Species Mapping and Modelling: Strategies and Opportunities

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Contents

1 Introduction

1.1 Project Background

The Coastal Douglas-fir Conservation Partnership (CDFCP), UBC Botanical Gardens and UBC Okanagan are developing a Biodiversity Atlas as part of a collaborative project called Action for Adaptation. The Atlas will include mapping layers that local government and First Nations have indicated that they need to guide planning and decision making.

In 2022 and 2023 through one-on-one conversations and workshops we heard that environmental mapping is typically at a resolution that is too low for local and regional planning; coverage is often incomplete, and maps are often out of date. **Table 1** presents comments shared about species data, mapping and modeling.

Table 1 Summary of comments from breakout groups during a workshop in Nov 2023

Topic Area	Opportunities	Challenges
What are the opportunities and challenges of using citizen science species data?	-Enables more records to be collected. -Enables increased engagement with the community, planners and decision makers.	-The records are biased by where people live; the species they can see or the species they are interested in. -There is potentially a higher risk of error. -The records may be harder to defend to the public.
What are the opportunities and challenges with mapping culturally significant species?	-Creates an opportunity for western science and indigenous knowledge to be presented together. -Provides evidence for the protection of sites with culturally valuable species. -Could help to build relationships.	-Data sovereignty / confidentiality of information / miss use of information would need to be considered. -Capacity might be limited for First Nations to engage in this work. -The project needs to work with each Nation to understand their needs. -Places a focus on single species vs whole environment
What are the opportunities and challenges in using provincial or other habitat suitability mapping?	-The models alleviate observer bias by drawing on a lot of resources to identify potentially suitable habitat. -Extends beyond jurisdictional boundaries. -Can be used to identify where to complete detailed surveys.	-The quality of the model is impacted by the quality of the information it is based on. -Models could only be completed for a few species. -The models would be difficult to enforce / regulate. -Need a clear indication of assumptions and how to use the models.

Note: the comments in Table 1 are those of attendees and may differ from the CDFCP.

1.2 Purpose of this Report

The purpose of this report is to present the results of a literature review and conversations with mapping experts. The intent that this report will then facilitate discussion about what could be the best approach to presenting species information for local government and First Nations to guide their planning and decision making.

2 Overview of Species Mapping and Modelling

Mapping biodiversity and threats to species is an essential tool for conservation planning, providing actionable insights into ecological priorities and challenges. Various approaches, including hotspot mapping, selective mapping, predictive modeling, and threat mapping, offer complementary methods for identifying areas of high ecological value and those under significant pressure. However, each approach comes with unique considerations, strengths, and limitations.

For instance, biodiversity hotspot mapping focuses on areas with high species richness or endemism, making it a valuable method for prioritizing these locations. However, its effectiveness may be limited due to variations in species distribution across taxonomic groups and the inconsistent overlap between hotspots (Xu et al., 2018).

In response to these challenges, alternative approaches such as selective mapping and predictive modeling focus on specific species with known habitat requirements, using advanced spatial techniques like Generalized Additive Models (GAMs) to predict habitat suitability. Threat mapping, on the other hand, overlays biodiversity data with anthropogenic pressures, identifying regions where conservation efforts are most urgently needed (Salafsky et al., 2008; Margules & Pressey, 2000).

The remainder of this report will explore in more detail the strengths and weakness of approaches to mapping and modelling by using existing examples.

2.1 Summary Potential Approaches

- **Biodiversity Hotspot Mapping:** Mapping biodiversity or species richness within one or multiple taxonomic groups to identify areas of ecological importance.
- **Selective Mapping:** Focusing on species with strict habitat requirements, species at risk, or those with extensive abundance data specific to the CDFmm.
- **Predictive Modelling:** Using existing datasets for a subset of selected species (e.g., those identified for selective species mapping) and extrapolating potential distributions using predictive modeling techniques. This approach leverages

available habitat raster datasets and would likely involve the use of Generalized Additive Models (GAMs).

- **Threat Mapping:** Identifying areas of overlap between biodiversity hotspots and regions facing significant threats (e.g., forestry, development). This approach provides an additional raster layer that highlights areas of high ecological value under the greatest pressure.

2.2 Potential Datasets to Draw From

Below is a list of tools from which species data can be accessed.

