OPTIMIZE *Biodiversity*

A Conservation Planning Project

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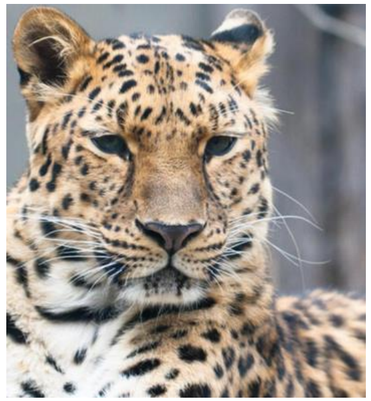
“In just over 40 years, there has been a 60% decline in the world’s populations of mammals, birds, fish, and reptiles
-WWF”

“The loss of biodiversity is a silent killer-” Pasca Palmer

ONE MILLION SPECIES

Threatened with extinction



Amur Leopard

Whales

Bonobos

Black Rhino

WHY IS THIS A PROBLEM?

Threats to Biodiversity

- Habitat loss, Climate change, Invasive species, Pollution, Deforestation

Resource Challenges

- Limited funding, workforce, logistical capacities

Threats to Society

"The impact of biodiversity loss can be extensive [...] causing **disruption** to supply chains"

-EY

"With more than half of global GDP being nature-dependent, [...] biodiversity loss can contribute to significant **economic disruption**"

-BMO Climate Institute

"Biodiversity loss can have significant direct human health impacts"

-World Health Organization

INTRODUCTION

Purpose: Develop an optimization model to maximize biodiversity outcomes within resource constraints.

Key Challeges: Biodiversity loss and the need for efficient resource allocation in conservation.

Significance: Addresses global biodiversity crisis, prioritizing impactful conservation strategies.

CHANGING THE NATURE OF BUSINESS

PRIORITY THREAT MANAGEMENT

Identify and prioritize conservation actions that:

1. **Deliver greatest biodiversity benefits**
2. **Cost Effectiveness**
3. **Feasibility**

WWF

Mission

- Largest and most influential conservation organizations globally
- Tackle critical environmental issue

HOW CAN WE ALLOCATE LIMITED CONSERVATION RESOURCES TO MAXIMIZE BIODIVERSITY OUTCOMES?

Legend

- = Migratory fish
- = Riparian & shoreline habitat associates
- = Aquatic habitat associates
- = Wetland habitat associates
- = Grassland/open habitat, or agricultural
- = Mature forest & peatland habitat associates
- = Forest openings & young forest habitat associates
- = Bats
- = Forest trees

INDIVIDUAL STRATEGIES	Cost per Year[1]									
Business as usual	$0	-	-	-	-	-	-	-	-	-
S1 Public land management	$61,405	-	-	-	✓	-	✓	-	-	-
S2 Forestry land management	$117,807	-	✓	-	✓	-	✓	✓	-	-
S3 Private/agricultural land management	$1,039,952	-	-	-	✓	-	-	-	-	-
S4 Wetland/aquatic habitat management	$1,206,655	-	-	-	✓	-	-	-	-	-
S5 Dam discharge flow management	$5,462,784	-	-	-	-	-	-	-	-	-
S6 Removal of Mactaquac Dam	$19,923,782	-	-	-	-	-	-	-	-	-
S7 Illegal and incidental take policy	$618,660	-	-	-	-	-	-	-	-	-
S8 Wetland policy and regulation	$307,654	-	-	-	✓	-	-	-	-	-
S9 Water quality management	$505,423	-	-	-	✓	-	-	-	-	-
S10 Breeding/reintroduction of aquatics	$130,462	-	-	-	-	-	-	-	-	-
S11 Disease management for bats	$40,907	-	-	-	-	-	-	-	-	-
S12 Forest pest management	$17,900	-	-	-	-	-	-	-	-	-
S13 Invasive species management	$962,704	-	-	-	-	-	-	-	-	-
S14 Predator management	$184,619	-	-	-	-	-	-	-	-	-
S15 Pollution reduction and management	$263,806	-	-	-	-	-	-	-	-	-
S16 Climate change policies and actions	$437,882	-	-	-	-	-	-	-	-	-

COMBINATION STRATEGIES	Cost per Year									
S17 Land management (S1, S2, S3)	$1,219,164	-	✓	-	✓	✓	✓	✓	-	-
S18 Riparian, wetland and aquatic management and policy (S4, S5, S8, S9)	$7,482,514	-	✓	✓	✓	-	-	-	-	-
S19 Policy development/implementation (S7, S8, S15, S16)	$1,628,002	-	-	-	✓	-	-	-	-	-
S20 Dam management and breeding/reintroduction of aquatics (S5, S10)	$5,593,246	-	-	-	✓	-	-	-	-	-
S21 Land and predator management (S1, S3, S14)	$1,285,977	-	✓	-	✓	-	✓	-	-	-
S22[2] All strategies (except removal of Mactaquac Dam: S6)	$11,358,618	-	✓	✓	✓	✓	✓	✓	-	-
S23[2] All strategies (except dam flow management for Mactaquac Dam: S5)	$25,819,617	✓	✓	✓	✓	✓	✓	✓	-	-

PROJECT GOALS

Maximize Biodiversity

Prioritize actions with the highest impact.

Incoporate Constraints

Address practical limitations (budget, time, labor).

Providing Recommendations

Actionable insights for policymakers and practitioners

DATA SOURCES

GBIF

Global Biodiversty Information Facility

- Taxon Focus: Species data for [Taxon Key 131] in Canada (2014-2024)

