Problem Chosen	2023 MCM/ICM Summary Sheet	Team Control Number
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Build an Army of Drones to Fight Wildfires

摘要

Keywords: Fighting Wildfires; Multi-Objective Optimization; Poisson Distribution; Tabu Search Algorithm; Sensitivity Analysis

目录

1 Introduction

1.1 Problem Background

Different species of plants react to stresses in different ways. For example, grasslands are quite sensitive to drought. Droughts occur at varying frequencies and varying levels of severity. Numerous observations suggest that the number of different species present plays a role in how a plant community adapts when exposed to cycles of drought over successive generations. In some communities with only one species of plant, the generations that follow are not as well adapted to drought conditions as the individual plants in communities with four or more species.

最近一篇文章指出，不同种类的植物种群对干旱的适应能力有所不同。特别是，物种之间的竞争较为适中的植物种群在面对干旱天气有着较强的适应能力。相反，竞争较大或竞争较小的植物群落在面对干旱时显得适应力不足。

图 1: Drought Adaptation of Plant Communities

(a) **因干旱导致粮食紧缺**: 据 2016 年联合国世界粮食计划署（WFP）的报道，由于严重干旱，全球粮食产量已经受到重创，预计中美洲大约有 230 万人需要粮食援助，比非洲东部和南部地区的粮食援助还要多。预计印尼、越南、菲律宾和东南亚一些国家将会发生大米短缺。

(b) **中国内蒙古荒原上的植物群落**: 全球气候变化已成为不争的事实，但降水变化本身存在着区域差异，同时未来降雨的不确定性也将继续增大，极端降雨事件，尤其是极端干旱事件的频率和幅度也会不断升高，使得全球干旱区干旱化加剧，对生态环境和经济发展造成严重的威胁和不可估量的损失。因此，对生态系统内各组分如何应对极端干旱事件的研究现已成为全球生态学家关注的热点。

1.2 Restatement of the Problem

我们需要建立一个模型，可以预测在各种不规则的天气周期中植物群落的变化。该模型适用于地球上所有的环境以及不同的地区，并符合以下条件:

- Develop a mathematical model to predict how a plant community changes over time as it is exposed to various irregular weather cycles. Include times of drought when precipitation should be abundant. The model should account for interactions between different species during cycles of drought.
- Explore what conclusions you can draw from your model with respect to the long-term interactions of a community of plants and the larger environment. Consider the following questions:
  - ★ How many different plant species are required for the community to benefit and what happens as the number of species grows?
  - ★ How do the types of species in the community impact your results?
  - ★ What are the impact of a greater frequency and wider variation of the occurrence of droughts in future weather cycles? If droughts are less frequent, does the number of species have the same impact on the overall population?
  - ★ How do other factors such as pollution and habitat reduction impact your conclusions?
  - ★ What does your model indicate should be done to ensure the long-term viability of a plant community and what are the impacts on the larger environment?

1.3 Literature Review

2 Assumptions and Explanations

3 Notations

4 Model Preparation

4.1 Data Overview

这个问题没有直接提供给我们数据，所以我们需要考虑在建立模型的过程中收集哪些数据。通过对问题的分析，我们需要收集中国在植物群落以及面对不规则的干旱天气的相关信息，如：**温度**、**降水量**、**植物群落的组成数据**等。由于数据量大，不方便一一列出，所以将数据可视化展示是一个好方法。

4.1.1 Data Collection

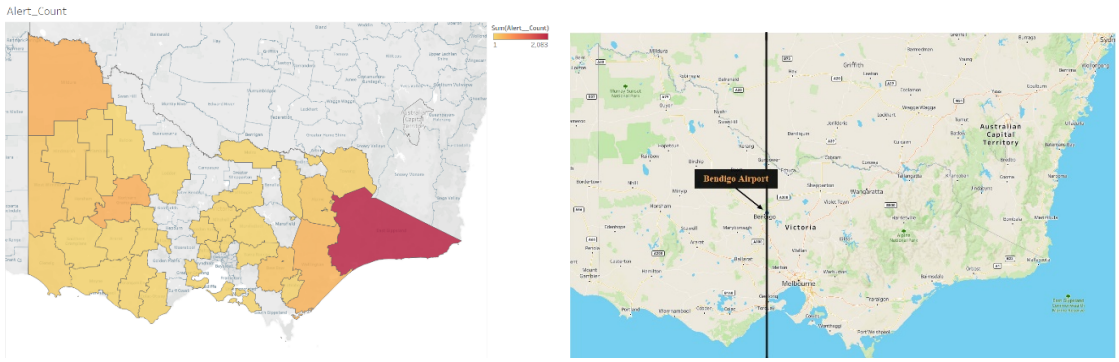
我们查询了中国植物科学院有关植物群落以及天气数据等各方面的官方网站，获得了很多关于野火的数据。其他数据来源见 T

