

Making better conservation decisions



Jeffrey Hanson



jeffrey.hanson@uqconnect.edu.au



jeffrey-hanson.com

Acknowledgements

Allison Binley

Brandon Edwards

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Hugh Possingham

James Allan

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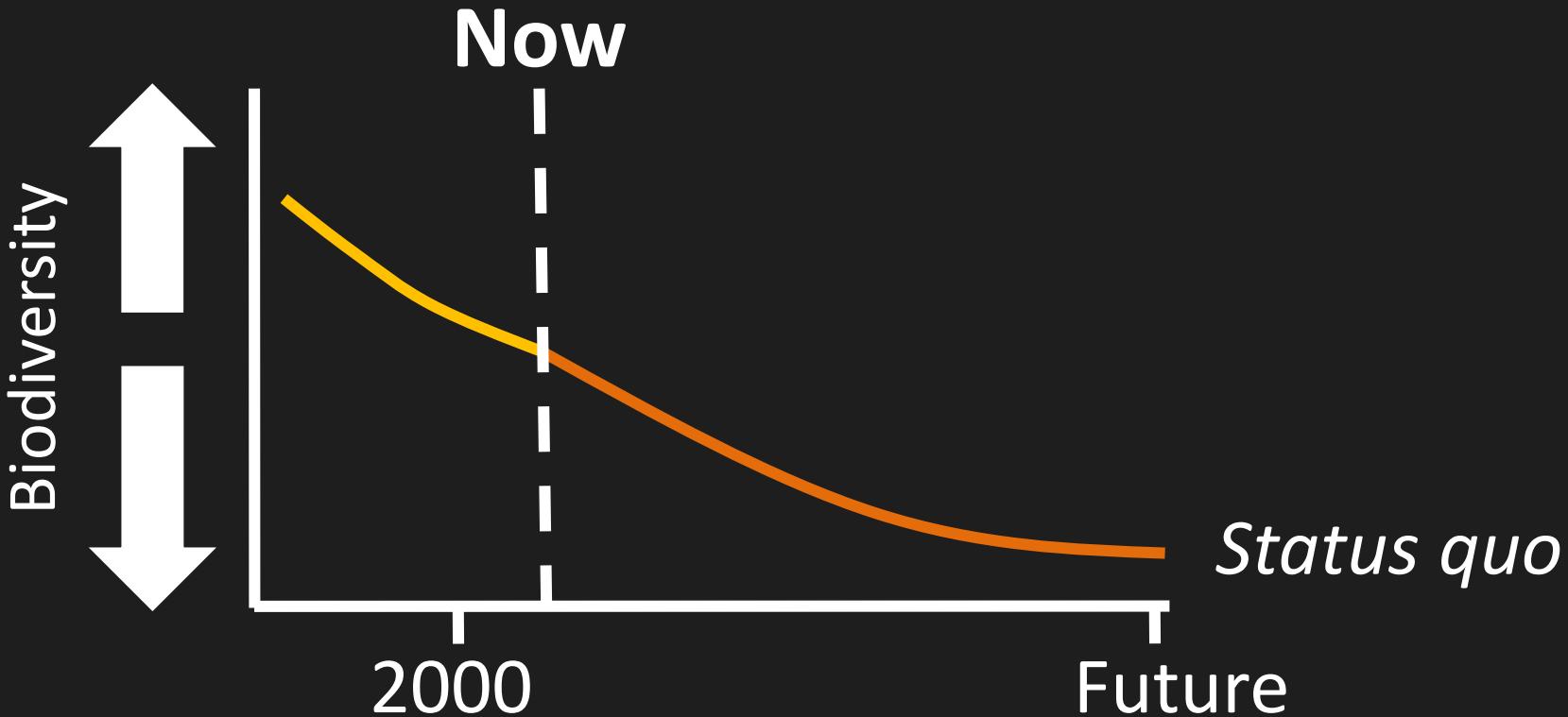
Nina Morell