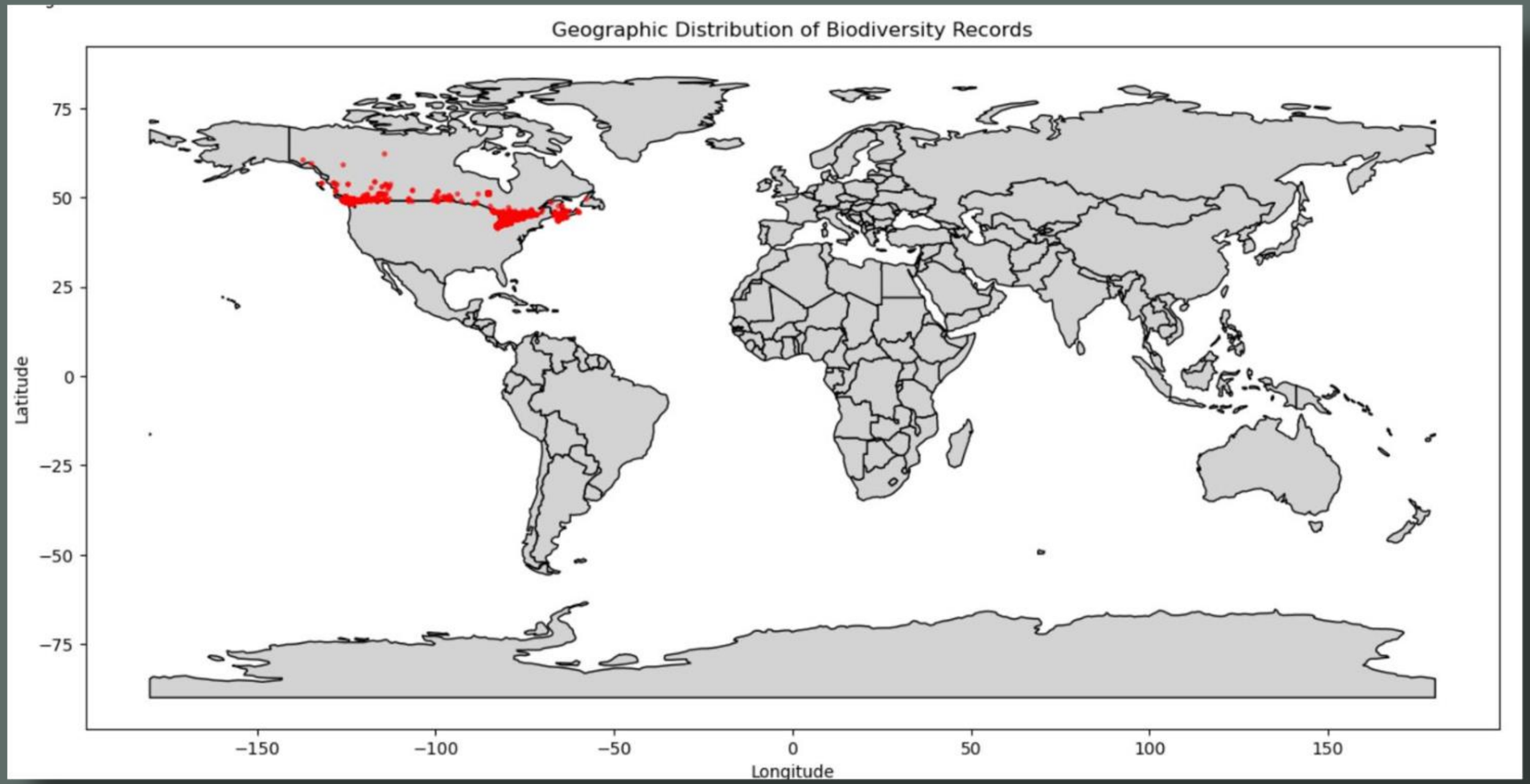
Key Metrics

- **Occurrences**: Number of species recorded each year
- **Species Richness**: Unique species identified each year
- **Biodiversity Score:** Calculated based on species occurrences and richness.

Conservation Costs:

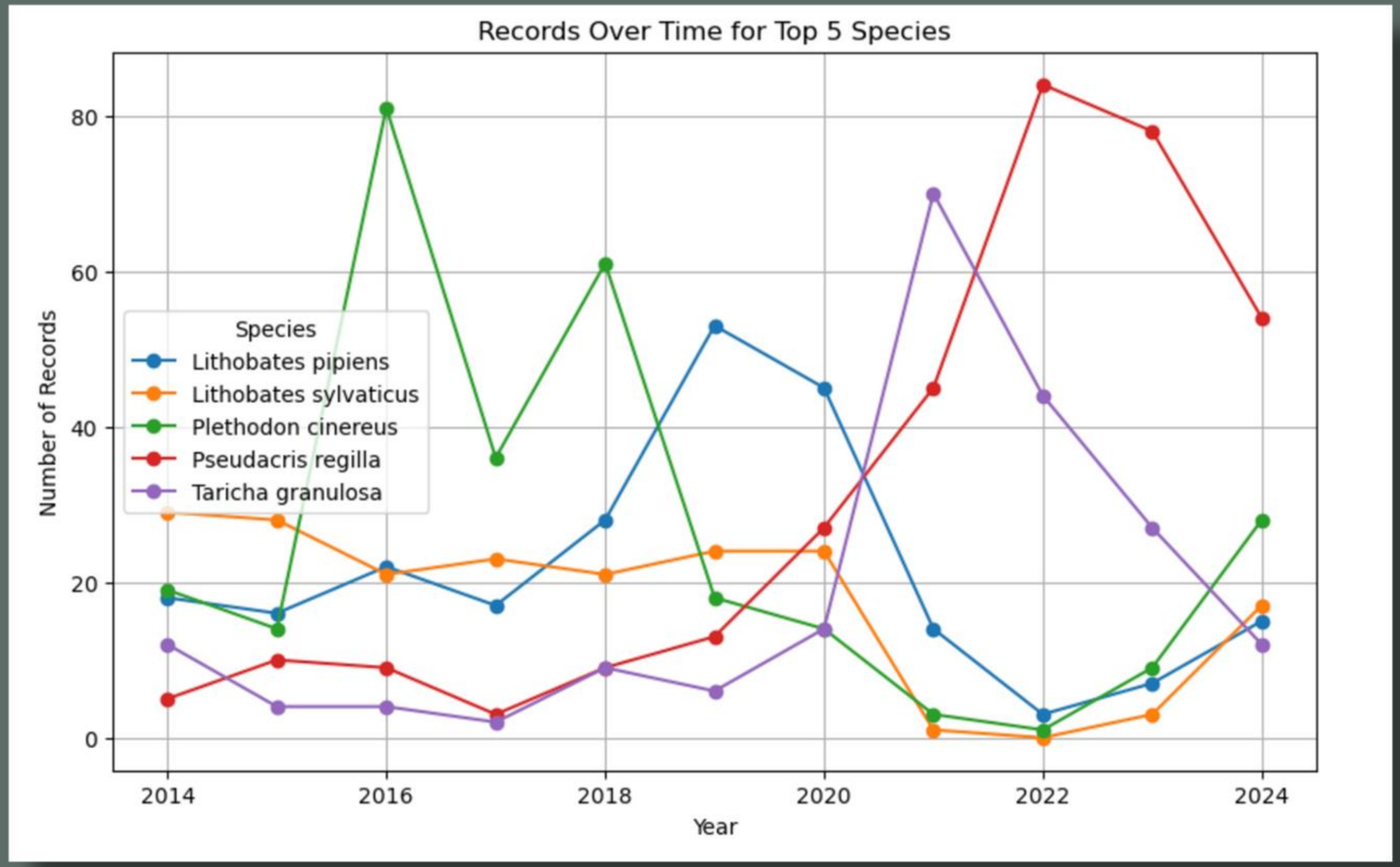
23 conservation strategies, each with a specific project area and cost range