表 1: Data and Database Websites

Database Names	Database Websites
Fire Alerts	https://www.globalforestwatch.org/map/
Altitude	https://search.earthdata.nasa.gov/search
Latitude and Longitude	https://www.kaggle.com/carlosparadis/
Google Scholar	https://scholar.google.com/
Maps	© 2021 Mapbox © OpenStreetMap

4.1.2 Data Screening

Judging from the map of Victoria in Figure 4 (right), the eastern region is mainly forest, while the western region is almost no forest. Furthermore, to demonstrate better the situa-tion of wildfires, we plot over a heat map in Figure 4 (left). Considering the heat map we made, it shows the number of wildfires in various states of Victoria from 2012 to 2021, the darker the color, the greater number of fires. Although fires have also occurred in the western region, the number of eastern regions is much higher than that in the western region.



(a) Data Screening(left) (b) Data Screening(right)

图 2: Data Screening

1. The analysis of locations of hovering VHF/UHF radio-repeater drones for fires can be more accurate if we have more complete data;
2. The assumption that the ”boots-on-the-ground” forward teams can be approximated as near the fire site is a bit idealized. If the trajectory of the team is taken into account, a more practical model and results can be obtained.
3. Some approximate analysis methods are applied to model other places, which may lead to the situation that not to be the most optimal.

5 通用植物群落干旱预测模型

在自然的植物群落中，在面对干旱的情况下，我们发现植物群落中物种之间的竞争关系是决定植物群落能不能更好地面对干旱即拥有干旱适应性的一个重要的条件，所以我们提出一种评价方法，它综合了植物群落的各个角度来评价一个地区的植物群落的抗干旱能力，我们把这种评价指标称为“植物群落干旱适应水平”，植物丰富度越高就代表该地区植物群落的干旱适应性越高。

5.1 基于熵权法的多元回归的植物种群预测模型

建立熵权法[?] 分析与植物干旱适应性相关的数据，最终得到一个综合的指标值称为植物群落干旱适应水平，将指标进行降维处理，熵权法建立步骤如下所示：

Step1 构造成分的决策矩阵：

$$X_{m\times n}=\begin{pmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ & & \vdots & \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{pmatrix} \tag{1}$$

Step2 进行正则化处理

$$\lambda_{ij}=\frac{x_{ij}}{\sqrt{\sum_{i=1}^{m}x_{ij}^{2}}} \tag{2}$$

Step3 计算第 j 项下的第 i 个值所占的比重

$$p_{ij}=\frac{\lambda_{ij}}{\sum_{i=1}^{m}\lambda_{ij}} \tag{3}$$

Step4 计算各成分的熵值

$$e_j=-k\sum_{i=1}^{m}p_{ij}\ln\left(p_{ij}\right) \tag{4}$$

其中的 K 为 $\frac{1}{In(m)}$

Step5 计算权重系数

$$\omega_j=\frac{d_j}{\sum_{i=1}^{n}d_j}\times 100\% \tag{5}$$

根据上述结论，可以定义一个新的指标设为 y_i, 他的计算公式为

$$y_i = \sum_{i=0}^{m} \omega_i x_i \tag{6}$$

将上述的 y_i 为因变量，$x_1, x_2, \cdots x_k$ 为自变量，并且自变量与因变量之间为线性关系时，则多元线性回归模型为：

$$y = b_0 + b_1 x_1 + b_2 x_2 + \cdots + b_k x_k + e \tag{7}$$

其中，b_0 为常数项，$b_1, b_2, \cdots b_k$ 为回归系数，b_1 为 $x_2, x_3 \cdots x_k$ 固定时，x_1 每增加一个单位对 y 的效应，x_1 对 y 的偏回归系数；同理 b_2 为 x_1, x_k 固定时，x_2 每增加一个单位对 y 的效应，即，x_2 对 y 的偏回归系数。

最终得到如下图所示结果：

5.2 基于 Guass 竞争关系的植物群落预测模型

在本节中，我们应用高斯竞争模型，并采用有限差分法进行预测。

参考文献

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