- **Global Biodiversity Information Facility (GBIF):** An open-access database aggregating biodiversity data from around the world, enabling analysis of species distributions and ecological patterns.
    - **eBird:** A global community science platform where birders contribute observations, generating real-time data on bird abundance, distribution, and migration patterns.
    - **iNaturalist:** a global online platform and mobile app that allows users to document and share observations of biodiversity. It serves as a community science tool where naturalists, researchers, and the general public can record sightings of plants, animals, fungi, and other organisms, contributing to a shared database of biodiversity information. iNaturalist uses crowd-sourced identification and expert verification, making it a valuable resource for ecological research, conservation efforts, and educational purposes.

  In addition to eBird and iNaturalist, GBIF aggregates from the following platforms – iSpot, Pl@ntNet, BugGuide, HerpMapper, MammalWeb, BirdTrack, Project FeederWatch, Reef Life Survey, SeagrassSpotter, iSeahorse, Butterflies and Moths of North America (BAMONA), Monarch Watch, The Great Sunflower Project, Zooniverse, EarthChallenge, Globe Observer, Nature's Notebook among some others.
- **The Breeding Bird Survey:** A standardized, continent-wide monitoring program for breeding bird populations in North America, providing essential data for understanding species trends and conservation needs.
- **NatureServe:** A biodiversity data platform that provides authoritative information on species at risk, including conservation status, habitat requirements, and distribution maps.
- **Botanical Information and Ecology Network (BIEN):** A comprehensive repository of plant-related data designed to support ecological research, conservation, and

biodiversity studies. BIEN integrates diverse datasets, including species distributions, functional traits, phylogenies, and environmental associations, to provide a detailed understanding of plant ecology and biogeography.

- **North Nocturnal Owl Survey:** A community science initiative focused on monitoring nocturnal owl populations across Canada, providing critical data on distribution, abundance, and long-term trends.
- **British Columbia Breeding Bird Atlas:** A comprehensive project documenting the distribution and abundance of breeding bird species in British Columbia, offering valuable insights into avian ecology and habitat use.
- **British Columbia Coastal Waterbird Survey:** A long-term monitoring program tracking coastal waterbird populations, helping to assess population trends, habitat use, and the health of marine ecosystems in British Columbia.

3 Approaches to Species Mapping and Modelling

3.1 Biodiversity Hotspot Mapping: An Overview

Hotspot mapping is a spatial analysis technique used to identify areas of high ecological significance, biodiversity, or conservation value. These "hotspots" are locations where species richness, endemism, or habitat functionality is exceptionally high, often overlapping with regions under significant anthropogenic pressure. The method is widely employed in conservation planning to prioritize areas for protection, restoration, or sustainable use.

The concept of biodiversity hotspots was popularized by Norman Myers (1988), who identified 25 regions globally with high levels of plant endemism and habitat loss. Hotspot mapping builds on this idea, integrating species distribution models, environmental data, and geospatial tools like GIS to highlight areas of concentrated ecological function.

Common inputs for hotspot mapping include species occurrence records, habitat suitability layers, and environmental variables (e.g., climate, land cover). By visualizing these data, researchers and policymakers can pinpoint areas critical for maintaining ecosystem services, conserving threatened species, or managing human-wildlife conflict.

Hotspot mapping has proven effective for informing decision-making at global (e.g., Convention on Biological Diversity targets) and local scales.

Project Examples:

- **Biodiversity Conservation Network (BioNET Maryland):** BioNet is a GIS-based digital mapping tool developed by Maryland's Natural Heritage Program (NHP) to prioritize areas for terrestrial and freshwater biodiversity conservation (**Figure 1**). Building on over 40 years of NHP data collection and analysis, BioNet highlights critical habitats for rare, threatened, and endangered species, as well as high-quality natural communities. It integrates data on 1,000 rare species, 1,500 Ecologically Significant Areas, and essential wildlife corridors, focusing on globally rare species and habitats and habitats that support large concentrations of rare species.

  The tool organizes priority areas into a five-tiered system, ranging from Tier 1 Critically Significant for Biodiversity Conservation to Tier 5 Significant for Biodiversity Conservation. BioNet aids proactive conservation efforts such as land acquisition, habitat restoration, and mitigation planning. It also considers large landscapes essential for migratory animals, population dispersal, and climate change resilience.

