and mitigation of wildfire risks by determining highly efficient management policies. A large-scale forest model is designed using a spatial MDP that divides the square-matrix forest into equal stands. The model considers the probability of wildfire dependent on the forest timber volume, the flammability, and the directional distribution of the wind. In this spatial MDP, the agent (decision-maker) takes an action at one stand at each step. We use an off-policy actor-critic with experience replay reinforcement learning approach to approximate the MDP optimal policy. In three different case studies, the approach shows good scalability for providing large-scale forest management plans. The results of the expected return value and the computed DRL policy are found identical to the exact optimum MDP solution, when this exact solution is available; i.e., for low dimensional models. DRL is also found to outperform a Genetic Algorithm (GA) approach which was used as a benchmark for the large-scale models' policy.

Key words: forest management, wildfire mitigation, Markov decision process, dynamic programing, deep reinforcement learning

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Modelling tradeoff between timber harvest volume and Red-breasted Nuthatch population density in Northeastern British Columbia

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ABSTRACT #45

Boreal landbirds, especially forest-associated ones, have been decreasing significantly since the early 70's. There are undeniable consequences of forest management to forest bird populations, especially mature forest areas that feature harvesting activities. Using an aspatial harvest schedule optimization modelling framework (based on the classic Model I formulation), we tested the inclusion of a linear anticipation function that links forest landscape state to Red-breasted Nuthatch (Sitta canadensis) population density in Northern British Columbia. Even though not currently perceived as threatened the Red-breasted Nuthatch nests mainly in mature conifer forests, habitat highly targeted by the forest sector in Western Canada and elsewhere. We developed a set of scenarios, ranging from maximizing harvest revenue to maximizing bird abundance retention, and demonstrate that this approach can be used to estimate the location and shape of Pareto-efficient tradeoff frontiers between even-flow harvest levels and bird population density. The method presented here could potentially be applied to other locations, as well as other non-timber forest values (e.g., threatened species, carbon storage, etc).

Key words: forest management, harvest scheduling, red-breasted Nuthatch, boreal birds, tradeoffs

A prescription writer founded on a Rule-based AI technique - a component of a flexible FMDSS

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ABSTRACT #46

Since the early 1960s, forest managers have been using optimization techniques to address the efficient allocation of resources. Due to the size of our problems, we have depended on computer-assisted methods since then. We often use a set of formulations named model-1 and model-2, which were proposed in the 60s and adapted to the new challenges over the last decades. Several literature reviews show that hundreds of Forest Management Decision Support Systems (FMDSS) worldwide have been developed continuously in this context. What justifies so many different FMDSS is the variety of our field reality and how forest managers intend to intervene in forest growth and landscapes. Also, we have encapsulated the mathematical models inside frameworks that deal with multicriteria, participatory processes, graphical interfaces, uncertainty, and knowledge management techniques. However, no matter how different is the forest or how many layers we have to add on top of the model, we keep using the same set of formulations that depend on the possible alternatives we have to manage the forests, which is the concept behind the of model-1 and model-2 formulations. This work aims to apply the Rule Based System, one of the Artificial Intelligence (AI) approaches, to develop the iGen, a flexible builder of forest management alternatives. iGen allows the forest modelers to define: (1) the attributes of the forest they want to control and how to calculate them; (2) what are the possible interventions managers can do and the rules to sequence them. We will present different types of forests and interventions, the alternatives generated by iGen, and how iGen can contribute to the flexibility of the FMDSS and reduce development efforts.

Key words: Forest Management Decision Support System; Rule-Based Expert System; Forest Planning

Developing transport management processes for multimodal wood supply

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ABSTRACT #47

In the Nordic context, wood supply often involves a mix of road, rail and sea transport. This study focuses on the further development of transport management processes for road and rail deliveries within an integrated forest company in Sweden. The study examines company management practices and transport system KPIs in order to find further development potentials. The host company has an annual wood consumption of over 10 million m3 where maximum transport distances for truck, train and vessel are generally limited to 100, 1000 and 3000 km, respectively.