DATA SOURCES

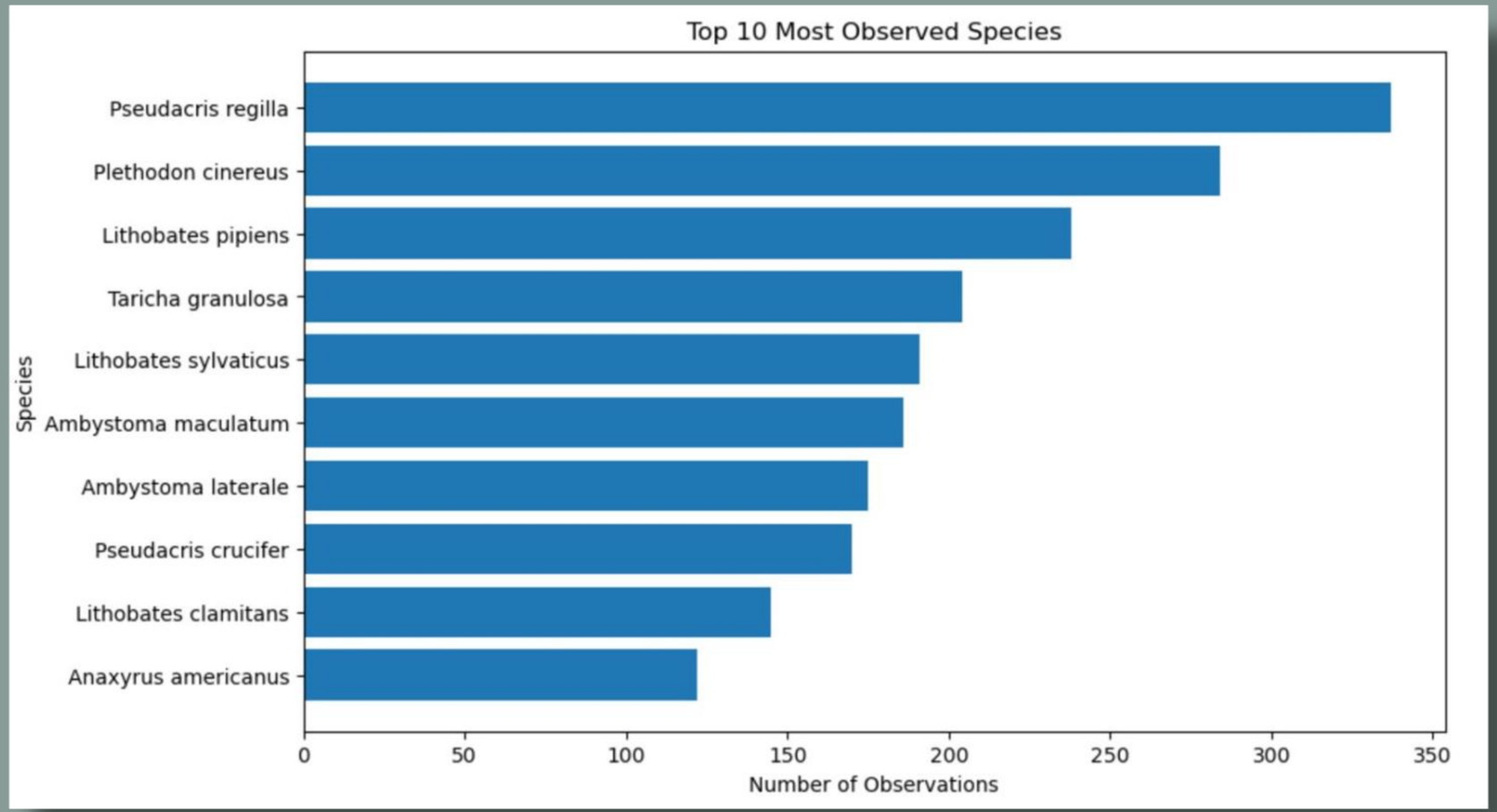


GBIF API

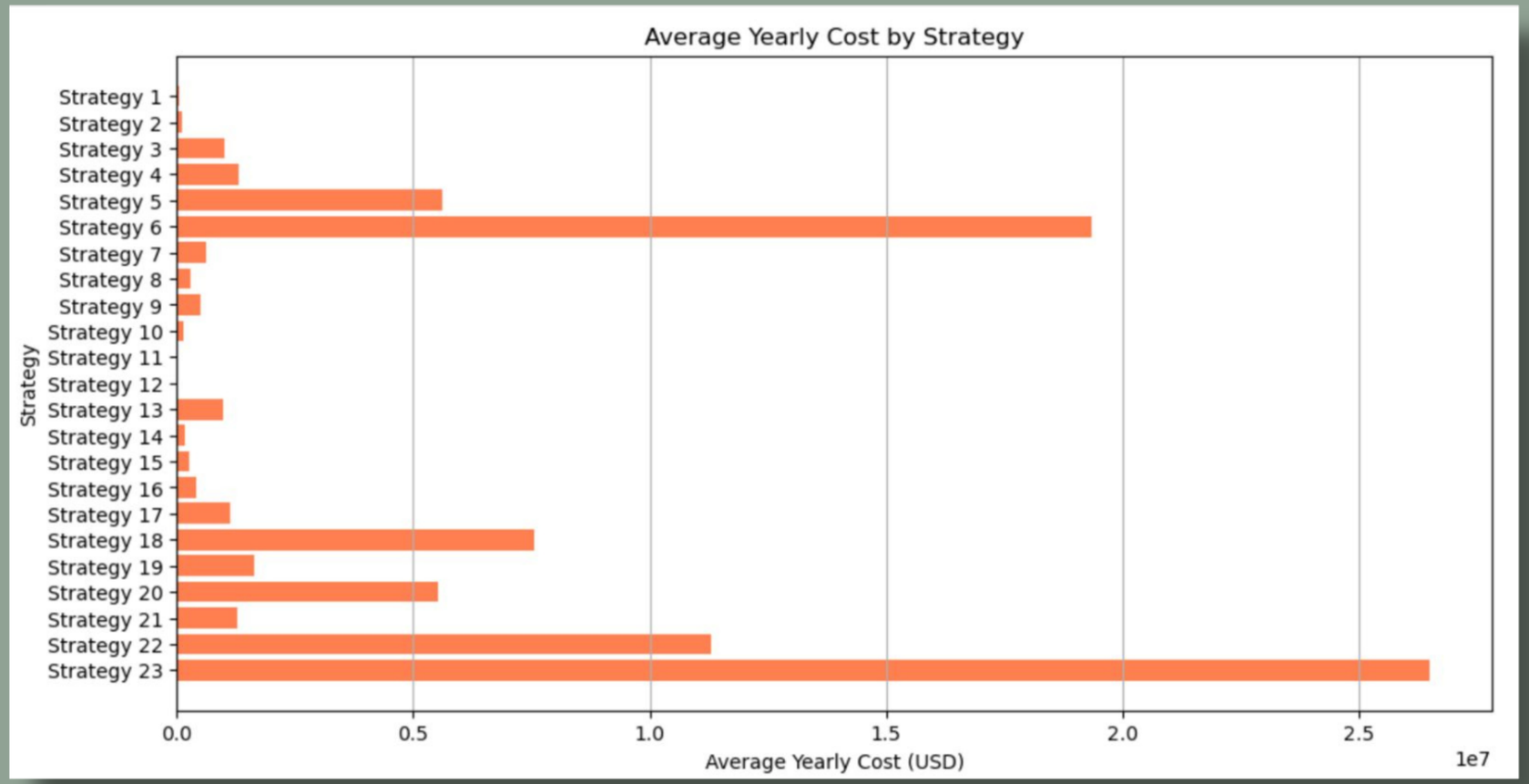
TOP 5 SPECIES -> RECORDS OVER TIME



TOP 10 MOST OBSERVED SPECIES



AVERAGE YEARLY COST BY STRATEGY



IMPLEMENTATION

DECISION VARIABLES

1. $x_{i,t} \in \{0, 1\}$

To identify which conservation strategies to implement in each year while adhering to budget constraints and synergy/mutual exclusion rules.

PARAMETERS

1. $\text{cost}_{i,t}^{s}$

- Costs for each strategy (i) in each year (t) vary by scenario (s).
- Simulated with ±20% variation around actual costs using a uniform distribution.

PARAMETERS

2. $\text{impact}_{i,t}^{s}$

- Biodiversity impacts for each strategy (i) in each year (t) vary by scenario (s).
- Simulated with ±10% variation around the expected impact.

PARAMETERS

3. p_s

- Probabilities for three stochastic scenarios

PARAMETERS

4. budget_t

- Yearly budgets defining the maximum allowable cost for selected strategies in each year.

OBJECTIVE FUNTION

MAXIMIZE EXPECTED BIODIVERSITY IMPACT:
DETERMINISTIC

$$\text{Maximize:} \quad \sum_{t=1}^{T} \sum_{i=1}^{N} \text{Impact}_{i,t} \cdot x_{i,t}$$

Index i : strategies, where $i \in \{1, 2, \ldots, 23\}$.