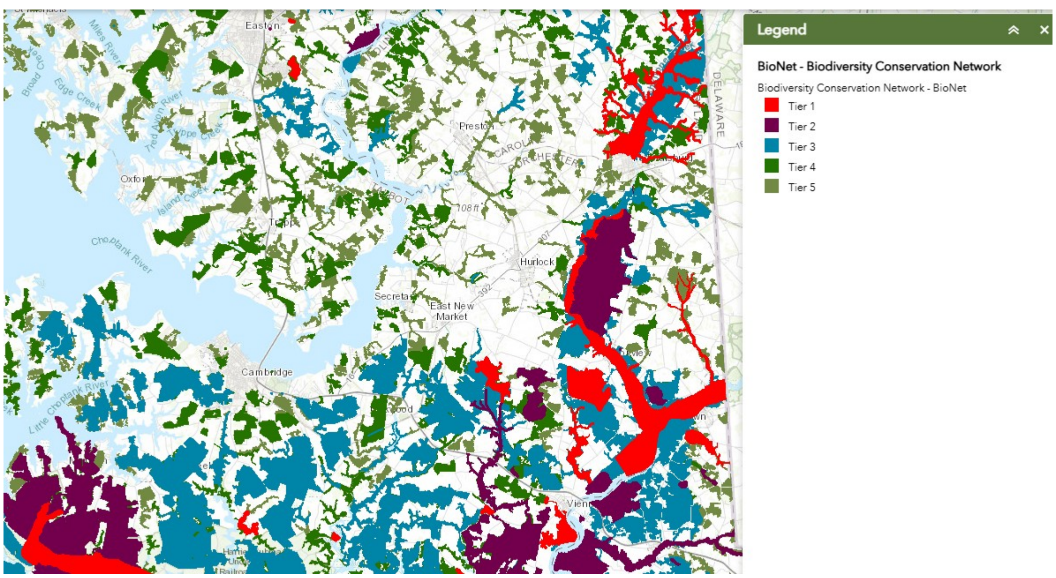


Figure 1. Maryland's GreenPrint mapping BioNET tool, parcel by parcel showing the conservation tiers, red are the highest priority for conservation according to BioNET.

- **E.O. Wilson Foundation's Half Earth Project (resolution 27 km^2):** The Half-Earth Project utilizes advanced geospatial and biodiversity modeling techniques to identify and prioritize areas critical for global species conservation (**Figure 2**). Central to the project is the integration of high-resolution species distribution data derived from global biodiversity databases, such as the International Union for

Conservation of Nature (IUCN) Red List, BirdLife International, and GBIF. These datasets are combined with environmental variables, such as climate, vegetation, and topography, to model habitat suitability and species ranges.

The project applies species richness and endemicity indices to quantify biodiversity value at a 1-km spatial resolution (although final maps are provided at 27 km^2 global resolution). A key metric, the Species Protection Index (SPI), evaluates the overlap between species distributions and protected areas. The SPI identifies gaps in existing conservation networks by highlighting regions with high biodiversity that remain under protected. Priority areas are identified using an algorithm that considers species vulnerability, habitat irreplaceability, and the importance of ecosystem connectivity for migratory and wide-ranging species.

The biodiversity analysis employs MaxEnt (Maximum Entropy Modeling) and ensemble modeling techniques to predict species distributions, validated against known occurrence records (Rinnan et al., 2021). This ensures robust spatial predictions, particularly for regions with limited biodiversity surveys. The resulting maps include layers for individual taxa: mammals, birds, amphibians, reptiles, and plants, as well as combined layers for multi-taxa richness and priority areas.