Transport management processes for truck transport were mapped via interviews with 7 transport managers. Annual, monthly and weekly routines were mapped, as well as supporting information flow and IT-system use. Typical challenges and management styles (i.e. degree of monitoring and delegation of responsibility to hauling contractors) were also categorized. The main KPIs tracked included weekly and monthly delivery precision, as well as responsiveness to variations in terminal or mill demand.

Freight rail transport in Sweden is typically characterized as rigid, primarily as a consequence of the public capacity allocation routines and competition with passenger traffic. However, with considerable geographic variation in seasonal wood availability, there is a constant need for re-balancing of supply volumes between regions and mills. Interviews with company and rail operator managers were therefore focused on flexibility; including current practices and limitations to potential enablers and cost-drivers. The main KPIs tracked included monthly flexibility in transport volume and transport output, as well as the frequency of deviations from schedules and their causes.

The study provides a quantitative benchmarking of current transport management practices and presents potential process improvements both within- and between road and rail transport of roundwood for the Nordic context.

Key words: road and rail transport, roundwood, precision, flexibility

Developing digital solutions for monitoring forest road availability in a new climate

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ABSTRACT #48

In the Nordic countries, planning of harvesting and transport have utilized both winter frost and summer drought to gain access to areas of low bearing capacity. Recent increases in temperatures and precipitation require adapting earlier approaches for maintaining even year-round wood supply.

The bearing capacity and seasonal availability of forest roads in non-industrial forests is often unclassified, and transport planning relies on the local knowledge of experienced transport managers and haulers. This study aimed to capture the resulting trends for road use directly from on-line digital transport messaging. Seasonal road use was tracked in two regions (coastal and interior Norway; three climate zones per region) with 100,000 PapiNet transport messages (loads) per region. Landing coordinates, transport dates and volumes (one PapiNet message per load) were joined to road network data, DTM-variables, quaternary surface deposit types and weekly weather in the respective climate zones (temperature, precipitation and snow depth).

In order to infer road availability, a simple research question was formulated; “For the given weekly weather conditions, how did transport volume vary between groups of forest road characteristics?”. Multivariate PCA was used to capture the aggregated trends. The main results relate to six deposit codes from NGU digital map sources, and their associated texture and water infiltration characteristics; fluvial deposits (codes 20, 50), moraine deposits (codes 11, 12), marine/fjord sediments (code 41) and organic materials (code 90).

This approach, based on implementation of PapiNet transport messaging in current digital infrastructures, ultimately enables real-time tracking of road use and monitoring of inferred availability based on manager/hauler capacity allocation. Capacity allocation decisions could be characterized according to i) necessity (feasible options during difficult weather conditions) and ii) opportunity (acceptable options during good weather conditions). Utilization patterns varied between regions due to their respective climate conditions and distributions of volumes between surface deposit types.

Key words: transport messaging, forest road classification, weather data

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Predictive and prescriptive analytics for efficient Interagency Hotshot Crew assignment

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ABSTRACT #50

We propose an integer optimization model to support the daily assignment of Interagency Hotshot Crews (IHCs) to wildfires, in order to minimize travel distances and crew fatigue over the course of a fire season. This model contributes to the literature by augmenting the treatment of inter-day dependencies and incorporating the rotational queueing constraint that governs IHCs' assignments outside of their home region. We develop an integer optimization formulation that returns assignment decisions in seconds—therefore enabling its practical implementation in the field. We also conduct an extensive computational case study based on historical crew assignments from 2014 to 2019. Results demonstrate the benefits of optimization models to improve IHC dispatch, delivering robust, year-over-year improvements in travel distance while improving compliance with policies governing out-of-region assignments and mandatory rest periods. Finally, we conduct sensitivity analyses to determine the impact of model specifications and practical constraints on travel times and crew fatigue, and we discuss the potential efficiency gains of a fully-centralized process for IHC dispatch.