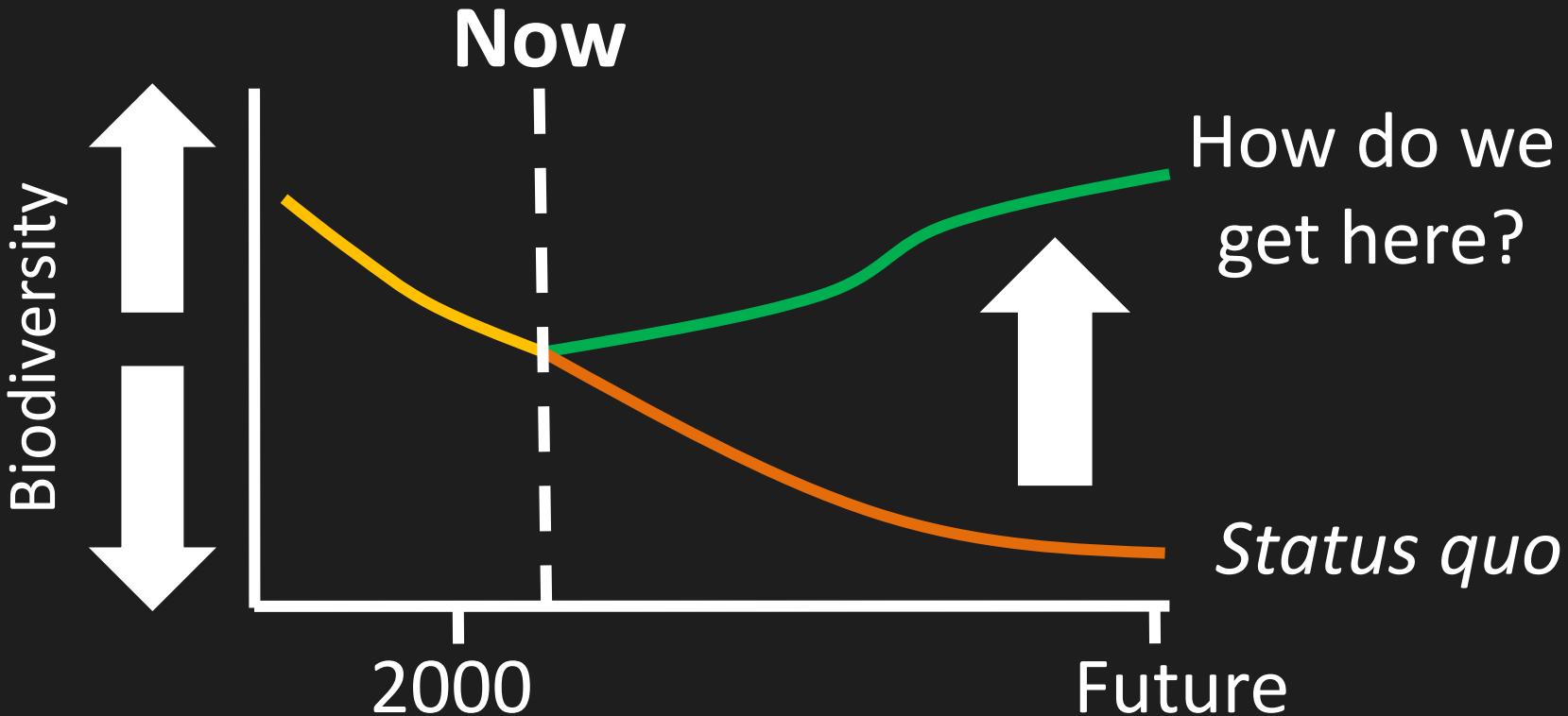
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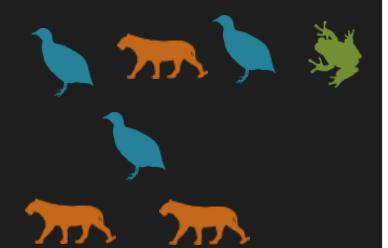


How can we get a better conservation decision?

