Incorporating better data availability into reserve design to improve the capacity of protected areas to safeguard biodiversity

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I. Introduction

Reserve networks are a cornerstone of conservation. Reserves are critical for preventing habitat loss and subsequent biodiversity loss (Deguise and Kerr 2006), and despite over a century of research developing a robust theoretical framework around it, reserve design remains a persistent and dynamic practical challenge. This is due, in part, to emergent complexity in our ecological understanding and, in part, to added complications from social factors such as human population expansion, resource extraction and climate change. These same factors add a level of urgency, further complicating the problem. Thankfully, the sophistication of computational methods has simultaneously evolved with our ecological understanding, and optimization problems are made much easier as a result. With advanced ecological theory and powerful computational tools, the next frontier is how best to synthesize the two and most accurately represent the problem, and which ecological parameters should be included in a highly dynamic optimization problem.

The most basic elements included in a reserve design problem include "features you are trying to protect (e.g. species or habitats), a protection objective (e.g. ensure 20% of the range of each species is within a protected area), and various constraints and limitations (e.g. land parcel cost). This becomes instantly more complicated with multiple features, how a protection objective is defined, and the complexity of the constraints.

Some global guidance on protection targets has been provided by the Convention on Biological Diversity. In their tenth meeting in 2010, this global policy-making body of the UN created targets for global biodiversity protection from 2011-2020, the Aichi Biodiversity Targets, based on a series of strategic goals. In support of their strategic goal to “improve the status of biodiversity by safeguarding ecosystems, species and genetic diversity” they propose a target of protecting at least 17% of global terrestrial and inland water “through effectively and equitably managed, ecological representative and well connected systems of protected areas and other effective area-based conservation measures.” (Convention on Biological Diversity 2011) These guidelines are informed by years of failed efforts to slow the decline of global biodiversity prior to 2010 (MacKinnon et al. 2015) and are broad and wide-reaching as a result. However limitations come from the broad definition of these goals. Area-based conservation measures are broadly-speaking, a logically sound goal, however in practice, the relationship between species abundance and area is not linear, or is the risk of extinction the same for all species. The breadth of the Aichi targets neglects the nuance inherent in ecological dynamics, and does not account for region-specific interpretation or challenges. Additionally, the location of many protected areas (PAs) has been chosen opportunistically, for their low opportunity cost rather than for their ecological value (Venter et al. 2018). Area-based targets can obfuscate the underlying reality of what is actually being protected in these reserve networks, and detract from the ultimate strategic goal of conserving ecosystems, species and genetic diversity (Watson et al. 2016). It follows that though some areas may contribute to the Aichi goal of 17% terrestrial protected areas, they may contribute far less to the strategic goal.

There are various suggestions to improve these targets, but one is to identify important biodiversity areas and focus on achieving ecological representation. One such method is to focus on where the species actually occur. Typically in reserve design, protection targets are based on generalized species ranges rather than detailed information on the spatial and temporal patterns of abundance. This is not unreasonable, because we don't usually have data available on where species actually occur. However, if these data are available, it could provide more effective and efficient PAs and help to evaluate existing ones.

A recent study from the Cornell Lab of Ornithology used data from their eBird community science project to look at how high resolution models of the spatiotemporal dynamics of migratory birds (referred to as eBird Status and Trends models) could help in the development of more effective protected areas (Johnston et al. 2020). Their novel method allows for the focus to be shifted to the actual abundance rather than more generalized range maps.

In this study, I will use the eBird Status and Trends data to examine the validity of abundance-derived optimization solutions against the traditional range-derived solutions. I will then use this same dataset to look at existing protected areas in British Columbia, and how well these areas protected breeding bird abundance (Fink et al. 2020).