Key words: fire management, integer optimization, analytics

The need for integrated management of airtankers to support wildfire management operations

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ABSTRACT #51

Wildfire managers need to decide how many of what type of airtanker to purchase, how many to lease and the terms of such leases each fire season, where to home base them, how to deploy then each day, their daily alert status, how they should be re-deployed throughout the day, how they should be dispatched to initial and extended attack fires and how they will be used on the fires to which they are dispatched, keeping in mind, the possibility of sharing their airtankers with other fire management agencies. The system can be viewed as being hierarchical with decisions at each level influenced by and in turn influencing what decisions are taken and what happens in the levels above and below. I will explore the challenges and some approaches to supporting cost effective management of such resources.

Key words: wildfire suppression operations, airtanker management, initial attack, extended attack, hierarchical planning

Tools for stand dynamics and scenario analysis under varying climatic conditions in Spanish forests

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ABSTRACT #52

Forest policy and planning require the analysis of forest dynamics under alternative management strategies and environmental conditions. We present a set of 182 individual tree models for 27 species and species groups in Spain, in order to simulate diameter increment, height increment, tree survival and ingrowth (the latter including the effects of colonization by nearby species). These models are integrated into a forest projection system to perform simulations of forest dynamics, including the effects of climate and forest management, and link the results to the provision of different ecosystem services generated by the forests. The data for the model calibration and assessment are based on the second, third and fourth surveys of the Spanish National Forest Inventory, including 72,346 plots and 1,353,080 tree measurements. These represent the broad gradient of climatic, topographic, environmental conditions and forest types in Spain, from mixtures to forest plantations. The resulting models are assessed for predictive performance, absolute and relative bias, RMSE, and according to the biological behavior of the predictions in long term simulations. These models and projection system provide suppose a unique, harmonized, and exhaustive approach at Spanish level and are a solid basis for the simulation of national or regional forest scenarios, with broad applications in forest policy, planning and management.

Key words: climate change scenarios; forest management; forest planning; ecosystem services; soil water holding capacity; species dispersal

Trade-offs between forest ecosystem services in mountain forest

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ABSTRACT #53

Mountain forests provides several provisioning, regulating, supporting and cultural ecosystem services (ES) such as regulation of hydrological cycles, carbon sequestration, erosion protection, recreational services, non-timber and timber products. We studied the provision of forest ecosystem services under difference forest management options in coniferous forest in the Pyrenean mountain area in Spain. We used a simulation optimization program to evaluate and select management alternatives and the provision of ES associated which them, namely timber production, carbon sequestration, erosion protection and biodiversity. The candidate management instructions were based on continuous cover forestry principles, modifying thinning and intensity of cuttings, and in some cases favoring the persistence of large trees as retention legacies. No management option produced other ecosystem services except timber. Depending on the management alternative and the forest structure some typologies benefit from harvesting e.g. in Abies alba increasing the erosion protection. The final trade-offs between different forest management alternatives were evaluated setting the importance to the management which defined the best combination of ES's. This study provides the possibility to compare optimal results obtained by formulating different variations of the planning problem. In the end the forest owner has the final decision but the knowledge of the trade-offs between forest ecosystem services can help in the decisions process.

Key words: continuous cover forestry, erosion protection, forest ecosystem service, multi-functional forest management, trade-offs

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Data and Tools for Applied Systems Analysis in the USDA Forest Service Southwestern Region

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ABSTRACT #55

This presentation introduces a survey of data, software and models used in operational management of lands located in Southwestern Region of the USDA Forest Service. The survey will cover a range of natural resources including forestry, wildlife, range, fire and hydrology.

