Multi-Objective Optimization Applied to Systematic Conservation Planning and Spatial Conservation Priorities under Climate Change

Shana Schlottfeldt
Dep. of Computer Science
University of Brasilia
Brasilia, DF, Brazil
shanass@unb.br

Jon Timmis
Department of Electronics
University of York
York, UK
jon.timmis@york.ac.uk

Maria Emilia M. T. Walter
Dep. of Computer Science
University of Brasilia
Brasilia, DF, Brazil
mia@cic.unb.br

Andre C.P.L.F. Carvalho
Dep. of Computer Science
University of São Paulo
São Carlos, SP, Brazil
andre@icmc.usp.br

Jose Alexandre F. Diniz-Filho
Department de Ecology, ICB
Federal University of Goiás
Goiânia, GO, Brazil
diniz@icb.ufg.br

Lorena M. Simon
Institute of Biological Sciences
Federal University of Goiás
Goiânia, GO, Brazil
lores_bio@hotmail.com

ABSTRACT

Biodiversity problems require strategies to accomplish specific conservation goals. An underlying principle of these strategies is known as Systematic Conservation Planning (SCP). SCP is an inherently multi-objective (MO) problem but, in the literature, it has been usually dealt with a monobjective approach. In addition, SCP analysis tend to assume that conserved biodiversity does not change throughout time. In this paper we propose a MO approach to the SCP problem which increases flexibility through the inclusion of more objectives, which whilst increasing the complexity, significantly augments the amount of information used to provide users with an improved decision support system. We employed ensemble forecasting approach, enriching our analysis by taking into account future climate simulations to estimate species occurrence projected to 2080. Our approach is able to identify sites of high priority for conservation, regions with high risk of investment and sites that may become attractive options in the future. As far as we know, this is the first attempt to apply MO algorithms to a SCP problem associated to climate forecasting, in a dynamic spatial prioritization analysis for biodiversity conservation.

Categories and Subject Descriptors

J.2 [**Computer Applications**]: Physical Sciences and Engineering—*Earth and atmospheric sciences*

GECCO'14, July 12–16, 2014, Vancouver, BC, Canada
ACM 978-1-4503-2881-4/14/07
http://dx.doi.org/10.1145/2598394.2598404.

Keywords

multi-objective optimization; systematic conservation planning; biodiversity conservation; climate change.

1. INTRODUCTION

The growing interest and concern regarding biodiversity demand strategies to target conservation goals. These strategies include the Systematic Conservation Planning (SCP), which determines the most cost effective way of investing in conservation actions.

Computationally speaking, SCP is formalized by the well-known NP-hard Set-Covering Problem [1]. In a simplified way, SCP is the problem of finding a minimum set of sites maximizing at the same time the characters under study. There are clearly two conflicting objectives to be optimized, which makes SCP a natural candidate for Multi-Objective Optimization (MOO). Furthermore, several other parameters, e.g., social and political objectives, can be incorporated to SCP, adding further dimensions to the problem, therefore increasing its complexity.

Although SCP is inherently multi-objective, it is frequently dealt with using a monobjective approach, assigning weights to the problem dimensions, in order to obtain an unique objective function [7]. Two main reasons justifies the use of MOO when dealing with the SCP problem; first, it is possible to find a set of solutions to the problem instead of a single one; and second, there is an increase in flexibility of both data type and problem constraints, at the same time that the problem is kept tractable [2].

Typically, SCP analyses are static, i.e., they assume that biodiversity does not change over time [6]. However, scientific evidences urge to incorporate climate change analysis into conservation plans [5].

In this paper, we propose a more sophisticated, yet general, solution to the SCP problem using MOO. This approach increases flexibility by including more decision objectives, which whilst increasing the complexity, significantly augments the amount of information used to provide users with an improved decision support system.

As far as we know, this is the first attempt to apply MOO to SCP associated to climate forecasting, in a dynamic spatial prioritization analysis for biodiversity conservation.

2. MATERIALS AND METHODS

2.1 Data

Plant species. We used data of occurrence of 96 plants with economic importance in Cerrado, a large biome in Central Brazil, in which many endemic and rare species are under high threat levels or extinction [4].

Climate Forecast. We used an ensemble forecast approach, obtaining the likely distribution of species in the considered region by 2080 [8].

Additional Objectives. *Annual Actual Evapotranspiration (AET):* a measure of the joint availability of energy and water in the environment. *Human Occupancy (H_O):* a measure obtained compiling data on social and economic variables indicating conservation conflicts. *Vegetation Remnants (VR):* the proportion of each grid cell covered by natural vegetation, based on remote sense information.