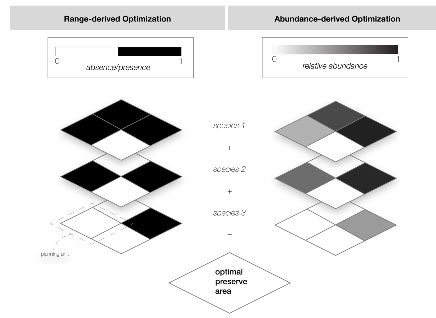


Figure 1: *Illustration of a range-derived optimization problem and an abundance-derived optimization problem*

II. Methods

Systematic reserve design exercises start by defining a specific, quantifiable objective. In this analysis I will use the minimum set cover problem, which is the most widely used objective in the reserve design literature (Alagador and Cerdeira 2020). In general terms, this objective consists of defining a set of features to protect (e.g. species), representation targets for each feature (i.e. how much of each feature is to be protected), and planning units (i.e. the areal units that are candidates for protection) with an associated cost metric (typically the area). The goal is then to select the lowest cost set of planning units that simultaneously meets all the representation targets.

In this analysis, I focused on identifying protected areas for a suite of 119 breeding birds in British Columbia. The features used in the prioritizations were the eBird Status and Trends abundance models, and the planning units were the cells of the 3 km raster grid in which these data were provided. The tool used to solve this optimization problem was prioritizr, an R package developed to solve conservation optimization problems. In order to look at how a range-derived optimization problem would differ from an optimization problem using abundance data, I examined four different feature scenarios: the abundance data and three different binary features derived from the 25th, 50th, and 75th quantiles of the abundance data, respectively. The higher the quantile, the more restrictive criteria for presence/absence. For example, the 75th quantile (q75) contains the top 25% of cells that have the highest abundance. For each feature type, I ran a set prioritizations using different protection targets: 20%, 40%, 60% and 80%. This set of four feature types and four protection targets resulted in a total of 16 scenarios (Figure 2.) To evaluate the effectiveness of each scenario, I compared the resulting solution to the original abundance data to assess what proportion of the population of each species was captured by each scenario, and compared this to the number of planning required for each solution.

I also wanted to compare the effectiveness of our current protected areas in British Columbia against an abundance-optimized solution. I downloaded the current protected lands raster from the BC Government Data Portal. Although the Aichi target is intended to be 20% for 2020, the currently available data show that 15.3% of the province is under some form of protection as of 2016. 'Protected lands' includes the land designations of 'Parks and Protected Areas' and 'Other Protected Lands'. (Environmental Reporting BC 2017). I compared the existing protected areas to a prioritization based on abundance data using 15.3% as the protection target to look at how the two overlapped spatially. I also examined how well the existing 15.3% protected areas actually protected the abundance of the suite of breeding birds in BC.

III. Results

i. Abundance vs. range targets

By definition, the optimization problem using abundance data will necessarily find a solution with the target as a minimum, whereas this is not the case when using range data. In Figure 3a, we see that out of the 12 binary scenarios,

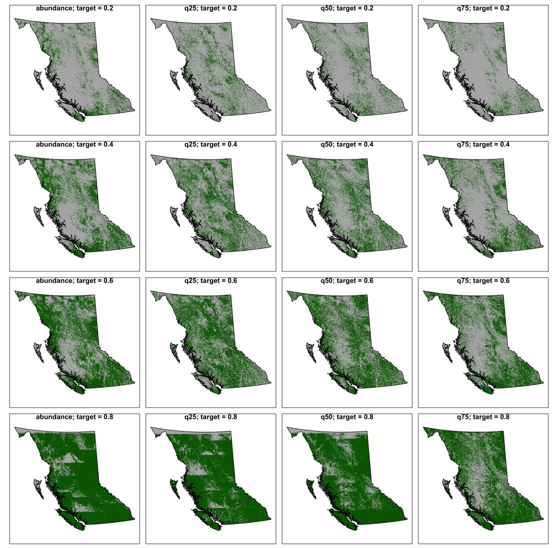
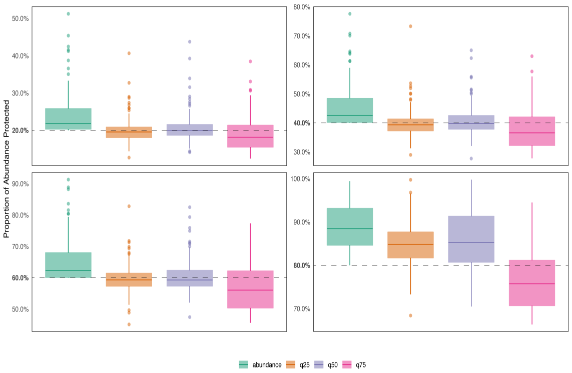