Key words: forest service, applied system analysis, data, models

The FIRE-RES project: Innovative Technologies and Socio-Ecological-Economic Solutions for FIRE RESilient Territories in Europe

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ABSTRACT #56

Extreme wildfire events exceeding control capacity are becoming a major environmental, economic and social threat not only in fire-prone regions in Southern Europe and America, Oceania, but also in new areas such as Central and Northern Europe. The EU H2020 FIRE-RES project aims to provide Europe with the necessary capacity to avoid it collapsing in front of Extreme Wildfire Events (EWE), projected to increase as the result of a harsher climate. FIRE-RES is a 4-year project (2021-2025) whose scope is to effectively promote the implementation of a holistic fire management approach and support the transition towards more resilient landscapes and communities to EWE in Europe. FIRE-RES brings together a transdisciplinary, multi-actor consortium of 35 partners, formed by researchers, wildfire agencies, technological companies, industry and civil society from 13 countries, linking to broader networks in science and disaster reduction management. The project will deploy a total of 34 innovation actions across a set of eleven living labs representing different environments in Europe and Chile. Its final mission is to boost the socio-ecological transition of the European Union towards a fire-resilient continent by developing a stream of innovative actions.

Key words: wildland fire, climate change, resilient landscape, social, economic

A fuel management system to minimize damage caused by forest fires

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ABSTRACT #57

We consider the problem of how to manage a forest, and other vegetation in a planning area, in order to minimize the damage that will be caused by future fires. This is a highly stochastic problem given the uncertainty of where and when a fire may ignite and spread. The system is based on models to predict ignitions, how a fire will spread after an ignition, integrated to optimizing decision making models. Significant information is needed to develop the system. It includes information on scars of previous fires, topography, cover and fuel, weather with its uncertainties in prediction, location of roads and towns. Ignition is mainly caused by human action (also by natural phenomena, typically lightning). An ignition probabilistic forecast model based on a machine learning algorithm was built, with over 85% accuracy in tests. A fire spread simulation model was developed (Cell2Fire), using parallel programming, so it is very fast, allowing to do thousands of simulations with small time efforts. A high number of simulations are needed to reflect the uncertainty in fire spread. A straightforward approach to decision making could be to propose a set of actions, like firebreaks. Then multiple stochastic simulations can determine the likely consequences of the measures proposed, like areas likely to burn. In the proposed system, decision making is integrated into the system, sequencing fire spread simulations with new actions derived from knowledge of previous iterations. The optimization part of the system can be based on heuristics, optimality approaches (Mixed integer programming) and Reinforcement learning. We present computational results on real forests in Canada, Chile and Spain.

Key words: fire spread, uncertainty, decision support, optimization, mixed integer programming

DecisionES-BiotaSynthesis - a joint research initiative to deal with complex public forest planning in the State of Sao Paulo, Brazil

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ABSTRACT #58

DecisionES is a network of collaborative contributors gathering approximately 120 researchers from 17 different institutions in the Americas and Europe, committed to synthesize the status quo about supplying and supporting ecosystem services under global change. BiotaSynthesis is a Brazilian center for ecological analysis and synthesis in which a team of more than 50 scientists and graduate students focuses on bringing together socio-environmental sciences and decision-makers to deal with social, environmental and human health climate-change challenging the state of Sao Paulo, Brazil. The Brazilian Forest Code regulates privately owned land in Brazil and determines that every ownership has to set aside a portion of land as forest reserves (FR) and permanently protected areas (PPA). The size of FR and APP varies according to the biome where they are located. Achieving economic feasibility in forest reserves would contribute to the diversification of the very competitive agribusiness industry in Brazil. The strong demand for strategies that are environmentally and economically feasible has promoted the restoration of degraded areas for the management of multi-species native tree plantations. Coordinators of the Decisiones and BiotaSynthesis initiatives are at an initial stage of detecting and contacting public agents in the State of Sao Paulo to map priority areas potentially prone to the development of multifunctional forests. Once mapped, participants of the joint research initiative will design, develop and prototype a system based on multi-criteria optimization techniques that will spatially locate the most suitable areas of interest for a concerted public effort to promote economically feasible, socially articulated and environmentally sustainable production systems. The initiative aims to develop a network that will work on multi-criteria processes that integrate public agents, decision makers and other stakeholders on adjustments needed to promote multifunctional forests and change land use in the state of São Paulo.

