Advancements of "CAPTAIN" in Plants Conservation Compared to Traditional Techniques

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Abstract

The rapid decline in plant diversity has become a pressing issue with significant implications for humanity. Numerous methods and technologies are being developed to address this problem. Traditional methods, primarily based on statistical analysis, are being used alongside modern conservation methods that leverage AI (Artificial Intelligence) technology. Among many conservation approaches, we compare the traditional and modern methods to find out how AI has been involved. Based on our research, two traditional models have been chosen for this report. Marxan has been widely used since it was developed. Based on the IUCN Red List database, PACA accelerates plant extinction risk assessments. However, these models have some limitations, including unsuitability for rapid and urgent conservation management, poor adaptability, etc. In contrast, CAPTAIN, based on artificial intelligence technology, not only overcomes the limitations of traditional models but also offers advantages such as non-locality and upgradability. By analysing the differences and correlations between statistical technology and AI technology, we aim to enhance our understanding of the advancements of AI in plant conservation and summarize their development status and prospects.

Keywords: plant diversity, PACA, Marxan, conservation management, CAPTAIN, AI

1 Project Background

Biodiversity is essential for ecosystem function. However, it is currently being lost at an unprecedented rate due to the complex factors of human activities and climate change[1]. The IUCN Red List of Threatened Species, which lists endangered species, is a crucial tool for conserving biological diversity[2]. In order to ensure the restoration, resilience, and adequate protection of ecosystems in the future, numerous methods are provided[3]. These methods mainly include two paths: one is to protect the species themselves, and the other is to protect the conservation areas where the plants are located. Our group focus on analyzing researches on latter one. We have chosen to analyze the modern conservation method based on AI technology CAPTAIN, along with two traditional methods based on statistics and spatial analysis, namely Marxan[4] and PACA[5]. In recent years, they are widely applied to biodiversity conservation planning and are deserving of further research.

1.1 Basic information

Marxan[4]

- Based on a mathematical optimisation model
- Balances conservation goals and spatial constraints
- Generates optimal planning solutions

PACA (Preliminary Automated Conservation Assessments)[6]

- Based on Geographic Information System (GIS) and spatial data analysis
- Assesses and identifies potential conservation areas

CAPTAIN (Conservation Area Prioritization Through Artificial Intelligence)[7]

- Based on GIS, genetic algorithms, AI, and machine learning techniques
- Prioritises conservation areas
- Provides optimal decision support

1.2 Aim

By analysing the technical features and relevance of the above-mentioned methods, and comparing their effectiveness and limitations in development, we aim to achieve the following objectives:

1. Identify the development of traditional and modern technologies;
2. To understand the AI process involved in the CAPTAIN model;
3. Analyse the application of different models;
4. Compare different models and summarize the highlights; and
5. Find the limitations and prospects for AI application in plant conservation.

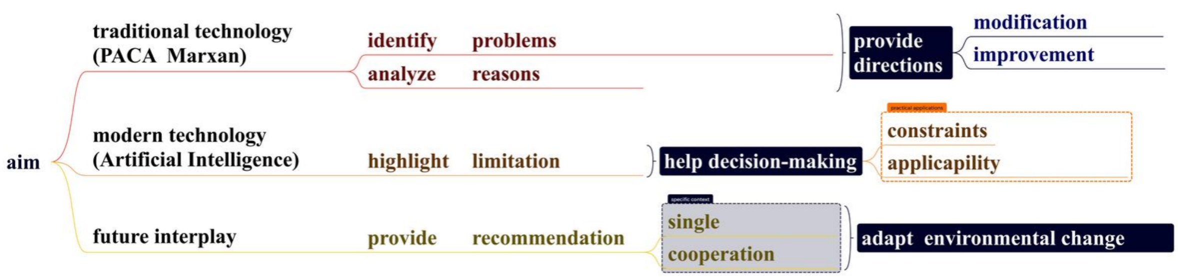

Figure 1: aim breakdown

2 Methodology

2.1 Resource collection

Widely researched articles about plant protection methods, as well as the application of artificial intelligence (AI) [8]. Gather information from various sources such as articles in scientific journals like Nature and Science, introductory websites and news.