Figure 2: *Illustration of a range-derived optimization problem and an abundance-derived optimization problem.*

the mean species abundance was under target in 5 of the scenarios. Digging deeper into these distributions, all of the binary feature optimizations had many species that did not meet the protection target. Of the 12 scenarios using binary features, 10 of them protected the target abundance for less than half of the existing species (see Figure 3b, Table 1). It is clear that using continuous abundance data rather than binary range data is more effective at optimizing land parcels to protect biodiversity. However, I wanted to ensure that a higher level of protection was not just a result of more planning units being included in the abundance optimization.

ii. Abundance targets are more efficient

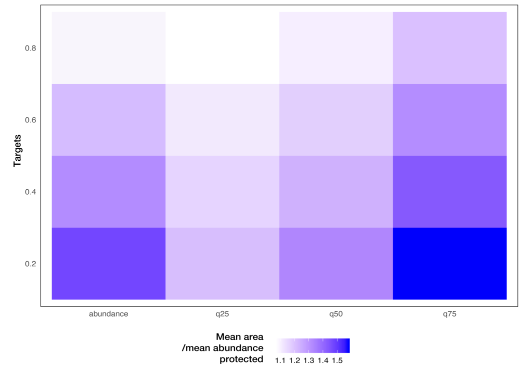
Looking at the ratio of mean area protected against mean abundance protected (Figure 4a), it does not appear that the abundance optimizations are necessarily any more efficient. If this ratio is normalized against the proportion of species abundance protected at the target level, as in Figure 4b this appears to change, and it becomes clear that the abundance-optimized



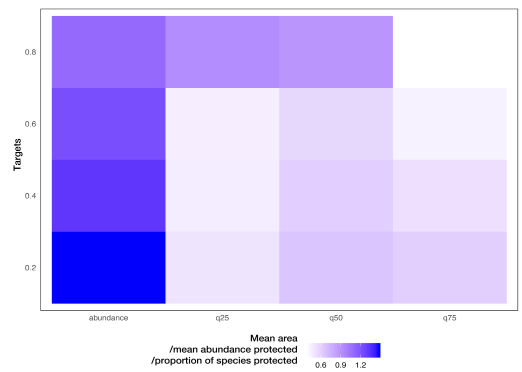
(a) *Boxplots showing the distribution of the species abundance protected by each of the features for the different targets.*

(b) *Each dot represents the proportion of abundance protected for one species. Red dots indicate that the protection target is not met for that species.*

Figure 3: *Measures of of the effectiveness of each scenario. Abundance-optimized solutions meet the protection target by definition, whereas all binary solutions had many species where the abundance protection was not met.*



(a) *The ratio of mean area and mean abundance protected (as in Table 1).*



(b) *The ratio of mean area and mean abundance protected, normalized to the proportion of species protected at the target level of 15.3%.*

Figure 4: *Measures of the efficiency of each cell. Darker colours indicate better protection.*

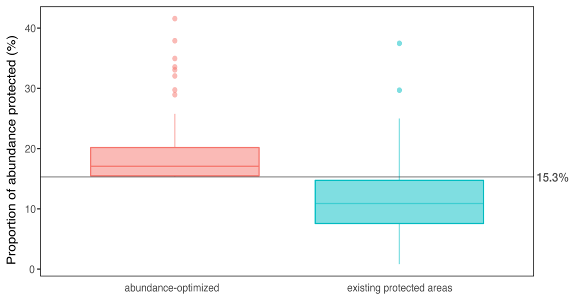
solution provides not only the most effective protection, but also the most efficient protection, per unit area.