Key words: multicriteria, planning, multifunctional forests

Mitigation of greenhouse gas emissions through landscape management

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ABSTRACT #59

Due to the large impact of wildfires on global carbon emissions, effective strategies for their mitigation should be investigated, especially as measures to face climate change. In this study, we propose a strategy to prevent and control wildfires known as Fuel Management in the context of reducing greenhouse gas (GHG) emissions. Specifically, we developed a strategy to locate firebreaks on the landscape, so that the release of GHG emissions resulting from the removal of vegetation in areas allocated to firebreaks is offset by the reduction in GHG emissions as a result of firebreaks' protective action. Our solution approach comprises an integrated simulation and optimization framework, along with a prioritization metric that identifies crucial cells that have a significant influence on the spread of fires on the landscape. The results show that using our localization strategy, an optimum is obtained when 3% of the landscape (crucial cells) is allocated to firebreaks. Our solution approach was tested on a landscape located in Alberta, Canada, whose forest fuels were classified according to the Canadian Fire Behavior Prediction System.

Key words: fire behavior, firebreaks, fuel management, simulation, optimization, Alberta

Learning and fire management: a deep reinforcement learning approach

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ABSTRACT #60

Deep reinforcement learning algorithms have shown remarkable results, having solved a wide range of challenging and complex sequential decision-making problems in industrial applications, robotics, or medicine. However, their applications in fire management are scarce, being a promising opportunity for the field. We present the application of a general DRL framework in the context of landscape management under wildfire uncertainty. We solve the complex combinatorial problem of firebreaks allocation subject to adjacency/connectivity constraints to minimize expected losses due to future wildfires. We extend the formulation including spatial correlation, obtaining a harder sequential combinatorial problem. Experiments indicate the effectiveness and promising results of the framework and its potential application to similar problems in the field.

Key words: sequential decision-making, landscape management, firebreak, combinatorial problem

Deep learning of ALS point cloud data for forest inventory improvement

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ABSTRACT #61

This presentation proposes a method based on an ensemble of machine learning (ML) and deep learning (DL) techniques for forest inventory improvement based on Airborne Laser Scanning (ALS) point cloud data. The aim is to build an efficient decision support tool that can be used to better estimate the wood quantity and quality. The tool was trained using ALS metrics derived from the GeoNB LIDAR data collected in the province of New Brunswick in addition to the Petawawa research forest (PRF) dataset. The results obtained demonstrate the effectiveness of the developed tool that makes it able to better estimate the wood volume in comparison with the most common method used; the Random Forest. More specifically, the proposed method achieves more accurate results than the ones obtained by the random forest model for the following predicted forest attributes: basal area (13.4%), diameter at breast height (8.6%), gross total volume (8%), and gross mass volume (9.9%). In addition, this talk on tree species will be also presented.

Key words: Airborne Laser Scanning (ALS) Point Clouds, LIDAR, artificial intelligence, machine learning and deep learning, ensemble, tree species, biomass volume, area based approach

Using partial cuttings as a solution to mitigate long-term timber supply reductions caused by major insect outbreaks