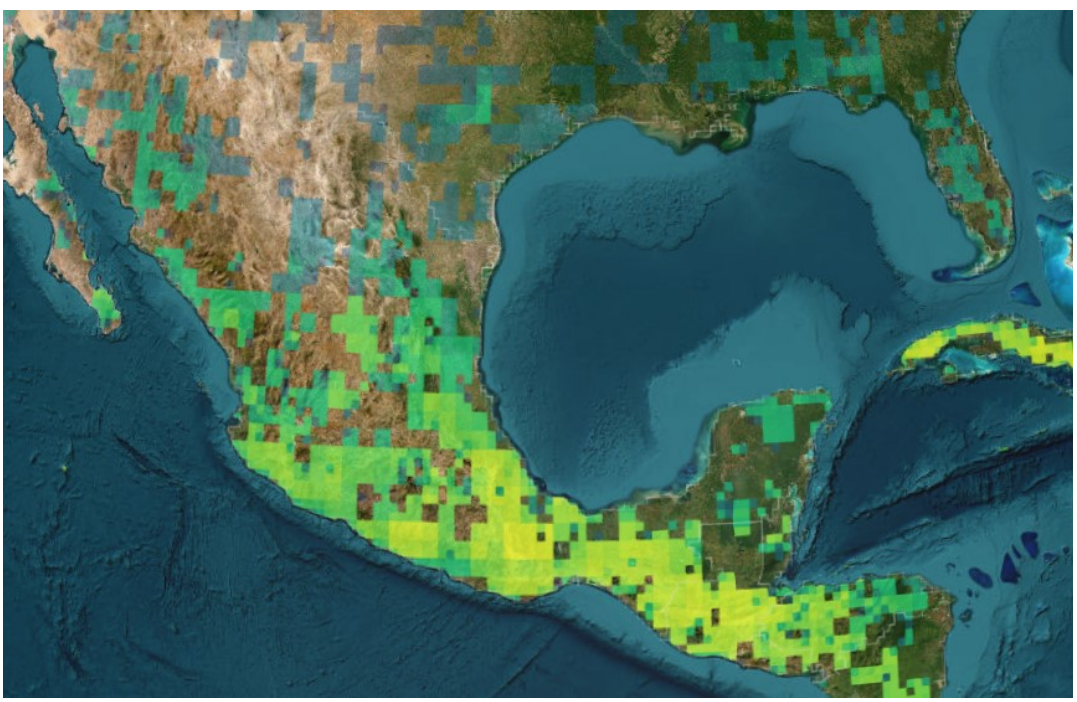


Figure 2 Half Earth Map of global biodiversity at a 27 km^2 spatial resolution. Analysis was conducted at a 1-km spatial resolution.

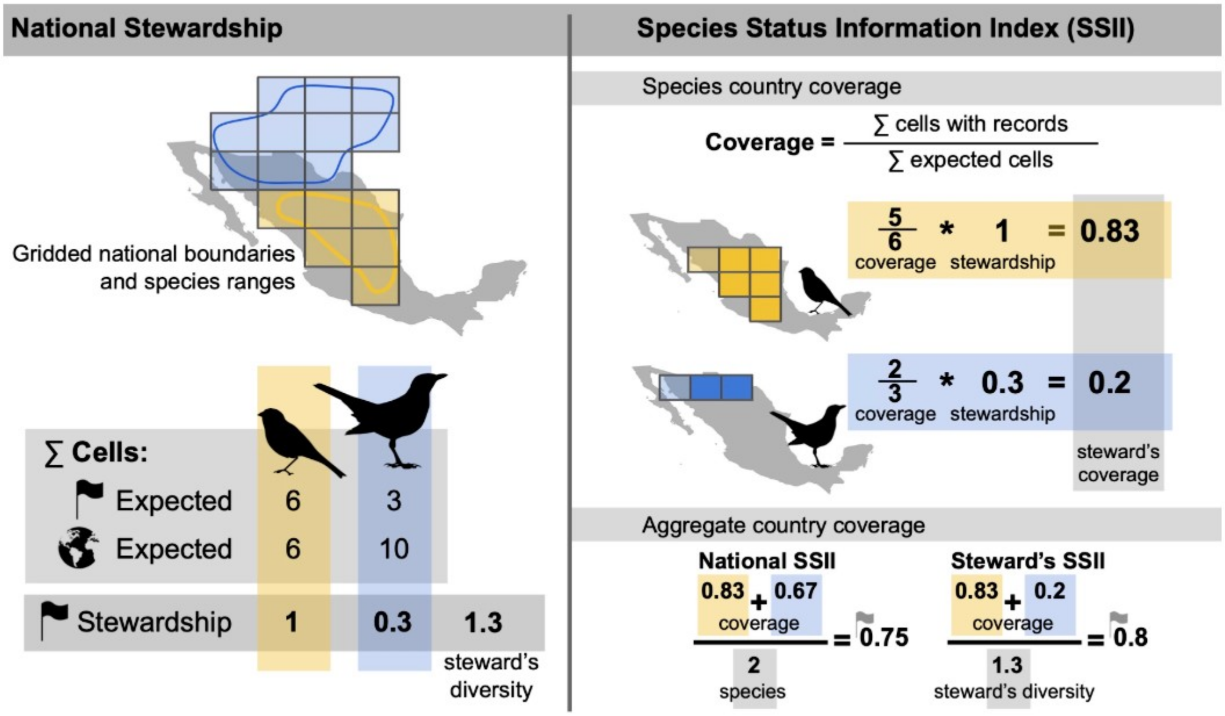


Figure 3 Half Earth's methods to calculate Species Status Information Index (SSII) which they use to understand whether species have the appropriate stewardship within the area of interest.