Index t : years, where $t \in \{1, 2, \ldots, 10\}$.

This objective ensures that the chosen strategies maximize biodiversity impact over the planning horizon (number of years), subject to budget and other constraints.

OBJECTIVE FUNTION

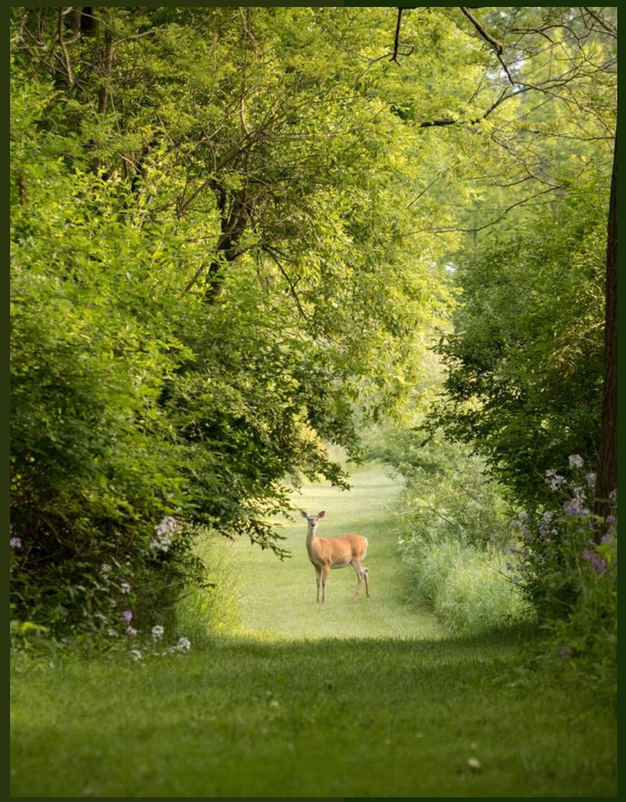
MAXIMIZE EXPECTED BIODIVERSITY IMPACT:
STOCHASTIC

$$\text{Maximize:} \quad \sum_{s=1}^{S} p_s \cdot \sum_{t=1}^{T} \sum_{i=1}^{N} \text{Impact}_{i,t,s} \cdot x_{i,t}$$

Index i : strategies, where $i \in \{1, 2, \ldots, 23\}$.
Index t : years, where $t \in \{1, 2, \ldots, 10\}$.
Index s : scenarios, where $s \in \{1, 2, 3\}$.

The function aggregates expected biodiversity impacts across all strategies, years, and scenarios, weighted by the probability of each scenario.

Constraints



1

BUDGET

The total cost of selected strategies must not exceed the available budget.

2

DEPENDANT STRATEGIES

These ensure that the implementation of certain strategies depends on the selection of others.

3

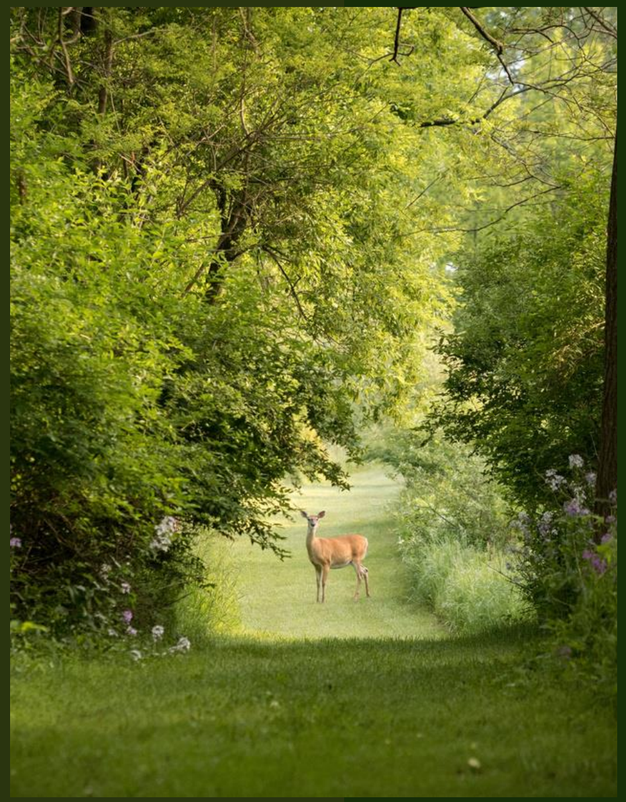
MUTUALLY EXCLUSIVE STRATEGIES

Some strategies cannot be selected together due to their conflicting goals or the need for different resources