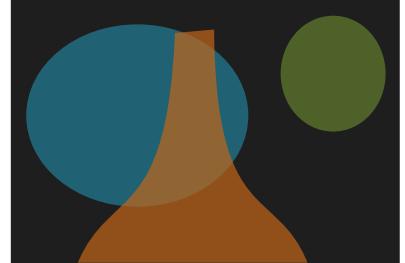
(1) Better algorithms

(2) Better data

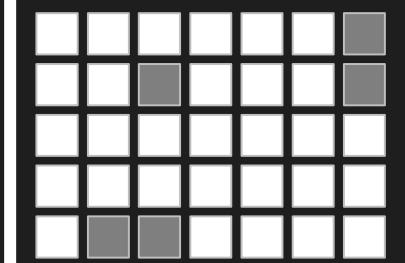
Ecological surveys



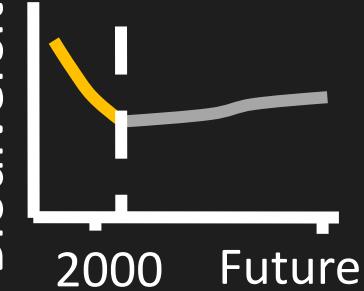
Distribution maps



Priority areas



Biodiversity



Data → Information → Plan → Outcome

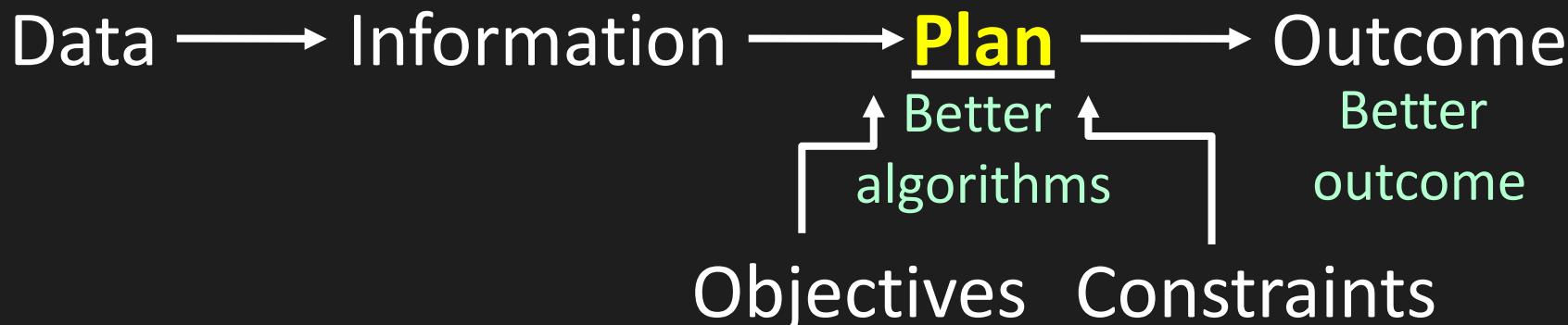
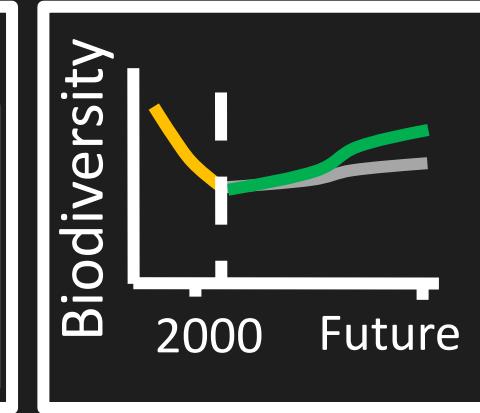
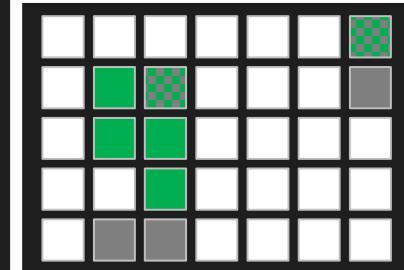
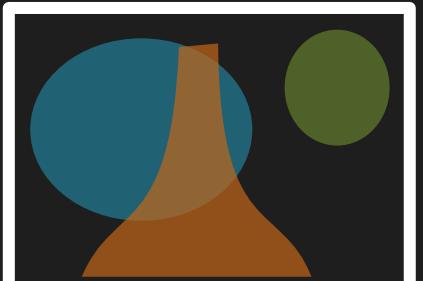