Conservation scenarios. For present and future data, we have a presence-absence matrix $A_{m \times n}$, $m = 181$ *sites* and $n = 96$ *plant species*. We have *five different objectives*: 1) minimize the number of sites; 2) maximize the number of represented plant species; 3) maximize AET; 4) minimize H_O; 5) maximize VR.

Our fitness functions were developed by having as many equations as objectives to be optimized. This allowed to simultaneously optimize distinct objectives instead of aggregating variables into one single function.

We defined three conservation scenarios: *Scenario 1*: to represent all species in current time, applying optimization in 2 dimensions (optimizing objectives 1 and 2); *Scenario 2*: to represent all species in current time, using optimization in 5 dimensions (i.e., optimizing simultaneously objectives 1 to 5); and *Scenario 3*: to represent all species in 2080 (since it happens to be a forecast, objectives 3 to 5 are not available, and optimization was performed considering objectives 1 and 2).

2.2 Experimental Setup

Algorithm and computer infrastructure. We performed 19,120 individual runs for each scenario previously described. For each run, a population of 500 initial solutions was randomly generated. These solutions were then evolved using Non-Dominated Sorting Genetic Algorithm-II (NSGA-II) [3], implemented in Matlab®. The experiments were performed on two servers, a HP ProLiant DL585 G7, 4xAMD 2.8Ghz 16-cores, 512GB RAM, and a HP ProLiant DL385p Gen8, 2xAMD 2.8Ghz 16-cores, 256GB RAM

Evaluation metric. Due to the algorithm stochasticity, we used the *selection frequency* metric (SF) [6], which represents the number of times each site is selected in the solutions to the overall problem. Once the SF to all cells was calculated, the grid cells were ranked based on their score. We ordered all the grid cells in a bi-dimensional plot showing the relative importance of each cell both to the current time and to 2080 (importance axis). This graph epitomizes the scheme for dynamic spatial prioritization analyses for biodiversity conservation [6].

3. RESULTS AND DISCUSSION

We found that optmization using additional objectives (Scenario 2) allowed us to supply decision makers (DM) with a more diversified portfolio of sets of sites to be conserved.

Furthermore, our method was able to identify (if they exist) sites of high priority for conservation, regions with high risk of investment and sites that may become attractive options in the future. In this context, this study focused on showing that predicted climate change could cause shifts on the distribution patterns of economically important plants, and that these data could be used in order to help DM to select their schemes of conservation. Supported by scientific data, DM can examine options made available to current time related to the future, and decide how to define their spatial conservation priorities, reviewing them if necessary.

4. CONCLUSIONS

Our results show the advantages of the new approach (MOO) with respect to previous solutions (monobjective). Moreover, the associated climate forecast showed that having a picture of how future scenarios will look like can be extremely useful for DM.

Next step is to develop a more specialized MOO algorithm for the SCP problem. Using artificial immune system, we intend to improve the work presented in this paper.

5. ACKNOWLEDGMENT

ACPLFC, JAFDF, MEMTW, MPCT, RDL and SSS have been continuously supported by CNPq. JT is part funded by The Royal Society.

6. ADDITIONAL AUTHORS

Rafael D. Loyola (Federal University of Goiás–UFG, email: diasloyola@gmail.com) and Mariana P.C. Telles (UFG, email: tellesmpc@gmail.com).

7. REFERENCES

[1] M. Cabeza and A. Moilanen. Design of reserve networks and the persistence of biodiversity. *Trends Ecol Evol*, 16(5):242–248, May 2001.

[2] C. A. Coello Coello at al. *Evolutionary Algorithms for Solving Multi-Objective Problems*. Springer-Verlag, New York, 2nd edition, Sept. 2007. ISBN 978-0-387-33254-3.

[3] K. Deb at al. A Fast Elitist Non-Dominated Sorting Genetic Algorithm for Multi-Objective Optimization: NSGA-II. *Trans. Evol. Comp*, 6(2):182–197, Apr. 2002.

[4] J. A. F. Diniz-Filho et al. Spatial Patterns of Terrestrial Vertebrate Species Richness in the Brazilian Cerrado. *Zool Stud*, 47(2):146–157, 2008.

[5] C. R. Groves et al. Incorporating climate change into systematic conservation planning. *Biodivers Conserv*, 21:1651–1671, 2012.

[6] R. D. Loyola et al. A straightforward conceptual approach for evaluating spatial conservation priorities under climate change. *Biodivers Conserv*, 22:483–495, 2013.

[7] S. Schlottfeldt-Santos at al. Multiobjective Optimization in Systematic Conservation Planning to Represent Genetic Variability within Species. In *Proceedings of the 8th International Conference on Ecological Informatics.*, 2012.

[8] L. M. Simon et al;. Effects of Global Climate Changes on Geographical Distribution Patterns of Economically Important Plant Species in Cerrado. *Revista Árvore*, 37(2):267–274, 2013.