**Title:** Optimizing the conservation of migratory species over their full annual cycle

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**Abstract**

**Introduction**

Systematic conservation planning is something.

Marxan is the most widely used SCP software globally, with over X users and projects. Marxan used the heuristic approach of similated annealing to find ‘near optimal’ solutions to SCSP problems. Recent developments in computational capacity and algorithms has made it possible to solve the SCP problems Marxan solves with integer linear programming (Beyer et al. 2016). Building on Beyer et al. (Beyer et al. 2016), we created a software package, that could solve Marxan type problems using integer linear programming (Hanson et al. 2019).

Here, we are using a real world case study from Western North America to compare Marxan (simulated annealing) and prioritizr (integer linear programming) to ask the following questions:

1. What is required to parameterize i) Marxan, ii) prioritizr using an open source solver, and iii) prioritzr using a proprietary solver?
2. How do processing time differ between the three approaches tested?
3. How cost effective, in $ values, are the three approaches tested?

**Methods**

*Study area*

We focused on a 27,250 km2 portion of the Georgia Basin, Puget Trough and Willamette Valley of the Pacific Northwest region spanning the US and Canada (Fig. 1), corresponding to the climate envelope indicative of the Coastal Douglas-fir (CDF) Biogeoclimatic zone in southwestern British Columbia (Meidinger and Pojar 1991). Land cover in the region is diverse, with approximately 57% of the land in forest, 8% as savanna or grassland, 5% in cropland, and 10% being urban or built.

*Data Layers*

*Biodiversity data.* Our prioritizations were run with eBird data, which is a citizen-science effort that has produced the largest and most rapidly growing biodiversity database in the world (Hochachka et al. 2012, Sullivan et al. 2014). From the 2013 eBird Reference Dataset (<http://ebird.org/ebird/data/download>) we used a total of 12081 checklists in our study area, then filtered these checklists to retain only those <1.5 hours in duration, <5 km travelled, and a maximum of 10 visits to a given location (unpublished R code; Hochachka, pers. com.). Sampling locations <100 m apart were collapsed to one location, yielding 5470 checklists from 2160 locations, visited from 1-10 times and 2.53 times on average. Following Schuster et al. (2014, 2017) we used a combination of quantitative models and expert elicitation to identify which species were associated either with forest habitat or with human-dominated habitat, such as built or residential land (Supplemental Material methods, Supplementary Table 1).

*Cadastral layer and land cost*. We incorporated spatial heterogeneity in land cost (Ando et al. 1998, Polasky et al. 2001, Ferraro 2003, Naidoo et al. 2006) in our plan by using cadastral data and 2012 land value assessments from the Integrated Cadastral Information Society of BC, resulting in 193,623 polygons for BC (Schuster et al. 2014). Cadastral data, including tax assessment land values from Washington State came from the University of Washington’s Washington State Parcel Database (<https://depts.washington.edu/wagis/projects/parcels/>; Version: StatewideParcels\_v2012n\_e9.2\_r1.3; Date accessed: 2015/04/30), as well as San Juan County Parcel Data with separate signed user agreement. The combined cadastral layer included 1.92M polygons. Cadastral data, including tax assessment land values from Oregon State had to be sourced from individual counties, which included Benton, Clackamas, Columbia, Douglas, Lane, Linn, Marion, Multnomah, Polk, Washington and Yamhill. The combined cadastral layer for Oregon included 605,425 polygons.

*Spatial prioritization approach*

Here we use the concept of systematic conservation planning (Margules and Pressey 2000), to inform choices about areas to protect, in order to optimize outcomes for biodiversity while minimizing societal costs (McIntosh et al. 2017). To achieve the goal to optimize the trade-off between conservation benefit and socioeconomic cost, i.e. to get the most benefit for limited conservation funds, we strive to minimize an objective function over a set of decision variables, subject to a series of constraints. Integer linear programming (ILP) is the subset of optimization algorithms used here to solve reserve design problems. The general form of an ILP problem can be expressed in matrix notation as:

Where x is a vector of decision variables (in our case, whether to prioritize an individual planning unit), c and b are vectors of known coefficients, and A is the constraint matrix. In the minimum set cover problem, c is a vector of costs for each planning unit, b a vector of targets for each conservation feature, the relational operator would be ≥ for all features, and A is the representation matrix with Aij=rij, the representation level of feature i in planning unit j. We set an objective to find the solution that fulfills all the targets and constraints for the smallest area, which we use as our measure of cost (Beyer et al. 2016). This objective is similar to that used in Marxan, the most widely used spatial conservation planning tool (Ball et al. 2009), but has been shown to lead to more efficient solutions11.

**Results**

**Discussion**

**Conclusion**

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