Ecological surveys

Distribution maps

Priority areas

Biodiversity



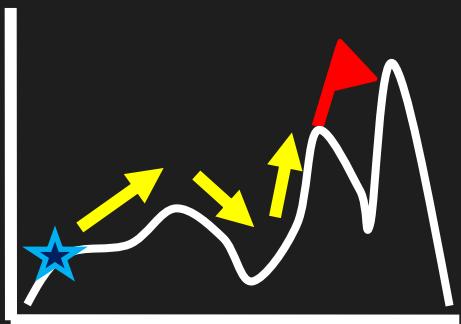
Heuristic algorithm

Meta-heuristic algorithms

Exact algorithms



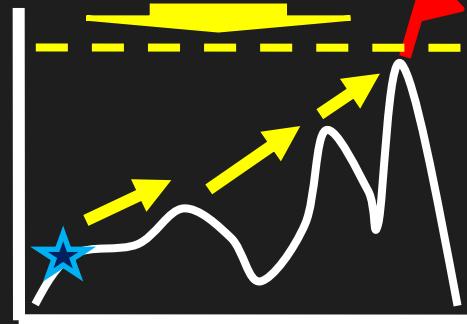
Different
solutions



Different
solutions



Estimate of best quality



Different
solutions



prioritizr: Systematic conservation prioritization in R

- it's an R package (yes, this is good)
- flexible interface to customize problems
- compatible with tabular and GIS data formats
- supports planning for multiple zones/actions
- powered by exact algorithm solvers



Worked example

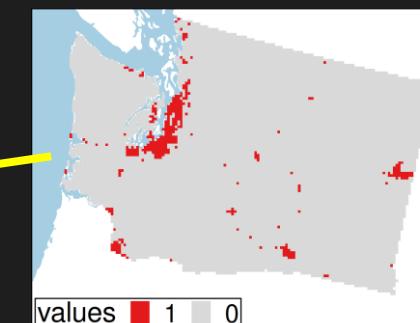
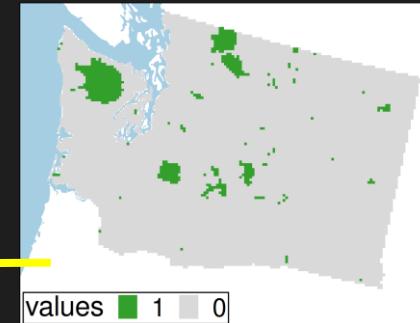
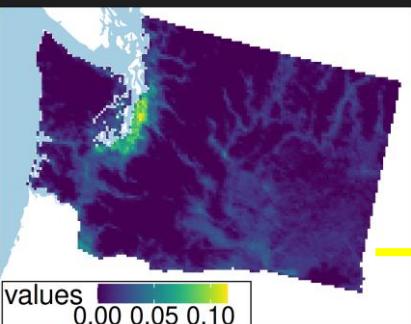
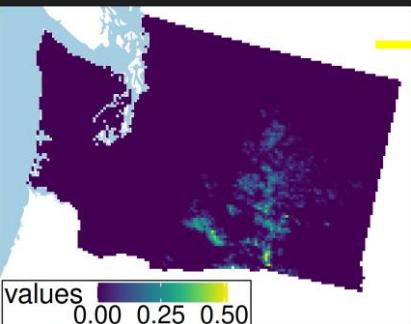
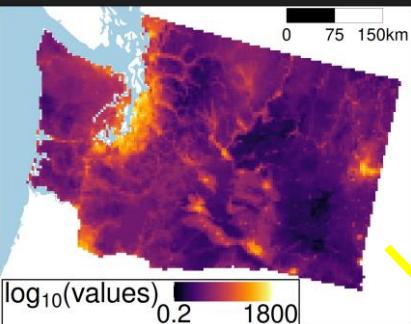
```
# load packages
library(prioritizr) # package for conservation planning
library(terra)        # package for raster data

# input data
## raster with continuous values indicating costs
planning_unit_data <- rast("pu.tif")

## multi-layer raster with relative abundance data
### feature_data[[1]] is the first feature,
### feature_data[[2]] is the second feature,
### and so on, with 396 features in total
feature_data <- rast("features.tif") ←

## raster with binary values indicating if each planning
## unit is covered by (1) protected areas or (0) not
protected_area_data <- rast("protected-areas.tif")

## raster with binary values indicating if each planning
## unit covered by (1) urban areas or (0) not
urban_area_data <- rast("urban-areas.tif") ←
```