Pros and Cons of Hotspot Mapping

Pros	Cons
Efficient Resource Allocation: Hotspot mapping helps prioritize limited conservation resources by focusing on areas of greatest ecological importance.	**Data Limitations:** Relies on the availability and accuracy of species occurrence records and environmental data, which may be incomplete or biased.
Biodiversity Conservation: Highlights regions with high species richness or endemism, aiding in the protection of critical habitats and species at risk.	**Static Representation:** Often reflects current or historical conditions, potentially overlooking dynamic ecological processes like migration or climate-driven changes.
Data-Driven Decision-Making: Integrates species occurrence data, environmental variables, and advanced spatial analyses to create evidence-based conservation plans.	**Focus on Richness Over Function:** May prioritize areas of high species richness while neglecting ecosystem functionality or ecological connectivity.

3.2 Selective Species at Risk Mapping: An Overview

Selective species at risk mapping focuses on identifying key habitats and regions essential to the survival of specific species. Unlike modeling, which predicts species presence based on environmental factors, mapping emphasizes the spatial distribution of known populations using occurrence records and habitat data (essentially range mapping). This approach highlights areas of ecological importance and informs targeted conservation planning.

For example, mapping the Western Screech-Owl (*Megascops kennicottii kennicottii*) provides insights into riparian and forest habitat connectivity, both critical for the owl's survival (Cannings & Angell, 2001). The Northern Goshawk (*Accipiter gentilis laingi*), which depends on mature forests, emphasizes the conservation of these intact ecosystems (Reynolds et al., 1992). Mapping the Marbled Murrelet (*Brachyramphus marmoratus*) reveals critical nesting areas within old-growth forests, a habitat under threat from logging (Burger, 2002).

Species like the Vancouver Island Marmot (*Marmota vancouverensis*), endemic to alpine meadows, and the Northern Red-legged Frog (*Rana aurora*), reliant on wetlands, underscore the need to protect sensitive ecosystems (COSEWIC, 2008; Blaustein et al., 1994). In aquatic systems, mapping the Coastal Cutthroat Trout (*Oncorhynchus clarkii clarkii*) and Pacific Water Shrew (*Sorex bendirii*) highlights the importance of clean, connected riparian habitats (Haig et al., 2006; Maser et al., 1981).

This mapping approach ensures that conservation efforts focus on regions of known ecological significance, supporting habitat protection and restoration priorities. By targeting representative species, it also reflects broader ecosystem health and resilience.

Current Projects:

- **Metro Vancouver's Evaluation of Regional Ecosystem Connectivity:** Metro Vancouver created maps for eight focal species that represented diverse habitat requirements, movement patterns, and tolerances to urban impacts. These species include birds, mammals, and amphibians, such as the pileated woodpecker and long-toed salamander. Habitat patches were identified using geospatial data, accounting for barriers like roads and rivers, and prioritized based on connectivity metrics like the Probability of Connectivity (PC) and the importance of stepping stones between patches (dPCconnect) (**Figure 4**).

  They then used specialized software, including Conefor and Zonation, to analyze and rank habitat patches for regional connectivity. Conefor evaluated the role of specific patches in the network, while Zonation highlighted unprotected areas critical for maintaining connectivity. The maps also incorporated layers of protected areas, allowing planners to identify gaps in conservation and prioritize unprotected but vital habitats. This systematic approach supports urban and regional planning, ensuring the protection of essential green spaces for biodiversity.