2.2 Resource evaluation

During the content evaluation process, we drafted the paper's main framework and classified the details. We summarised and compared the primary goals of various approaches to discover how plant protection strategies evolved and how AI has been involved through particular results.

2.3 AI in plant protection learning process

To explore AI's role in plant conservation, we learned the methods of different conservation strategies. Traditional methods use statistical analysis or spatial distribution optimisation strategies; in the CAPTAIN approach, AI has been involved in the framework development. We participated in workshops and training focused on AI in plant protection. We perfromed analysis through understanding of the content and the application cases, learned machine learning as pertinent to conservation, and discussed future applications.

2.4 Methods comparison overview

Key info	Marxan	PACA	CAPTAIN
Released	in 2000	in 2017	in 2022
Aim	Decision-support for spatial conservation prioritization	Accelerate plants extinction risks assessment	Provide dynamic biodiversity protection priorities solutions
Main coverage	Majority of species	Majority of species	Majority of species
Based on	cost-efficient networks protection	IUCN Red List database and criterion	Reinforcement learning algarithm
Theory	Statistical analysis and spatial distribution	Statistical analysis and spatial distribution	Artificial intelligence with multi-scale solutions

Figure 2: Different methods comparison overview

2.5 Workflows by method

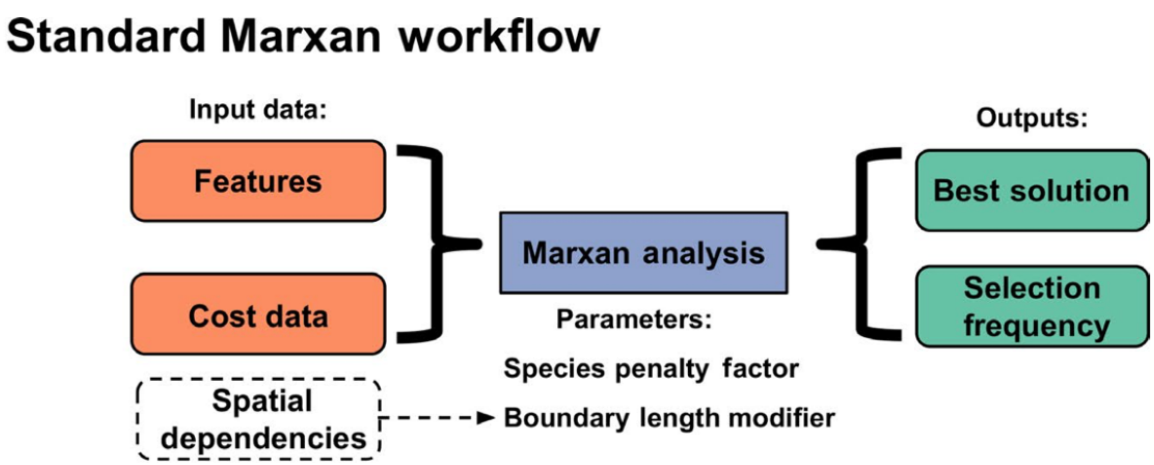

Figure 3: Standard Marxan workflow [9]