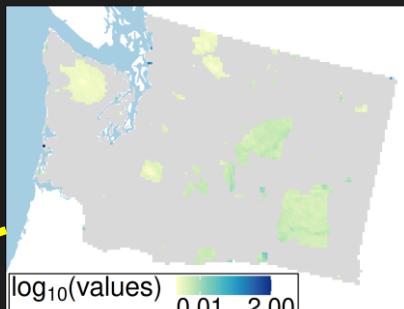
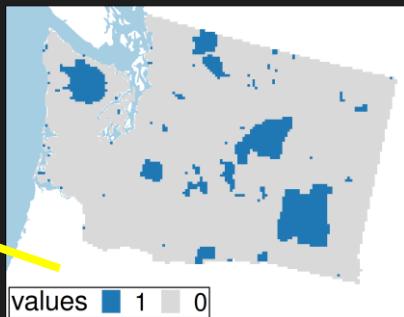


```
# build problem
## specify the data, formulation, and solver
conservation_planning_problem <-
  ### initialize with planning unit and feature data
problem(planning_unit_data, feature_data) %>%
  ### add minimum shortfall function with budget
add_min_shortfall_objective(3917.631) %>%
  ### add representation targets for 20% coverage of each feature
add_relative_targets(targets = 0.2) %>%
  ### add penalties to reduce spatial fragmentation
add_boundary_penalties(penalty = 0.00001) %>%
  ### add constraints to ensure existing protected areas are selected
add_locked_in_constraints(protected_area_data) %>%
  ### add constraints to ensure urban areas are not selected
add_locked_out_constraints(urban_area_data) %>%
  ### specify that decision variables are binary (0 or 1 values)
add_binary_decisions() %>%
  ### specify software to perform optimization,
  ### and set gap parameter for near-optimal solution
add_gurobi_solver(gap = 0.1)
```

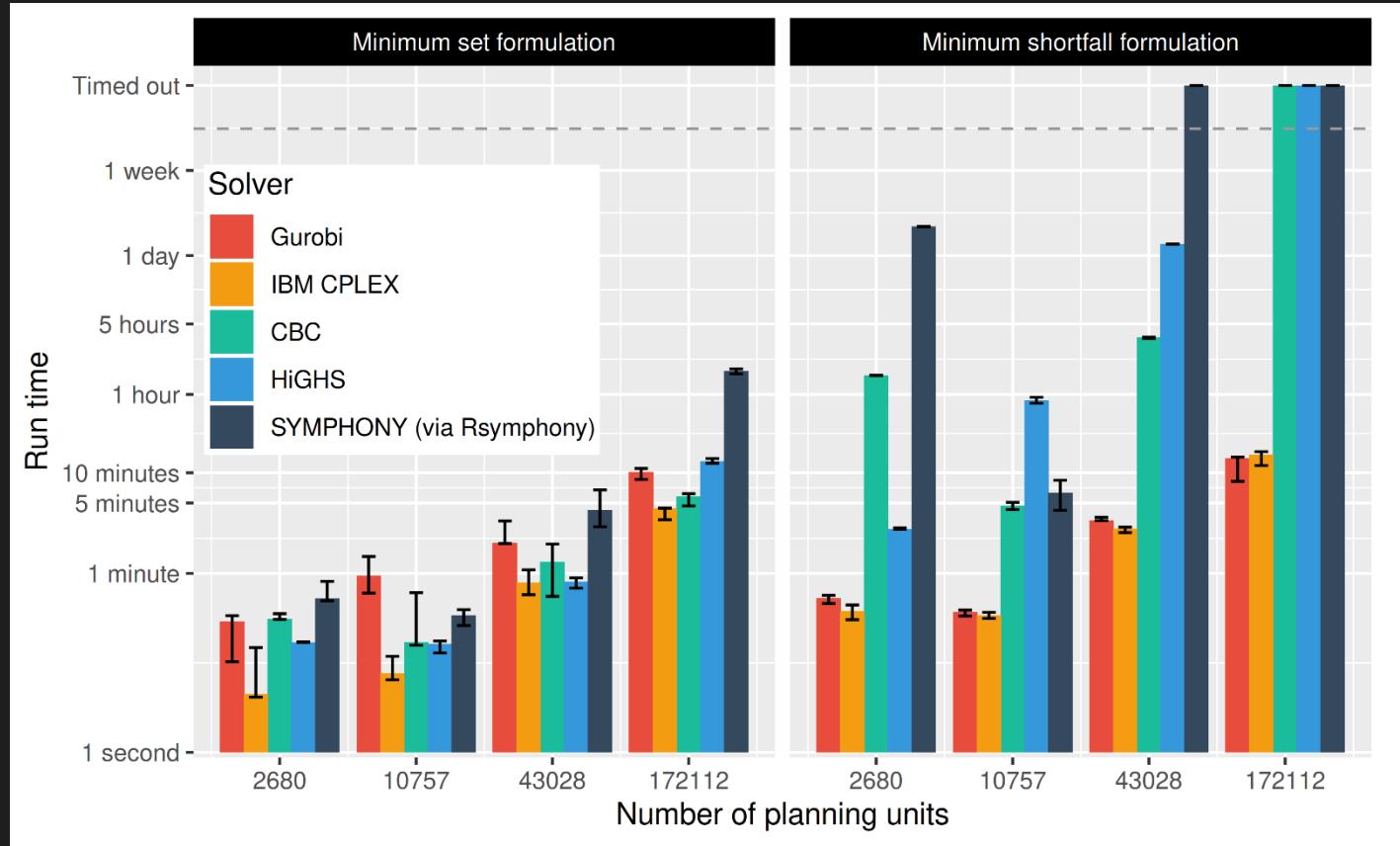
```
# solve problem
## output raster has binary values indicating if
## each planning unit is (1) selected or (0) not
prioritization <- solve(conservation_planning_problem)

# evaluate prioritization
## calculate overall cost of prioritization
eval_cost_summary(
  conservation_planning_problem, prioritization)
#> # A tibble: 1 × 2
#>   summary      cost
#>   <chr>      <dbl>
#> 1 overall 3911.832

## calculate relative importance of selected planning units
### output raster has continuous importance values
relative_importance <-
  eval_ferrier_importance(
    conservation_planning_problem, prioritization)
```