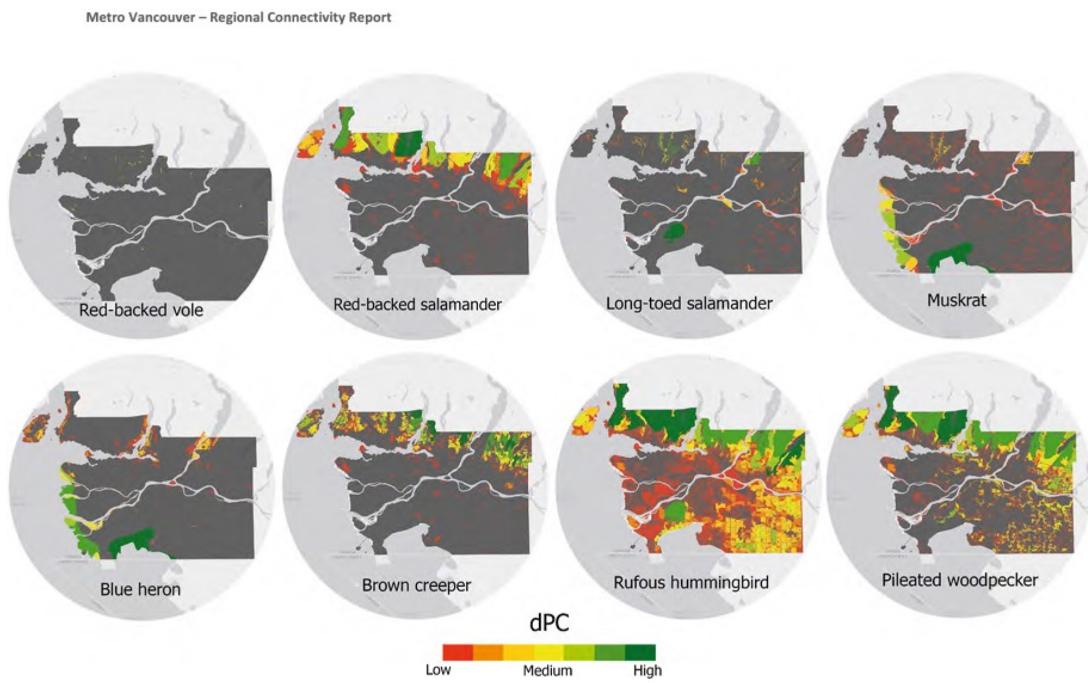


Figure 4 Probability of Connectivity mapped for the eight focal species in Metro Vancouver.

Pros and Cons of Selective Species at Risk Mapping

Pros	Cons
Targeted Conservation Efforts: Focuses resources on species and habitats with the highest conservation priority, ensuring effective use of time and funding.	**Focus on Known Species:** May neglect lesser-known species or ecosystems not represented by the selected species, leading to potential conservation blind spots. May be biased in our species selection process.
Representative of Ecosystem Health: Species selected often represent broader ecosystem health, helping to identify key areas critical for maintaining ecological integrity.	**Overlooks Functional Roles:** Prioritizing specific species might miss critical ecosystem services provided by less visible or less charismatic species.

Pros	Cons
Enhances Stakeholder Engagement: Clear and easily interpretable visual outputs (maps) communicate ecological importance effectively to policymakers, funders, and the public.	**Resource Intensive:** Gathering and processing occurrence data, validating it, and generating maps can be time-consuming and costly.

3.3 Predictive Species at Risk Modeling: An Overview

Predictive species at risk modeling uses environmental and habitat data layers, such as Digital Elevation Models (DEM) and Vegetation Resource Inventory (VRI), to predict the distribution of species. By correlating known occurrence data with habitat characteristics, the approach generates spatial models that identify areas of potential habitat suitability, guiding conservation and land-use planning.

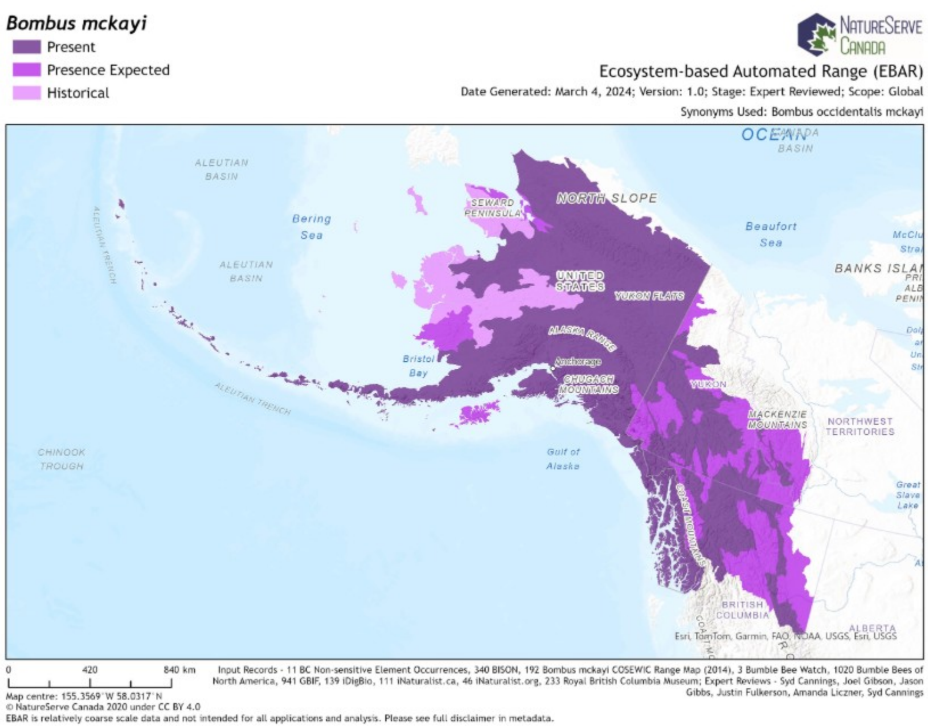
For example, DEM layers can provide critical information about elevation, slope, and aspect, which are key factors for species like the Vancouver Island Marmot and Northern Red-legged Frog, both of which depend on specific topographic features for survival (COSEWIC, 2008; Blaustein et al., 1994). VRI data, capturing forest age and composition, is essential for species such as the Marbled Murrelet, which nests in old-growth forests, and the Northern Goshawk, which relies on mature forest stands (Burger, 2002; Reynolds et al., 1992).