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ABSTRACT #62

In Canada, major insect outbreaks are part of the natural disturbance regimes of forest ecosystems. The Eastern boreal forest is periodically subject to Spruce budworm outbreaks: the previous one in the late 1970's-early 1980's, impacted 50 million hectares and killed a significant portion of mature trees. More recently, the Mountain Pine Beetle in British Columbia affected 18 million hectares, with a long-lasting effect on timber supply: in interior BC, a 20% reduction of sustainable timber supply is anticipated for the next 40 years, compared to the pre-outbreak period. Climate change is affecting the location, frequency, and amplitude of these outbreaks, that will still be part of the future reality of forest management. After the outbreaks, the shortage of mature stands to harvest is caused by the combination of the alteration of the forest age structure, and the management policies aiming for a non-declining long-term timber supply and the maintenance of the ecological integrity of the landscape, for example by keeping a proportion of mature stands over time. The later tends to increase the age where stands are planned to be clear-cut, beyond the stand-level optimal rotation age. Partial cuttings, like commercial thinning and uniform shelterwood, may be a potential solution to mitigate the mid-term impacts of insect outbreaks on timber supply. At the stand level, these interventions provide an additional opportunity for harvesting over time, without altering the age structure of the forest. We hypothesise that for an outbreak-impacted forest managed under an even-aged regime, partial cuttings in premature and/or mature stands could increase the sustainable timber supply, without increasing the fibre supply cost. A timber supply analysis was done to test the hypothesis, using a long-term planning model based on linear programming, for a 578 km^2 forest management unit dominated by balsam fir (Abies balsamea) in Eastern Canada.. Management scenarios involving 50% partial cuttings (PC) in premature and mature stands, with and without precommercial thinning (PCT), were compared for different supply cost targets. The yields of partially cut stands was modelled using a proportional growth assumption. PCT was assumed to reduce the minimum age for clearcutting by 10 yrs. A non declining yield constrained for the next 150 years was considered, along with a constraint maintaining a minimum of 20% of the productive area occupied by stands 70 years-old and over. The area annually treated by either PCT, PC and clear-cutting (CC) by stand type were the decision variables, and the objective function was the maximization of the minimal harvest volume per period over the next 150 years. Without any supply cost target, the baseline timber supply for spruce-fir with only CC was estimated at 140 000 m^3/yr. The combination of PCT and CT increased the timber supply by 37%, while the single effect of each treatment was respectively +17% and +8%. The maximum supply cost was 48.41 \$/m^3 for the baseline scenarios; it increased by +20% for PCT alone, +27% for PC alone and +26% for EPC+PC. When the maximum supply cost was fixed at 40 \$/m^3, the baseline timber supply remained the same, with an increase of +13% for PCT, +17% for PC and +18% for PCT+PC. The later case equals to an additional supply of 124 000 m^3/yr., which corresponds to 34% of an average softwood sawmill in Quebec. The analysis confirmed that partial cutting can significantly increase the sustainable timber supply from insect-impacted forests, and that the magnitude of the increase is dependent on the target supply cost. Additional case studies are needed to generalize this conclusion.

Key words: timber supply, sustainable forest management, natural disturbance, partial cutting, mitigation strategies, climate change, even-aged regime, long-term planning

Woodshed maps for industry, extension, and woodland owners in the Great Lakes States

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ABSTRACT #63

Managers and decision-makers are often tasked with accomplishing large landscape-scale goals with limited resources. This is especially true when conceptualizing forest product harvesting as a management strategy. This project uses economic modeling to create a woodshed of the great lakes forested region using delivered wood prices for major wood products collected using user group needs assessments for three broad end-user groups: forest landowners, industry, and forestry and Extension professionals. The project's goal is to map procurement zones and a spatial competitiveness index to allow end-users to determine if their forested region is suitable for different types of forest product markets. We conduct network analysis in GIS utilizing the current transportation network, primarily roads and processing facilities (e.g., primary wood processing mills, pulp producers, plywood, OSB), in identifying cost-based procurement zones for primary wood products. To show the market extent and competition, we will utilize existing and potential mill locations coupled with a road network database to determine the geographical extent of each facility's potential procurement zone or woodshed. The output of this project is then used to develop an interactive web-based geospatial tool to map hotspots of market coverage and competition to identify high-priority areas to direct funding. Once the high-priority areas are identified, managers are able to make informed decisions on how to direct funding to these high-priority areas.

Key words: wood products, procurement zones, geospatial tool, transportation cost, market coverage

From the observers to AI - progress in fire protection on the example of Poland

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ABSTRACT #64

Forest fires are an inevitable aspect of our reality. They have been shaping the image of our planet and driving evolution for millions of years. Nevertheless, the progressive development of civilisation and, as a consequence, climate change has disturbed the natural balance. Temperature growth, change in forest species composition and many other factors have ranked firefighting among the priorities of modern times. With the increasing number of fires and growing personnel costs, applying modern tools is becoming not just a need but a necessity.