4

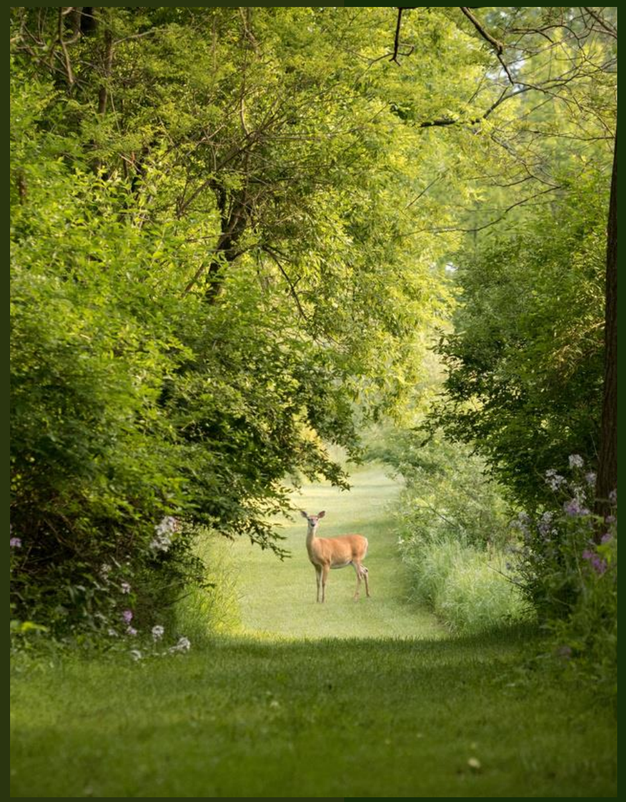
SYNERGIC STRATEGIES

These enforce rules about combined effects of strategies. Certain strategies, when selected together, activate or complement other strategies.



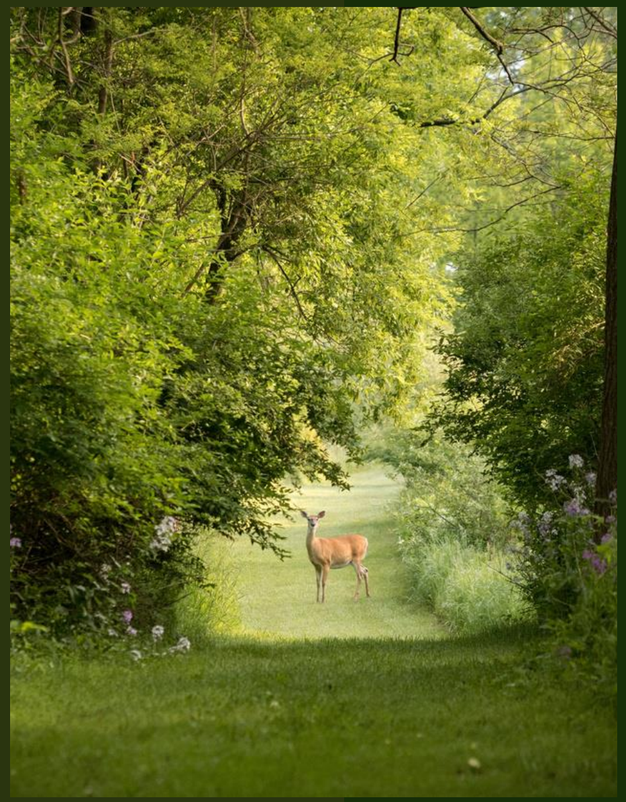
DEPENDANT STRATEGY EXAMPLE

If Public Land Management (S1), Forestry Land Management (S2), and Private/Agricultural Land Management (S3) are implemented, the Land Management Combination Strategy (S17) is activated.



MUTUALLY EXCLUSIVE STRATEGY EXAMPLE

Dam Flow Management (S5) and Removal of the Mactaquac Dam (S6) cannot be implemented in the same year because the actions contradict one another.



SYNERGIC STRATEGY EXAMPLE

If Land and Predator Management (S21) is chosen, it requires the selection of Public Land Management (S1), Private/Agricultural Land Management (S3), and Predator Management (S14).