This approach can also include hydrological data for aquatic species like the Coastal Cutthroat Trout and Pacific Water Shrew, ensuring riparian and wetland habitats are accurately mapped. The resulting models provide a dynamic framework for identifying ecological hotspots and prioritizing conservation actions. These predictive maps can be overlaid to identify areas of high conservation value for species at risk. This process can be enhanced using Generalized Additive Models (GAMs), which are particularly effective in capturing nuanced habitat associations. GAMs are well-suited for scenarios where species exhibit non-linear relationships with specific habitat variables, allowing for more accurate predictions of habitat suitability and ecological value. Alternatively, you could employ MaxEnt models (explained below) or tuned Random Forest Models to generate model predictions.

Predictive modeling enhances traditional mapping by projecting potential range shifts due to climate change, ensuring adaptive management strategies (Elith & Leathwick, 2009).

- **Conservation Data Centre (CDC) Habitat Modeling Project:** The project has been ongoing for the past four years, with significant progress made this year following the hiring of Dr. Lilian Sales, a full-time Provincial Species Habitat Modelling Specialist with the CDC. The mapping is designed to align with the NatureServe species habitat modeling program in the United States and aims to deliver models at both 800-meter and 30-meter spatial resolutions (**Figure 5**). While the project continues, the process of having all species habitat models reviewed and approved by species experts is expected to take around 2-3 years.

  Initially the project used tuned Random Forest Models to predict species distributions. However, Dr. Sales has transitioned to using MaxEnt models, which estimate the most uniform (least biased) distribution of a species across a landscape. This approach is based on the principle of maximum entropy and uses environmental data (e.g., temperature, precipitation) from locations where the species is known to occur to predict its potential distribution.



The finalized McKay's Western Bumble Bee (Bombus mckayi) EBAR map after the expert review phase.

Figure 5 Example of NatureServe range maps for McKay's western bumblebee (*Bombus mckayi)* based on predictions from MaxEnt and tuned Random Forest Models and has gone through a final expert review.

- **Integrated Species Distribution Models (iSDMs) (Dr. Erin Crockett's recommendation):** iSDMs are advanced tools used to predict where species are found by combining different kinds of biodiversity data, such as observations from citizen scientists, surveys, and expert knowledge (**Figure 6**). Traditional methods often relied on just one type of data, which could lead to biases or gaps in predictions. iSDMs address this by integrating multiple sources of data for a more complete picture.

  Key methods include:

  1. **Pooling Data:** All data sources are combined, sometimes with adjustments to give more weight to high-quality data.
  2. **Using Prior Knowledge:** Information like a species' preferred habitat or range is added to guide predictions.
  3. **Weighted Integration:** Different types of data are combined with specific weights to balance quality and quantity.
  4. **Bayesian Models:** Advanced statistical methods are used to estimate uncertainties and improve predictions, especially when data is sparse.
  5. **Scenario Projections:** iSDMs can predict changes over time by incorporating environmental factors like climate or habitat alterations.

