Report on

Integer linear programming outperforms simulated annealing for solving conservation planning problems

This study compares the performances to identify priority areas for conservation of two optimality guarantee integer linear programming (ILP) solvers: Gurobi and SYMPHONY, and of Marxan simulated annealing (Marxan/SA) heuristic.

The models considered are ILP formulations for identifying a set of sites that meet conservation targets for each species while minimizing the sum of costs of sites, i.e., the set covering problem: find $x \in \{0,1\}^N$ that $\min \sum_{j \in N} c_j x_j$, subject to $\sum_{j \in N} a_{sj} x_j \geq t_s$, for every $s \in S$, where N is the set of sites, S is the set of species, a_{sj} indicates the "amount" of representation of species s in site j, and t_s the representation target (sum of the "amounts" of representation) required for species s. Author(s) also considered incorporating in the previous model additional 0-1 variables and linear inequalities promoting some level of compactness on the optimal solutions.

Using real data from a region in British Columbia and results from species distribution models for each of 72 bird species, the author(s) created 135 different instances of set covering, of varying number of sites $|N| \leq 148510$, number of species $|S| \leq 72$ and representation targets t_s up to 90% of the total "amount" of representation estimated for species s on the sites of set N. Using the same data, author(s) also created 45 different instances for the set cover with compactness purposes, with $|N| = 50625$, $|S| = 72$, and varying values of representation targets $t_s \leq 90\%$ and five different levels of compactness desired for solutions.

For each instance, the processing times of Gurobi, SYMPHONY and of each of several runs of Marxan/SA (corresponding to different choices of the input parameters species penalty factor, number of starting solutions and number of iterations) were recorded, as well as the deviations from optimality of the solutions obtained by Marxan/SA (i.e., the differences between the costs of the solutions produced by Maxent/SA and the optimal cost).

From the obtained results author(s) conclude that i) the ILP solvers, especially Gurobi, were faster than Marxan/SA, ii) the solutions produced by Maxant/SA showed large deviations from the optimal values, and iii) findings i) and ii) were more evident for the larger instances.

These results and findings are thoroughly presented in the manuscript.

My main concern with this submission is the novelty it brings. On the one hand, the ILP models that were tested are well-know in the context of systematic conservation planning (see references below). On the other hand, a similar analysis (Beyer et al. 2016. Solving conservation planning problems with integer linear programming. Ecological Modelling 328: 14–22), quoted in the manuscript, that compares computational performances between Gurobi and Marxent/SA on solving identical problems, was recently published. That study concludes that the ILP solver Gurobi (with optimality gap 0.5%) outperformed Marxant/SA heuristic regarding the quality of the obtained solutions and processing times, on simulated data. The submitted manuscript confirms these findings on instances generated from real data.

Minor points follow.

- In my opinion the ILP formulations should be explicitly given.

- Lns 40, 41: "... (SA), an iterative, stochastic metaheuristic algorithm for approximating global optima of complex functions with many local optima..."

  The use of SA does not dependent on the number of local optima. I suggest to remove 'with many local optima".

- Lns 50, 51: "They compared Marxan to integer linear programming (ILP) (Dantzig 2016)...".

  Reference "Dantzig, G. 2016. Linear Programming and Extensions. - Princeton University Press." is not adequate. Firstly, this is a new edition of an old, classic book: copyright year 1963. Secondly, the book is not about integer linear programming, but rather about (continuous) linear programming, subject on which Dantzig is regarded to be the founder (indeed, among other pioneer contributions, he devised the simplex method for linear programming in the nineteen-forties).

  Among many others classic books on ILP, Nemhauser, G. and Wolsey, L. (1988), Integer and Combinatorial Optimization, Wiley, New York, is an adequate reference to replace Dantiz's book.

- Ln 55: "... will find the exact optimal solution..."

  Replace by "... will find an optimal solution..."

- Ln 81: "... resoltuion..."

  Replace by "... resolution..."

- Ln 97: "... Integrated Cadastral Information Society of BC."

  "BC" (which I guess refers to British Columbia) has not been previously introduced.

- Ln 215–217: "We found that ILP algorithms outperformed SA both in terms of cost-effectiveness and processing times, even when including non-linear problem formulations, when planning for spatially compact solutions."

  ILP algorithms are procedures to solve Integer **Linear** Programming problems. A model to be given to an ILP algorithm has to be: a **linear** (objective) function to be maximized or minimized, and **linear** inequalities and/or **linear** equations in which some or all of the variables are integer.

  Thus, it is not correct saying that IPL algorithms were used to solve models including non-linearities. The sentence should be rewritten and other mentions in the text that go on the same line (e.g. ln 248) should be checked for reviewing.

- Ln 232: "... be calibrated improve solution quality..."

  Replace by "... be calibrated to improve solution quality..."

- Lns 249–254: "There is the potential ... (Franco et al. 2014)."

  Not clear. Consider reviewing this sentence.

- Table 1.

  - "Paremeter" → "Parameter"
  - Define **n**.

- Figure S11.

  Since figures produced by Gurobi and by SYMPHONY are obviously the same, a single column named e.g. "Gurobi/SYMPHONY" could replace columns now named "Gurobi" and "Symphony".

Some works addressing spatial contiguity of set covering solutions:

- T.J. Cova and R.L. Church, Contiguity constraints for single-region site search problems, Geogr. Anal. 32 (2000) 306–329.
- J.C. Williams, A zero-one programming model for contiguous land acquisition, Geogr. Anal. 34 (2002) 330–349.
- A.O. Nicholls and C.R. Margules, An upgraded reserve selection algorithm, Biol. Conserv. 64 (1993) 16–169.
- R.A. Briers, Incorporating connectivity into reserve selection procedures, Biol. Conserv. 103 (2002) 77–83.
- H. Önal and R.A. Briers, Incorporating spatial criteria in optimum reserve network selection, Proc. R. Soc. Lond., B Biol. Sci. 269 (2002) 243–2441.
- D.J. Nalle, J.L. Arthur and J. Sessions, Designing compact and contiguous reserve networks with a hybrid heuristic algorithm, For. Sci. 48 (2002) 59–68.
- H. Önal and R.A. Briers, Selection of a minimum-boundary reserve network using integer programming, Proc. R. Soc. Lond., B Biol. Sci. 270 (2003) 1487–1491.
- H. Possingham, I. Ball and S. Andelman, in: Mathematical Methods for Identifying Representative Reserve Networks, Quantitative Methods for Conservation Biology, eds. S. Ferson and M. Burgman (Springer-Verlag, New York, 2000) pp. 291–306.
- M.D. McDonnell, H.P. Possingham, I.R. Ball and E.A. Cousins, Mathematical methods for spatially cohesive reserve design, Environ. Model. Assess. 7 (2002) 107–114.