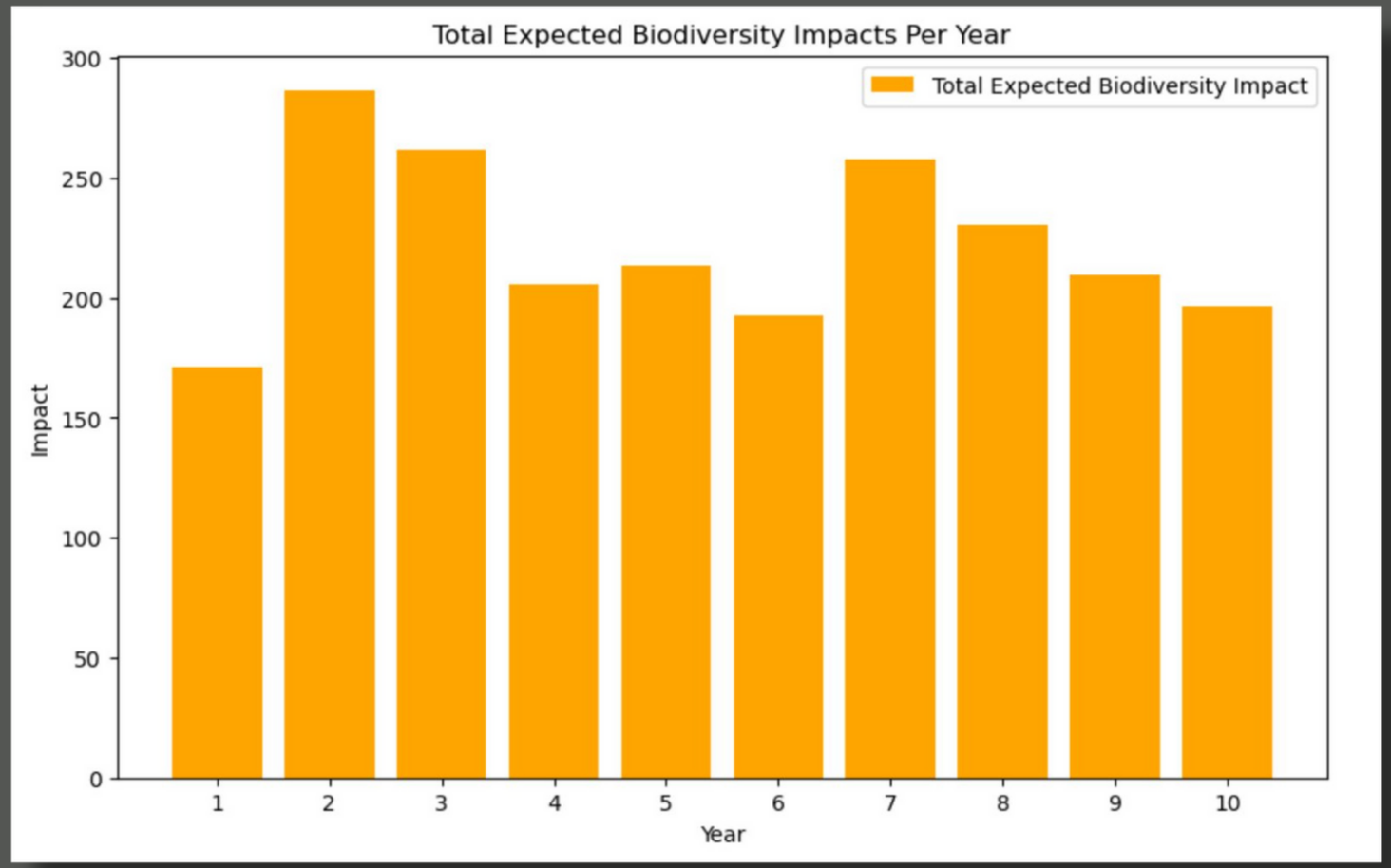

RESULTS &
INSIGHTS

STOCHASTIC OUTPUT

```
Optimal Strategies:

Year 1:
  - Strategy 12: Expected Cost = 18662.88, Expected Impact = 161.71
  Total Expected Cost: 18662.88
  Total Expected Biodiversity Impact: 161.71

Year 2:
  - Strategy 12: Expected Cost = 15268.59, Expected Impact = 151.68
  Total Expected Cost: 15268.59
  Total Expected Biodiversity Impact: 151.68

Year 3:
  - Strategy 11: Expected Cost = 32166.46, Expected Impact = 131.23
  - Strategy 12: Expected Cost = 15201.41, Expected Impact = 136.01
  Total Expected Cost: 47367.87
  Total Expected Biodiversity Impact: 267.25

Year 4:
  - Strategy 1: Expected Cost = 35580.47, Expected Impact = 102.59
  - Strategy 11: Expected Cost = 28655.58, Expected Impact = 105.12
  Total Expected Cost: 64236.05
  Total Expected Biodiversity Impact: 207.71

Year 5:
  - Strategy 11: Expected Cost = 25799.40, Expected Impact = 106.26
  - Strategy 12: Expected Cost = 12440.98, Expected Impact = 111.04
  Total Expected Cost: 38240.38
  Total Expected Biodiversity Impact: 217.30
```

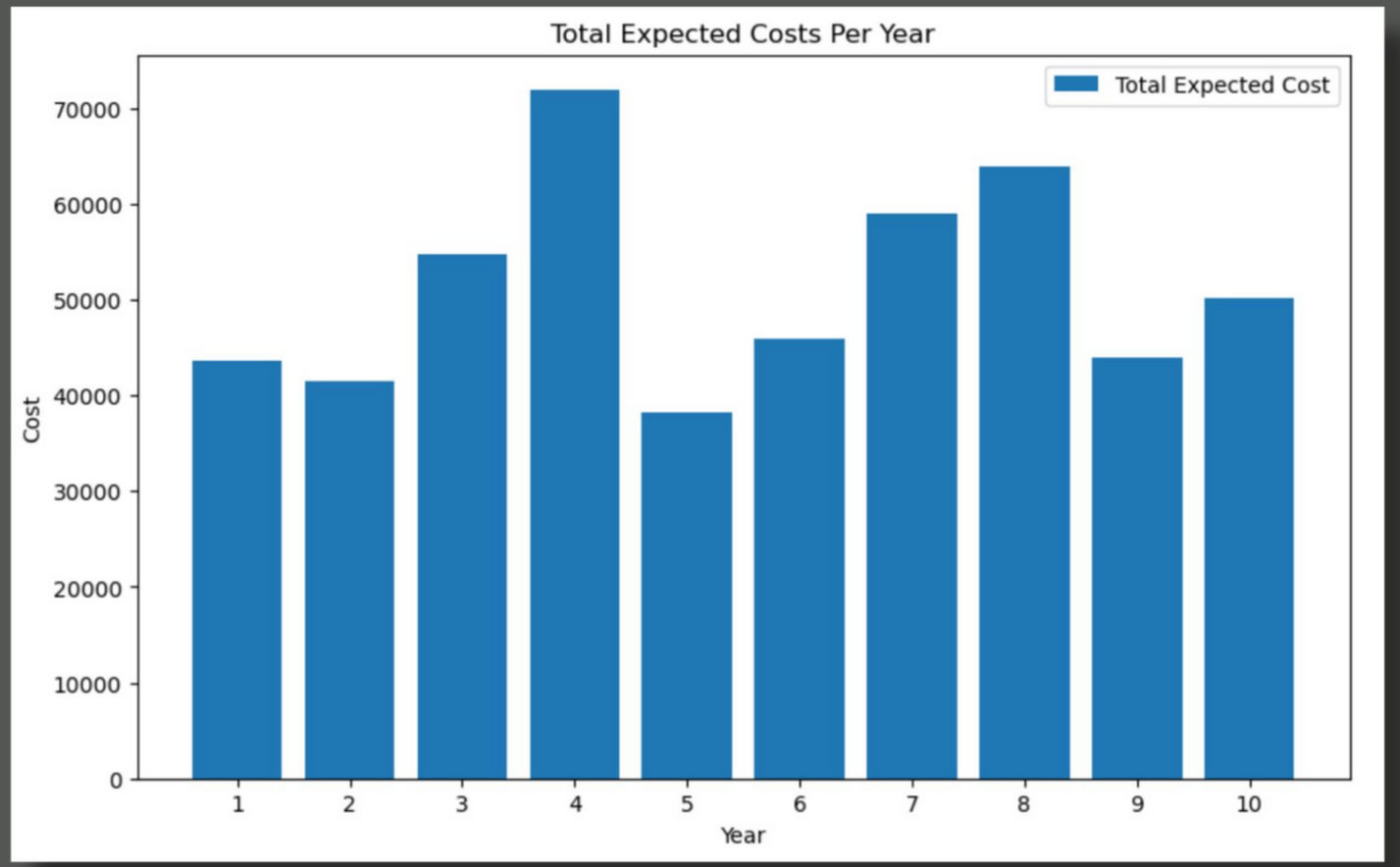
```
Year 5:
  - Strategy 11: Expected Cost = 25799.40, Expected Impact = 106.26
  - Strategy 12: Expected Cost = 12440.98, Expected Impact = 111.04
  Total Expected Cost: 38240.38
  Total Expected Biodiversity Impact: 217.30

Year 6:
  - Strategy 11: Expected Cost = 26905.34, Expected Impact = 104.08
  - Strategy 12: Expected Cost = 9586.94, Expected Impact = 95.38
  Total Expected Cost: 36492.29
  Total Expected Biodiversity Impact: 199.46

Year 7:
  - Strategy 1: Expected Cost = 35351.18, Expected Impact = 86.13
  - Strategy 11: Expected Cost = 27373.18, Expected Impact = 87.77
  Total Expected Cost: 62724.36
  Total Expected Biodiversity Impact: 173.90

Year 8:
  - Strategy 1: Expected Cost = 25961.70, Expected Impact = 76.14
  - Strategy 11: Expected Cost = 21673.85, Expected Impact = 80.40
  - Strategy 12: Expected Cost = 10217.45, Expected Impact = 83.65
  Total Expected Cost: 57853.00
  Total Expected Biodiversity Impact: 240.19

Year 9:
  - Strategy 1: Expected Cost = 23201.73, Expected Impact = 72.84
  - Strategy 11: Expected Cost = 14540.55, Expected Impact = 71.24
  - Strategy 12: Expected Cost = 8035.09, Expected Impact = 65.85
  Total Expected Cost: 45777.37
  Total Expected Biodiversity Impact: 209.93

Year 10:
  - Strategy 1: Expected Cost = 26646.74, Expected Impact = 66.71
  - Strategy 11: Expected Cost = 16991.57, Expected Impact = 64.29
  - Strategy 12: Expected Cost = 7038.79, Expected Impact = 65.68
  Total Expected Cost: 50677.10
  Total Expected Biodiversity Impact: 196.68
```