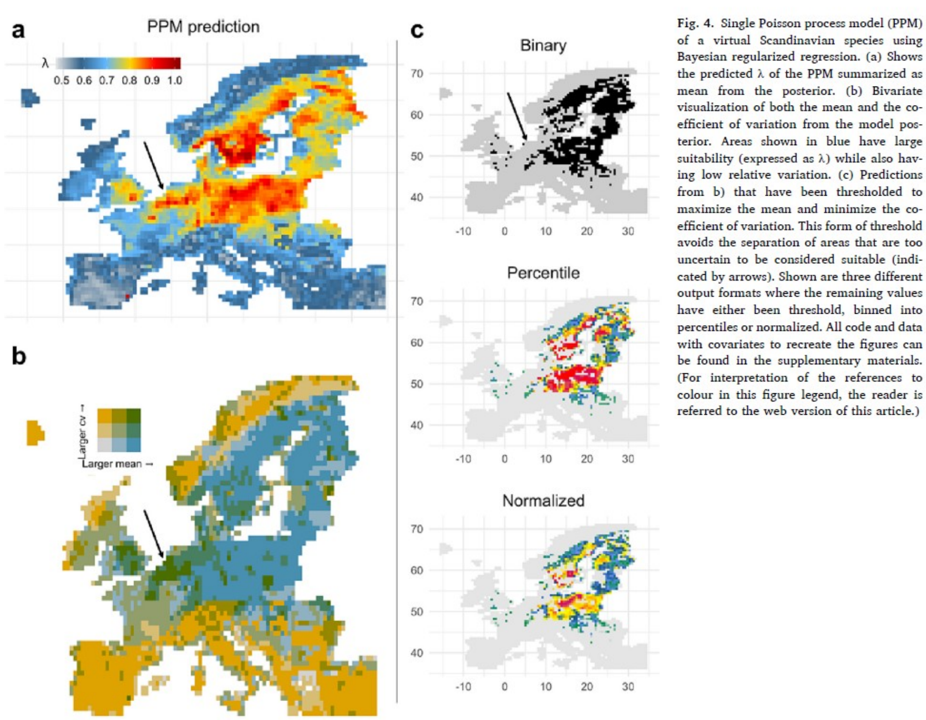


Figure 6 Raster layers feeding into the model that forms the Integrated Species Distribution Models (iSDMs), snapshot from Jung 2023.

Pros and Cons of Predictive Species at Risk Modeling

Pros	Cons
Identifies Potential Habitats: Predictive modeling helps locate suitable habitats even in areas without recorded species observations, expanding the scope of conservation efforts.	**Reliance on Data Quality:** Requires high-quality occurrence and habitat data; inaccuracies or gaps can compromise model reliability.
Integrates Complex Environmental Data: Incorporates multiple habitat data layers (e.g., DEM, VRI, hydrology), allowing for a detailed understanding of species-environment interactions.	**Assumptions and Simplifications:** Models may oversimplify ecological processes, leading to errors in habitat predictions.
Adapts to Non-Linear Relationships: Techniques like Generalized Additive Models (GAMs) capture complex, non-linear habitat associations, improving model accuracy and ecological relevance.	**Complexity and Expertise Required:** Developing and interpreting models demands significant technical expertise and computational resources, and can also be incredibly time consuming and expensive.

3.4 Threat Mapping: An Overview

Threat mapping is a spatial analysis technique used to identify and prioritize risks to biodiverse areas, enabling informed conservation and management decisions. By integrating environmental, socio-economic, and human activity data, threat maps reveal the spatial extent and intensity of pressures such as deforestation, habitat fragmentation, climate change, pollution, invasive species, and overexploitation (Salafsky et al., 2008).

The process involves overlaying biodiversity data, such as species richness or ecosystem types, with datasets on land-use changes, industrial activities, or climatic variables. For example, threat mapping can highlight regions where logging overlaps with old-growth forests or where urban expansion encroaches on wetlands. This spatial approach also helps identify areas where multiple threats converge, posing compounding risks to ecosystems.

Advanced methods incorporate predictive models to assess future threats, such as shifts in climate suitability for ecosystems or increased agricultural pressures due to human population growth (Margules & Pressey, 2000). Threat mapping outputs can be used to guide the establishment of protected areas, prioritize restoration projects, or inform policy changes.

By identifying hotspots of risk to biodiversity, threat mapping helps focus conservation efforts where they are most needed, ensuring the protection of ecosystems critical to biodiversity and ecosystem services.

Pros and Cons of Threat Mapping

Pros	Cons
Prioritization of Conservation Efforts: Identifies areas where threats to biodiversity are most concentrated, helping allocate resources efficiently.	**Data Limitations:** Requires detailed, high-quality data on threats, which may be unavailable or inconsistent across regions.
Encourages Proactive Management: Highlights potential future threats, allowing for preventive measures before significant damage occurs.	**Complexity of Cumulative Effects:** Integrating multiple threats can be challenging, and models may oversimplify or underestimate combined impacts.
Integrates Multiple Threats: Can combine data on various threats (e.g., forestry, development, climate change) to assess cumulative impacts on ecosystems.	**Bias Toward Visible Threats:** Easier to map physical threats (e.g., deforestation) than less tangible ones (e.g., climate stress or ecosystem degradation).

4 Next Steps

The purpose of this report is to facilitate engagement with biologists who have experience of species mapping and modelling and its application, to understand the best approach for local government and First Nations planning and taking into consideration the timeframes of the project (1 year) and capacity to undertake this work e.g. MSc level graduate.

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