SmokeD is one of the latest fire monitoring systems in the world. It incorporates numerous state-of-the-art technologies such as specialised smoke detectors, drones, Artificial Intelligence, and Deep Learning.

In the presentation, we would like to show how forest monitoring in Poland has changed over the past eight years. How ordinary watch towers operated by watchmen have evolved into complex and highly advanced monitoring systems operated by artificial intelligence.

Key words: wildfires, monitoring, artificial intelligence

Developing a fuelbreak prioritization model using stochastic fire simulation results

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ABSTRACT #65

Establishing, maintaining and improving fuelbreaks could help fire managers improve fire suppression effectiveness. Prioritizing fuelbreak management needs to consider multiple factors including the likelihood of future fire ignition location, spreading patterns, intensities, and how those established fuelbreaks may interact with fire and influencing fire spreads, i.e. engaged, not-engaged, held, or breach etc. We developed a two-stage MIP model to utilized the spatially explicit footprints of a large number of stochastically simulated fires to inform the first-stage fuelbreak management decisions. Our presentation introduces the general modeling concepts, the MIP model formulation, the input data requirements and the neccessary data processing steps to populate the model. We present a case study from the Southern California that uses this MIP model to support their fuelbreak prioritization effort.

Key words: mixed integer programming, two-stage model, optimization, spatially explicit optimization

Assessing the synergistic value and robustness of ecosystem services in European beech forests under climate change uncertainty

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ABSTRACT #66

Current policy pledges promote the expansion of conservation areas and mixed forests with endemic species. Climate change, however, may undermine these efforts and modify the relationships and benefits related to the ecosystem services provided by forest ecosystems. Hence, managers must account for climate impacts on future forest dynamics, based on the understanding of processes and functions. Here, we address this issue and compute the value of multiple ecosystem services (wood production, carbon sequestration and biodiversity conservation) linked to European beech forests, considering local economic conditions. Moreover, we quantify the uncertainty of future projections due to the inherent deep uncertainty of climate change and stochastic processes affecting the ecological and economic outcomes, including uncertainty in prices, interest rate, and biodiversity and carbon payments. Using a compromise programming approach, we trade the robustness of decisions for their conditional optimality and determine the cost of sustaining ecosystem services. The results show that mature European beech forests may sequester up to 4 tC.ha -1.year-1 and contribute to climate mitigation actions. The optimal management solutions may focus on wood production in regions with higher productivity and wood price. In regions with high productivity and low interest rates, carbon sequestration and biodiversity conservation may be simultaneously promoted by an expansion of forest conservation areas. In general, biodiversity conservation and carbon sequestration acted synergistically. In contrast, wood production displayed trade-offs with the former ecosystem services, especially in countries with higher interest rates and low wood price. Robust optimization was able to find Solutions with lower volatility to the multiple sources of uncertainty aforementioned. In general, this was achieved by a diversification of forest management strategies that enable to dilute the risk to the total profitability of forest management, including payments for wood, carbon and biodiversity.

Key words: robust decision-making, multi-objective optimization, uncertainty analysis

Tropical forest and likely futures: An analysis of different pathways to reach sustainable economic growth in Indonesia