STOCHASTIC OUTPUT



Bar plot for total expected impacts per year

STOCHASTIC OUTPUT



Visualization of Total Expected Costs & Impacts Per Year


IMPORTANT
CONSIDERATIONS

MODEL SIMULATIONS

DISCOUNTED TIME FACTOR FOR COSTS

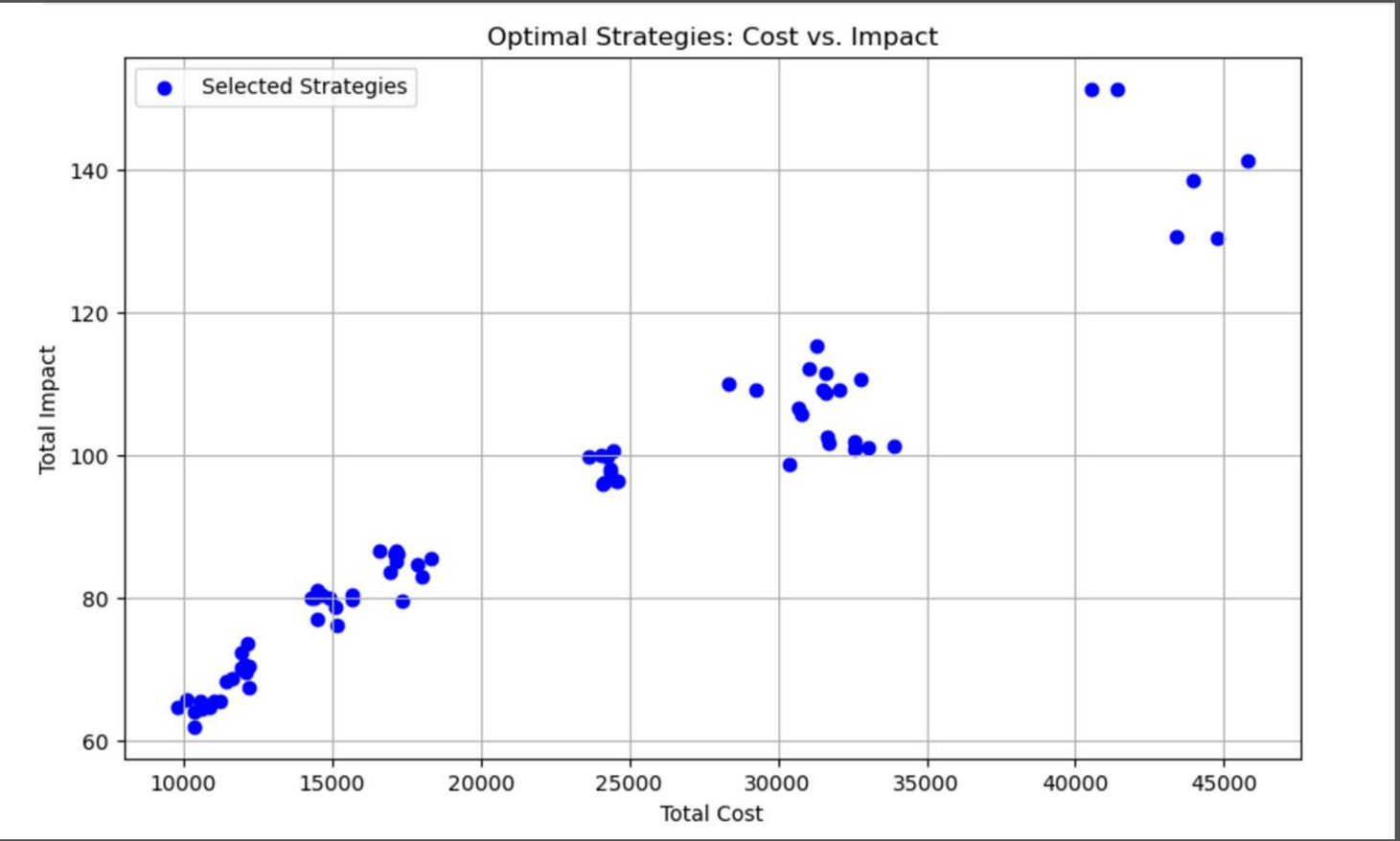
The time discount factor accounts for the present value of future costs and impacts. Since costs and impacts occurring in the future are typically considered less valuable than those in the present (due to inflation, risk, and opportunity cost), the model applies a discount factor to adjust future values accordingly. For each year, a discount factor (less than 1) is applied to costs and biodiversity impacts, reflecting the decreasing value over time.