iii. Underprotecting birds

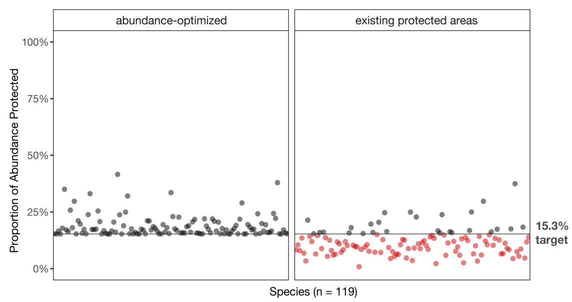
Using this method to compare to BC's existing protected areas to an abundance-optimized solution, I found that the abundance-optimized solution was, similarly, more effective at protecting existing bird abundance in BC. Figure 5a shows a significant difference between the two distributions and the interquartile range of the for the existing protected areas distribution does not reach the target protection level. Figure 5a shows that the target of 15.3% is reached for only 27 out of 119 species, leaving 77.31% of species abundance under-protected.

IV. Discussion

Interestingly, the overlap between the existing protected areas in BC and the abundance-derived solution is quite minimal. This highlights an important distinction between the two problems, in that one is reality and one is entirely theoretical. In this optimization, I've included no cost layers, no other taxa or biogeoclimatic zones, or any additional constraints, making this a highly idealized solution, spe-



(a) *The distribution of the species abundance protected within the abundance-optimized solution (left) and of the existing protected areas in British Columbia (right).*



(b) *Each dot represents the proportion of abundance protected for one species. Red dots indicate that the protection target is not met for that species.*

Figure 5: *Both (a) and (b) show that British Columbia's existing protected areas are currently under-protecting bird abundance. The abundance-optimized solution meets the target by definition.*

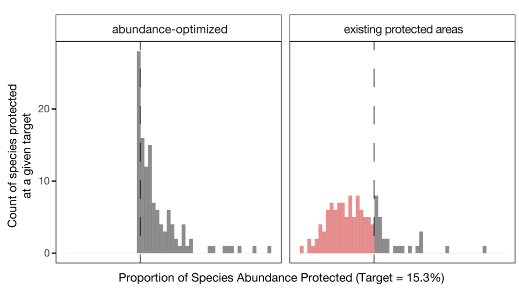


Figure 6: *Histograms showing the counts of species protected within the abundance-optimized solution (left) and of the existing protected areas in British Columbia (right) The line shows the protection target of 15.3%.*

cific to birds. However, the comparison serves an important function nonetheless. It highlights a false equivalency between protected areas and protected biodiversity. Area-based targets are valuable because they are easily measurable, but they run the risk of giving the impression that the ultimate goal of preserving biodiversity is reached if an equivalent area-based goal is reached, and we can see that this is not the case (Watson et al. 2016). Not all land parcels are of equal ecological value, and it has been shown that protected areas have often been selected based on minimizing conflict with agriculturally valuable land rather than targeting land parcels with high concentrations of biodiversity (Venter et al. 2018).

Evaluating land parcels based on an ideal spatial model might serve as an effective method for assessing the value of our existing areas. As ecological data availability improves, we can assess the value of existing land parcels and which taxa are being under-protected, in order to inform our focus in future planning. These models can hopefully incorporate potential external threats facing protected areas, such as surrounding overdevelopment and climate change, to provide spatially- and temporally-considerate representations of ecological important areas (Wulder et al. 2018). If the goal is to protect biodiversity, then we should protect biodiversity as directly as possible, and using higher-resolution abundance data, even without other representative parameters, gives us a spatial view of what that would ideally look like.