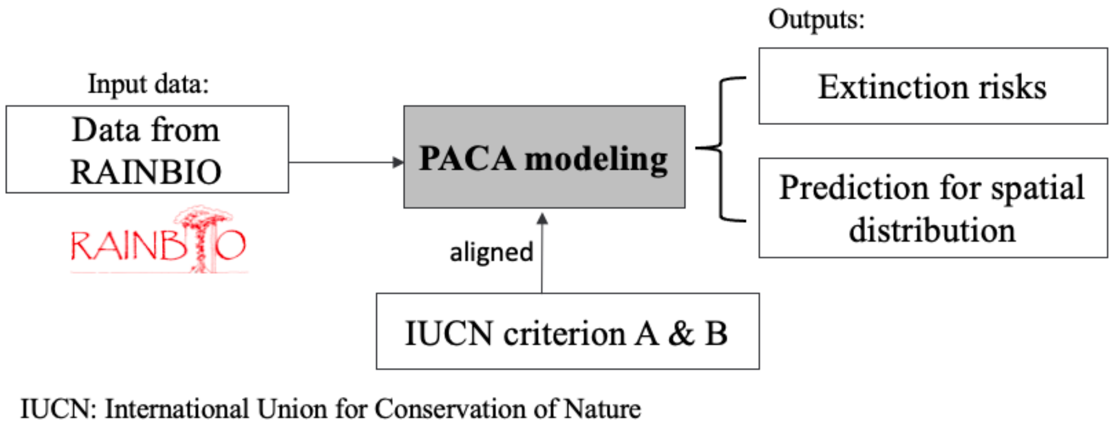

Figure 4: PACA workflow [6]

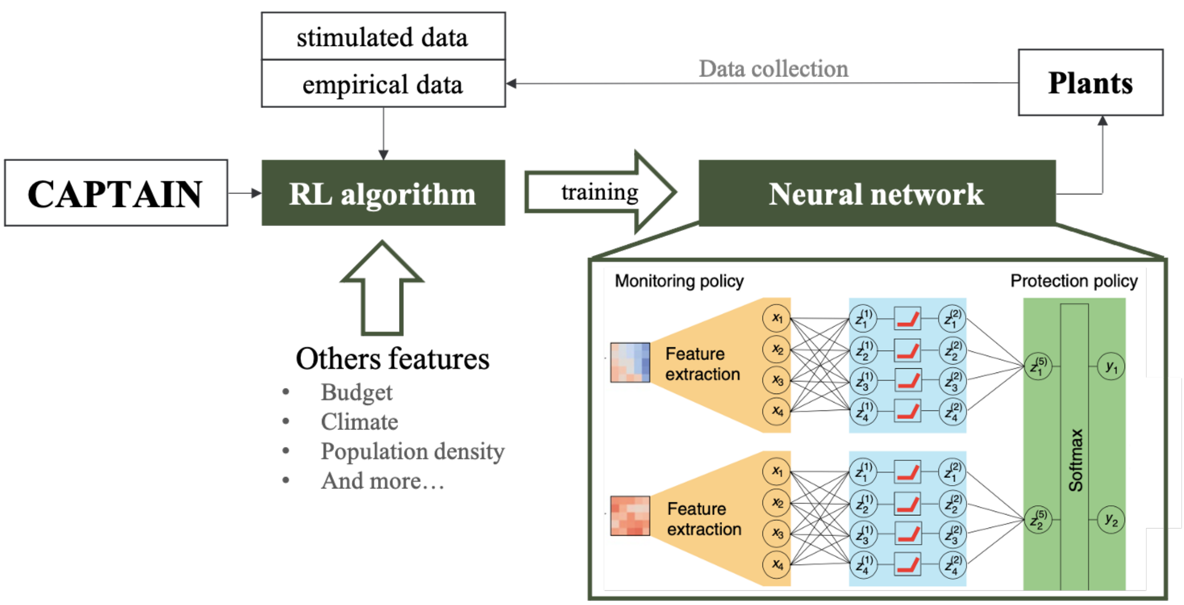

Figure 5: CAPTAIN workflow [7]

3 Results

3.1 AI applied framework proves an advanced data monitoring strategy

Comparing to traditional data collection methods, CAPTAIN shows greater advancement in the *impact* of a data gathering strategy[7]. Using CAPTAIN simulations, authors found that full recurrent monitoring - where the system is monitored at each time step - results in the smallest species loss: It succeeds in protecting on average sixty percent more species than a random protection policy. The citizen science recurrent monitoring technique (citizen science initiatives such as 'bioblitzes', an intense period of biological surveying) produces an almost similar result (24.9 percent improvement)[10]. The standard Marxan and PACA methods do not include data monitoring.