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ABSTRACT #67

Tropical regions are at the center of current climate and biodiversity policy pledges and will play a key role on the attainment of Sustainable Development Goals throughout the 21st century. In Indonesia, commitments to reduce GHG emissions by 26% by 2020, together with a moratorium on clearing of primary forests and peatlands helped strengthen the countries' environmental goals. The country has some of the highest productive potentials (NPP) globally, and experiences significant economic growth based on national resources and growing demand for some of its key products. At the same time, it houses large shares of the global biodiversity and terrestrial carbon stocks. These features give rise to trade-offs among environmental and economic objectives on the land use sector, where economic growth and expansion of agriculture and forestry might occupy areas previously covered by primary forests. Among the primary strategies to reduce the pressure on primary forests caused by the expansion of agricultural frontiers and forest management are the improvement in management practices and production technologies, as well as the enhancement of conservation actions. This study presents a spatially-explicit assessment of Indonesia's agriculture and forestry-sector trajectories, and how these policies influence them, until 2050. GLOBIOM-Indonesia, a recursive-dynamic bio-economic model tailored to Indonesia, is used to assess the impact of agricultural intensification, natural forest and peatland conservation, restoration of degraded forests and rewetting of peatlands as distinctive future scenarios, and evaluate its implications to sustainable development goals (SDGs), including biodiversity conservation, food security and economic growth. Our results show that palm oil and cropland expansion will continue to exert pressure on forests and the creation of conservation areas in primary forests was most effective to avoid their conversion to other land uses. However, we observed a leakage caused by this policy, increasing the pressure over other natural lands, such as shrubland areas. Improved crop management and increased yields consolidated the comparative advantage of Indonesia in global markets and increased the pressure on forests. Conversely, the restoration of degraded forest areas and peatland rewetting increases climate benefits with low trade-off with food and forest production. Together, this highlights a need for inclusive policy making, considering the most optimal combinations of sustainable intensification, conservation and restoration that maintain economic growth and increase food security while preserving carbon and biodiversity hotspots, taking into account leakage both nationally and globally.

Key words: Sustainable development goals, Forest restoration, Food security, Biodiversity, Climate change mitigation

Multi-objective integer programming to aid timber, carbon and deer habitat management in the Tongass National Forest, Alaska, United States

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ABSTRACT #72

The Tongass National Forest of Alaska, USA is one of the largest timber- and carbon stores in the world. This temperate rainforest is also a critical resource for subsistence hunting and gathering for local Native American communities. Designing management plans that would lead to an optimal balance of timber, carbon and habitat for subsistence hunting and gathering is challenging because some of these desired services might conflict with one another. For example, timber harvesting might compromise old-forest habitat which could in turn negatively affect habitat for deer – an essential resource for subsistence hunting. In this presentation, we will describe a multi-objective integer programming model that can schedule harvesting and precommercial thinning activities over a 70-year planning horizon in the Thorne Bay area of Prince of Wales Island. We postulate that quantifying the tradeoffs and synergies behind these services would help Tongass decision makers build consensus among their stakeholders and agree to a long-term management plan. Our scientific contribution is a combinatorial model that relates different landscape elements (e.g., early- vs late successional stage forest habitat) to applicable management actions and ecosystem services such as deer habitat over space and time.

Key words: carbon, hunting, decision making, combinatorial model

A Neural Network Model to Study Factors Impacting the Selection of Hazard Fuel Treatment Types in Colorado's National Forests

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ABSTRACT #73

Hazardous fuel treatments are implemented to reduce the negative impacts from severe wildfires. This paper presents a method that employs artificial neural networks (ANNs) to model potential hazardous fuel treatment locations within National Forests in Colorado. The modeling data was collected from the Forest Activity Tracking System (FACTS) provided by the US Forest Service which contains spatial polygons of fuel treatment locations. Several predictor variables were used to estimate fuel treatment types, including information about fuels, landscape characteristics, anthropogenic features, and wildfirerisk. After multicollinearity testing and normalization, the dataset was divided into training and testing sets. Using the predictor variables as input vectors, a backpropagation neural network was implemented to establish categorical models of hazardous fuel treatment types. Using this classification method, an accuracy of 90.1% was achieved across all prediction fuel treatment classes. In addition, each predictor variable was isolated to determine the importance with respect to the model predictive capabilities. Distance to structures, distance to roads, and elevation proved to be the most important variables influencing the selection of fuel treatment types. These results provide insight into how hazardous fuel treatments are currently being conducted in the National Forests in Colorado and may also help managers select harzard fuel treatment types in future land management decisions.

Key words: fuel treatment, spatial analysis,