That said, there were many limitations to this optimization study. If the goal of using higher resolution data is to more closely represent reality, then other parameters must evidently be considered. Their omission in this study was largely the result of a lack of computational power, but some of these parameters bear description. First, a more robust, representative model would have included a cost layer. This is not currently available for BC, and using a proxy, such as population density, for example, may have introduced inaccurate and unintended bias, that wouldn't have been valuable enough to outweigh the computational time it would add. Second, I was not able to take into consideration any boundary penalty in my optimization problem, which would have preferentially selected adjacent planning units in order to limit edge effects (Cabeza and Moilanen 2001). This is a very ecologically important parameter to consider in reserve design in order to limit biodiversity loss through edge effects. This, and other reserve design principles, would have been important to include for a more interesting comparative study, particularly in comparing the abundance-optimized solution to existing PAs in BC (Hawkes et al., 1997).

In addition to the inclusion of a cost layer, and a boundary penalty, further optimization problems would be well served by the inclusion of a weighting for sensitive species. Adding in a preference for species on the Species At Risk Act, for example, would add in another dimension of nuance, enriching the representation to be closer to reality (Bolliger et al. 2020).

Birds are often cited as good indicators of biodiversity. Studies have shown evidence to support this to some degree, but the correlation is not very strong, and is scale– and biome– dependent. I have focused on birds for the availability of robust data, but bird diversity does not reflect broader biodiversity, per se. According to a meta-analysis on birds as biodiversity indicators, bird diversity best reflects mammal diversity, so it may be useful in also accounting for this taxon, but a more complete representation would include abundance targets for taxa of concern (Eglington, Noble, and Fuller 2012).

Despite these limitations, this study supports the idea that using higher resolution abundance data is far more effective, not only because it allows us to target species where they actually occur, but because it allows us to move away from area-based protection targets. The ability to protect species abundance directly makes the identification of high biodiversity areas easier, and this translates into more effective protection, more quickly (Watson et al. 2016) and this expediency is highly valuable when considering the onslaught of potential threats to biodiversity, such as development, habitat loss and climate change.

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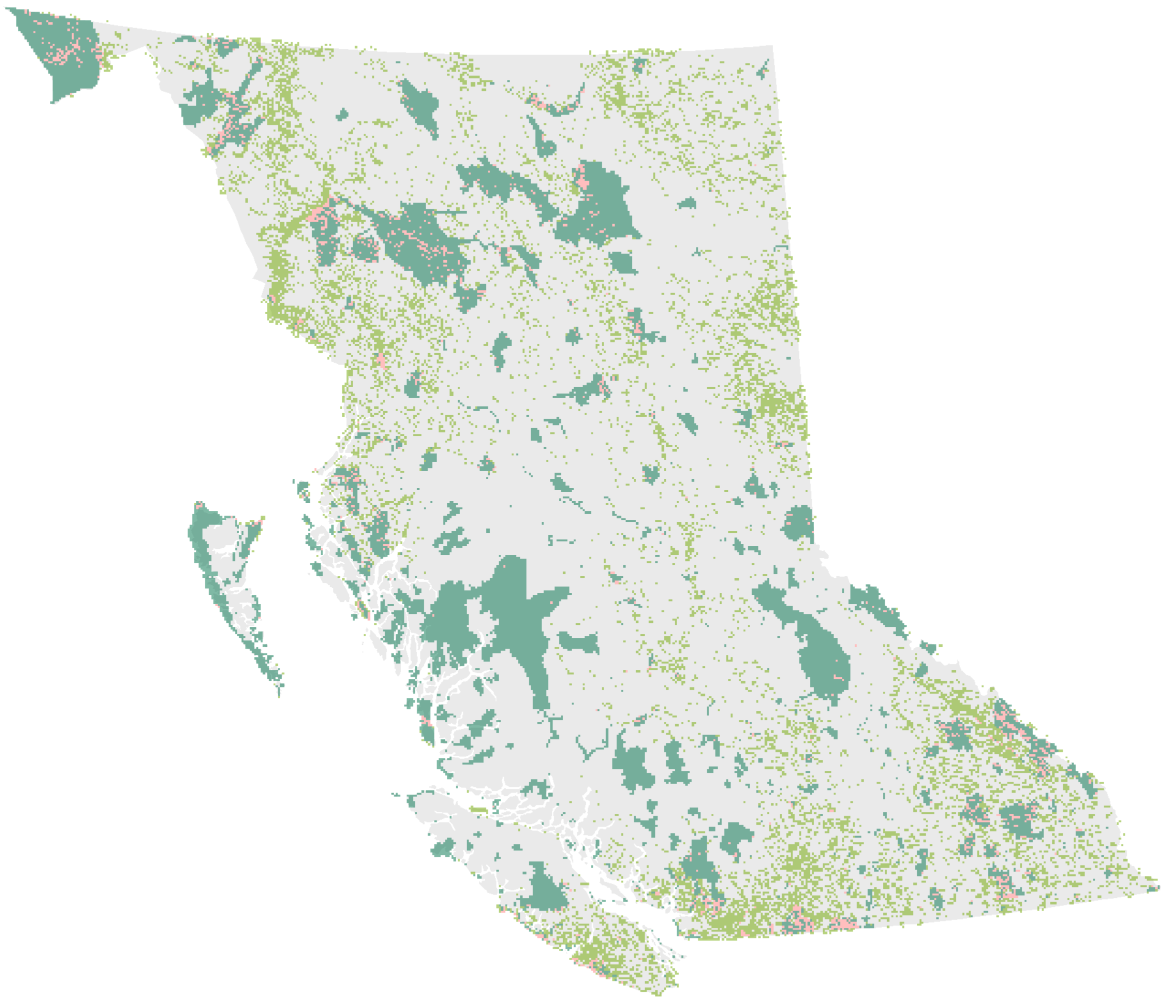
Table 1: *Summary Statistics for 16 Optimization Scenarios*