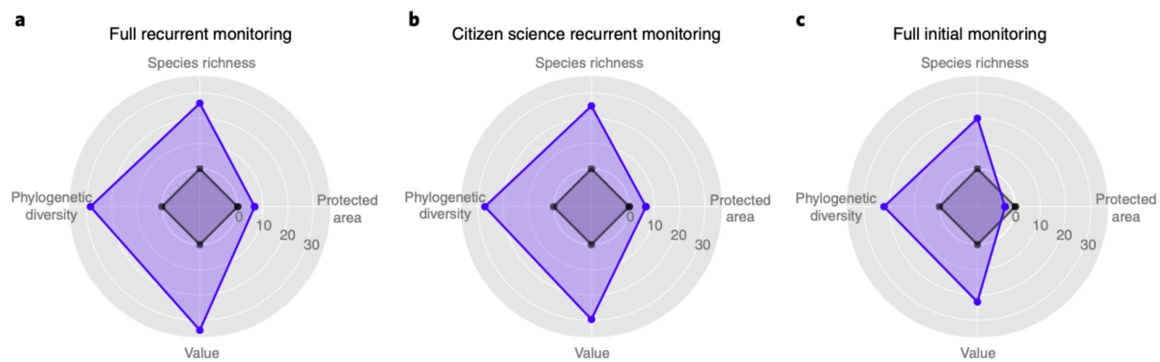

Figure 6: CAPTAIN data monitoring: a) the full recurrent monitoring b) citizen science recurrent monitoring c) full initial monitoring

Results compare species loss, protected area, value, and diversity between random protection (black polygon) and CAPTAIN optimization (blue polygon), averaged from 250 simulations with consistent budget and resolution.

3.2 A comparison of simulation under Marxan and CAPTAIN

The violin plots show the distribution of species loss outcomes across 250 simulations run under different monitoring policies based on the CAPTAIN framework developed and on Marxan [4]. Species loss is expressed as a percentage of the total initial number of species in the simulated systems. The research used CAPTAIN with full recurrent monitoring and allowed the establishment of a single protection unit per time step for both programs. Under this condition, CAPTAIN outperforms Marxan in 77.2 percent of the simulations with an average reduction of species loss of 18.5 percent.

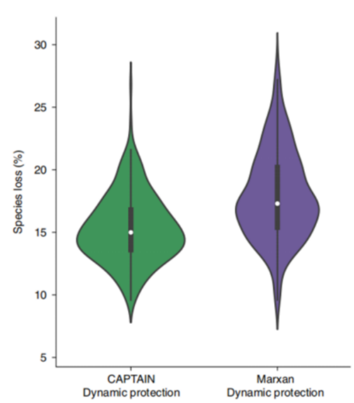

Figure 7: CAPTAIN data monitoring

3.3 Reinforcement learning algorithms show more advantages

CAPTAIN uses a reinforcement learning algorithm to optimise conservation policies, showing more advantages than traditional methods.

- Dynamic conservation policies: CAPTAIN can adjust and optimise conservation policies in real-time along with changing conditions and data to adapt to varying conservation needs.
- Swift and efficient predictions: Reinforcement learning enables rapid prediction of optimal conservation strategies, saving time and resources.
- Providing scientific support for decision-making: CAPTAIN offers decision support. It emphasises trade-offs, the solutions are based on conservation aims. It optimises static or evolving policies, particularly suitable for designing fitting short- and long-term goals, while Marxan method focusses on one-time policy, lacks temporal adaptability, and assumes single biodiversity and cost data gathering [11].