MODEL SIMULATIONS

THE PARETO FRONT

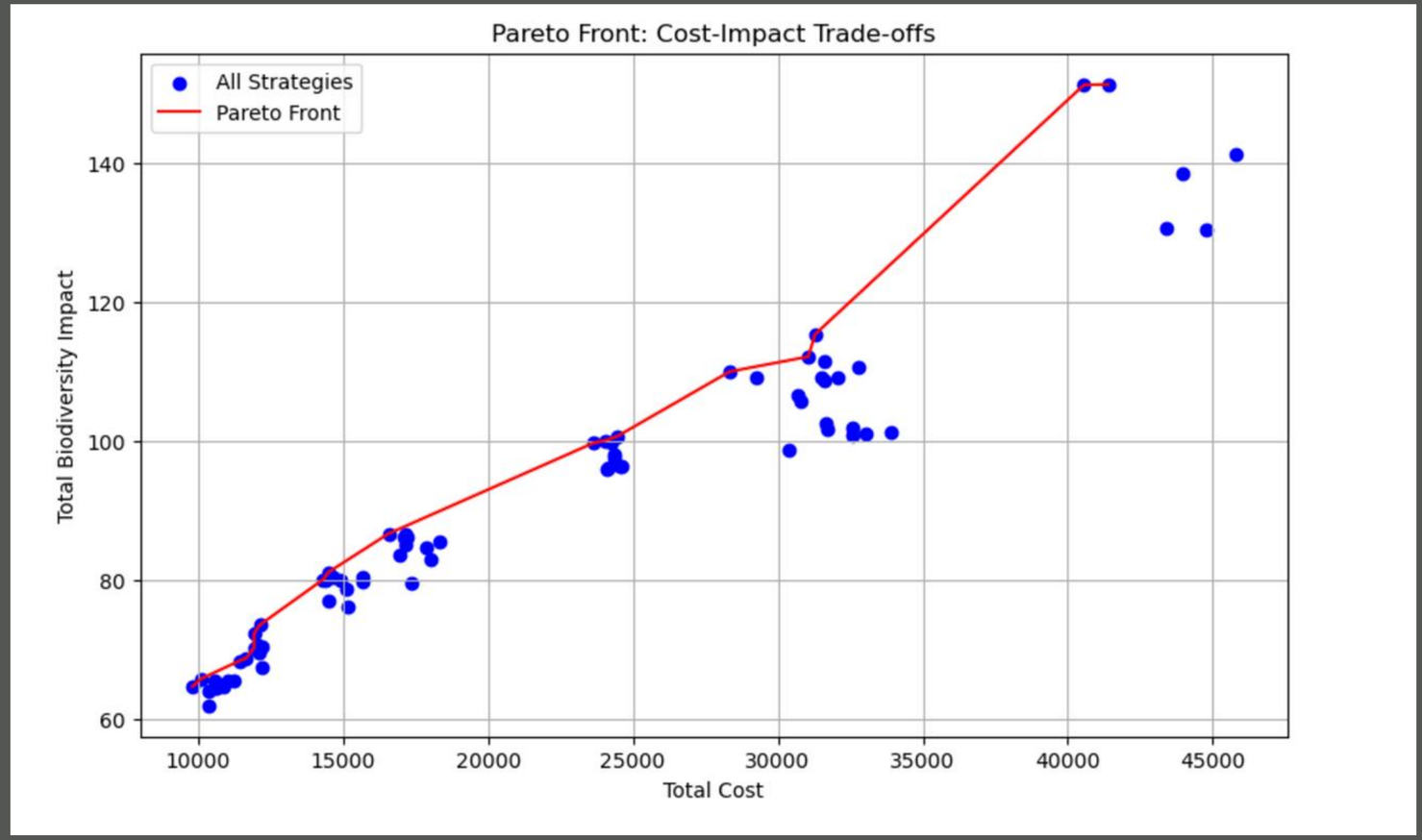
The model simulates a Pareto front by optimizing the trade-off between two competing objectives: biodiversity impact and cost. Each strategy has associated costs and impacts, and the optimization seeks to find the best combinations of these two metrics. The Pareto front represents the set of efficient strategies where improving one objective (e.g., biodiversity impact) would worsen the other (e.g., cost). This allows stakeholders to understand the optimal solutions for various cost-impacts combinations and choose the most appropriate strategies based on their priorities.

PARETO FRONT



Visualization of optimal strategies and their trade-offs.

PARETO FRONT



Plotting the Pareto Front

NEXT STEPS

Future extensions

1

ENGAGE STAKEHOLDERS

- Involving local communities, governments, and NGO's
- Engaging with Indigenous communities
- "By learning from Indigenous experts, we open a door to an approach to conservation that respects interconnections between people and place" - WWF Living Planet Report 2022

2

INCORPORATE ENVIRONMENTAL SHOCKS

- Natural disasters
- Climate projections
- Long - term monitoring
- Iterative refinement of strategies

3

POLICY ALIGNMENT

- Work with policymakers
- Engage with with international conservation frameworks
- United Nations Sustainable Development Goals

4

EXPAND SCOPE

- Go beyond the sites seen in our model
- Satellite imagery and geospatial data to identify new high-priority areas
- Extend model to cover multiple regions

CONCLUSION

1 ECONOMIC STABILITY

2 ENVIRONMENTAL RESILIENCE

3 GLOBAL LEADERSHIP

4 COLLABORATION

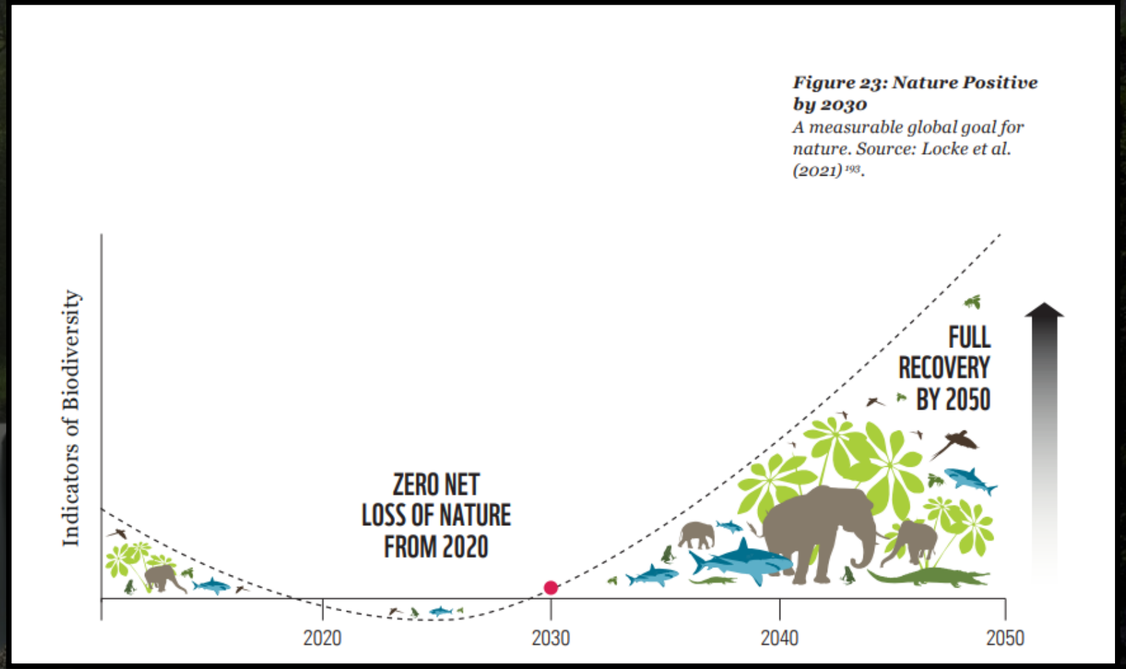


Figure 23: Nature Positive by 2030
A measurable global goal for nature. Source: Locke et al. (2021)[193].


QUESTIONS?

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