Features	Target (%)	# Planning Units	Area (%)	SD	Mean Abundance Protected	Area/Mean Abundance	# Species Unprotected	% Unprotected
abundance	20	18775	16.44	37.07	24.2	1.47	0	0.0
q25	20	19003	16.64	37.25	20	1.20	70	58.8
q50	20	17917	15.69	36.37	20.8	1.33	62	52.1
q75	20	13769	12.06	32.56	19	1.58	75	63.0
abundance	40	39520	34.61	47.57	45.6	1.32	0	0.0
q25	40	39711	34.78	47.63	40.1	1.15	72	60.5
q50	40	37897	33.19	47.09	40.8	1.23	61	51.3
q75	40	30280	26.52	44.14	37.9	1.43	76	63.9
abundance	60	61672	54.01	49.84	65.3	1.21	0	0.0
q25	60	61741	54.07	49.83	59.8	1.11	71	59.7
q50	60	59537	52.14	49.95	60.7	1.16	63	52.9
q75	60	49506	43.35	49.56	56.9	1.31	80	67.2
abundance	80	93596	81.97	38.45	88.6	1.08	0	0.0
q25	80	91080	79.76	40.18	84.8	1.06	18	15.1
q50	80	89740	78.59	41.02	86.3	1.10	25	21.0
q75	80	72804	63.76	48.07	76.4	1.20	82	68.9

Table 2: *Summary Statistics for Existing and Abundance-Optimized Protected Areas in British Columbia*

Features	Target (%)	# Planning Units	Area (%)	SD	Mean Abundance Protected	Area/Mean Abundance	# Species Unprotected	% Unprotected
existing	15.3	17017	14.90	35.61	11.66	0.97	92	77.31
abundance	15.3	13716	12.01	32.51	18.82	1.26	0	0

Abundance-Derived Optimization Solution Units vs. Existing Protected Areas in British Columbia

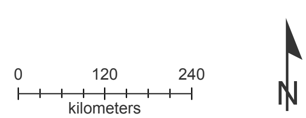


Planning Units common to both scenarios

Existing Protected Areas in BC

Abundance-Optimized Solution

features	number of cells	mean area (%)
existing protected areas	17,017	14.90
abundance-optimized solution	13,716	12.01
overlapping units	1,616	1.42
total	**114,190**	**100**



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