3.4 Empirical validation of CAPTAIN

Regarding the distinguishing features of CAPTAIN in prioritising plant conservation areas over traditional methods, the demonstration below illustrates the usefulness of the framework and direct applicability of models trained through RL (Reinforcement Learning), using an empirical dataset of endemic trees of Madagascar. This dataset was used in a systematic conservation planning experiment under Marxan and CAPTAIN. Figure 8 articulates the comparative results as follows: a-b) Describes

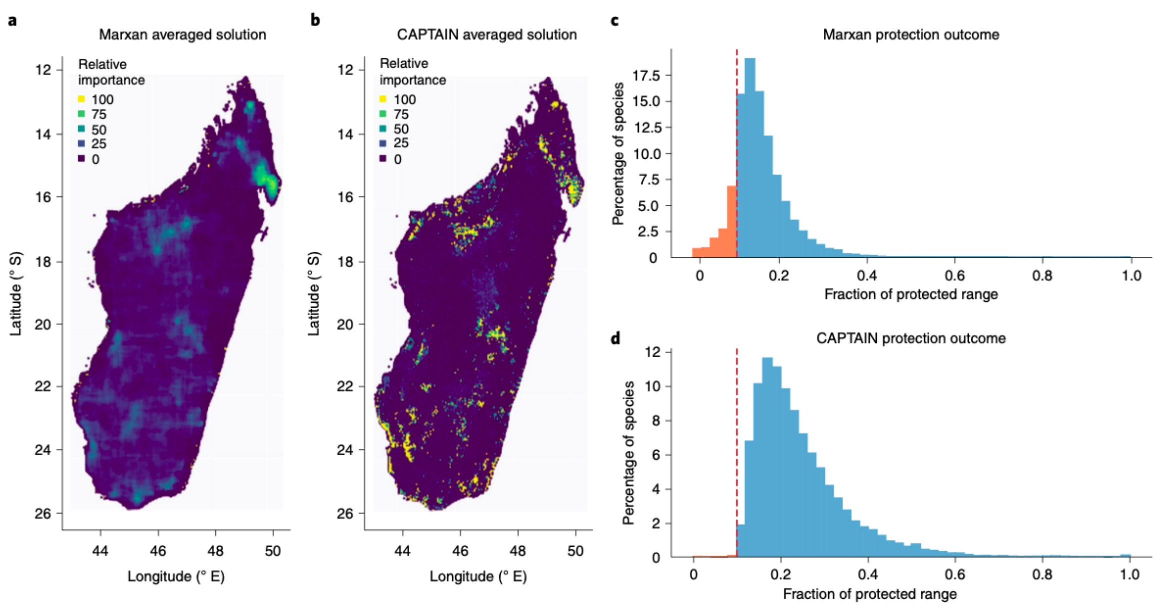

Figure 8: Outcomes comparison of Marxan and CAPTAIN with Madagascar data

maps showing the priority areas for protection in Madagascar based on endemic trees with limited budget. The color scale on the maps represents the importance of each protected unit. c-d) Histograms show the percentage of species ranges included in the protected units. The red dashed line indicates the target of protecting 10 percent of species ranges; orange bars represent species that did not meet the target.

Methods used: Marxan and CAPTAIN. Objective: Conservation planning experiment on Madagascar archipelago. Conclusion: CAPTAIN performs better than Marxan in this case. Findings:

- CAPTAIN identifies with higher spatial resolution, improving interpretability of the results. CAPTAIN successfully meets the target of protecting 10 percent of species ranges in 68 percent of the cases, while Marxan only reaches that target in up to 2 percent of the results.

- CAPTAIN identifies a higher percentage (median of 22 percent) of each species range within protected areas, surpassing the 10 percent target and the 14 percent achieved by Marxan.
- CAPTAIN provides priority conservation areas at a more detailed and understandable spatial resolution.

4 Conclusion

4.1 Support for multi-scale decision-making

CAPTAIN optimizes trade-offs in biodiversity conservation, balancing total protected area and potential species loss. Economic value and total protected area may not adequately indicate biodiversity protection. A comprehensive approach is required, considering both economic value and actual biodiversity conservation outcomes.

4.2 Learning from the models

An effective approach involves selecting protected areas with intermediate to high species richness. CAPTAIN considers ecosystem variations and environmental gradients.

4.3 Prospects for different technology

Standard Marxan has been developed into different versions, such as Marxan Zone, Marxan Connected, and Marxan MaPP[9]. In the Malagasy trees case, with the same input data, CAPTAIN performs better than Marxan[10]. Using additional data and developing the protection policy can further improve CAPTAIN's results.

5 Discussion

Due to the rapid development of biological and genome-related techniques, biologists and environmentalists have been working on conservation genomics for years. This involves the use of molecular techniques[12] or apply the prediction of global distribution of extinction species[**?**], which require extensive input[13]. With the increasing amount of data being collected from various sources, there is a growing need for efficient data analysis and forecasting in this field[8]. In the future, the use of smart software with AI will be the preferred option for plant conservation[14]. By comparing traditional and recent techniques, it is expected that AI has great potential for future development and application.

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Intellectual Property The authors attest that copyright belongs to them, the article has not been published elsewhere, and there is no infringement of any intellectual property rights as far as they are aware.

References

[1] B. J. Cardinale, J. E. Duffy, A. Gonzalez, D. U. Hooper, C. Perrings, P. Venail, A. Narwani, G. M. Mace, D. Tilman, D. A. Wardle *et al.*, "Biodiversity loss and its impact on humanity," *Nature*, vol. 486, no. 7401, pp. 59–67, 2012.

[2] J.-C. Vié, C. Hilton-Taylor, and S. N. Stuart, *Wildlife in a changing world: an analysis of the 2008 IUCN Red List of threatened species.* IUCN, 2009.

[3] W. Simonson, *BIODIVERSITY, ITS LOSS AND WHY IT MATTERS*, 2014, https://jri.org.uk/wp-content/uploads/2021/02/Simonson-JRI-Briefing-29.pdf.

[4] "Marxan solutions. (n.d.)." accessed 13 December 2023. https://marxansolutions.org/software/.

[5] I. R. Ball, "Mathematical applications for conservation ecology: the dynamics of tree hollows and the design of nature reserves / ian r. ball." *theses*, 2000.

[6] T. Stévart, G. Dauby, P. P. Lowry, A. Blach-Overgaard, and T. L. P. Couvreur, "A third of the tropical african flora is potentially threatened with extinction," *Science advances*, vol. 5, no. 11, p. eaax9444.

[7] Captain. (n.d.). Accessed 13 December 2023.Captain. (n.d.).

[8] C. Li, "Biodiversity assessment based on artificial intelligence and neural network algorithms," *Microprocessors and Microsystems*, vol. 79, no. 3, p. 103321, 2020.

[9] I. R. Ball, H. P. Possingham, and M. E. Watts, "Marxan and relatives: Software for spatial conservation prioritization," *Oxford University Press*, 2009.

[10] D. Silvestro, S. Goria, T. Sterner, and A. Antonelli, "Improving biodiversity protection through artificial intelligence," *Nature Sustainability*, no. 5, p. 5, 2022.

[11] M. S. Sosef, G. Dauby, A. Blach-Overgaard, X. van der Burgt, L. Catarino, T. Damen, V. Deblauwe, S. Dessein, J. Dransfield, V. Droissart *et al.*, "Exploring the floristic diversity of tropical africa," *BMC biology*, vol. 15, no. 1, pp. 1–23, 2017.

[12] R. G. Kerry, F. J. P. Montalbo, R. Das, S. Patra, G. P. Mahapatra, G. K. Maurya, V. Nayak, A. B. Jena, K. E. Ukhurebor, R. C. Jena *et al.*, "An overview of remote monitoring methods in biodiversity conservation," *Environmental Science and Pollution Research*, vol. 29, no. 53, pp. 80 179–80 221, 2022.

[13] E. Sacre, R. Weeks, M. Bode, and R. L. Pressey, "The relative conservation impact of strategies that prioritize biodiversity representation, threats, and protection costs," *Conservation Science and Practice*, 2020.

[14] S. V. Silva, T. Andermann, A. Zizka, G. Kozlowski, and D. Silvestro, "Global estimation and mapping of the conservation status of tree species using artificial intelligence," *Frontiers in Plant Science*, vol. 13, p. 839792, 2022.