Solve problems pretty quickly!



Notes: 396 features, no planning units locked in or out, prioritizations $\leq 10\%$ from optimality

??? et al. under review

Where to work

<https://ncc.carleton.ca>

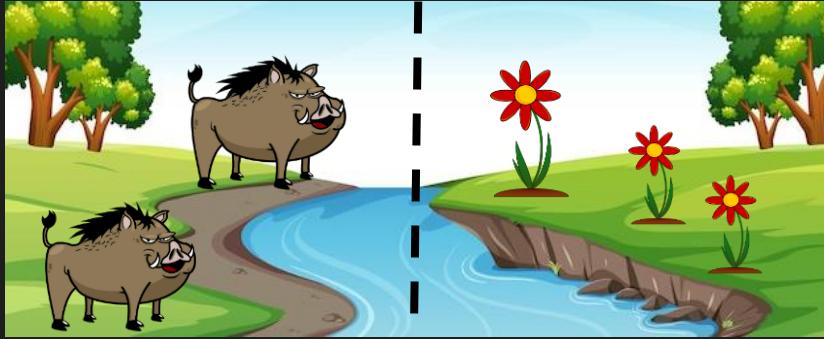
How can we get a better conservation decision?

(1) Better algorithms

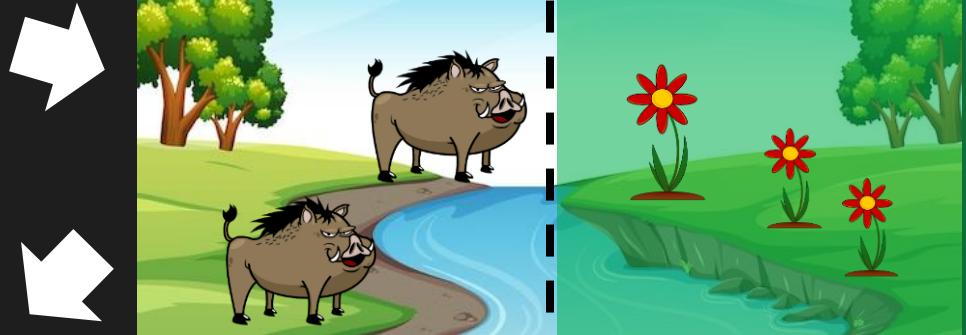
(2) Better data

Conventional conservation planning

1. Area with biodiversity and area impacted by threat



2. Establish protected area to safeguard biodiversity

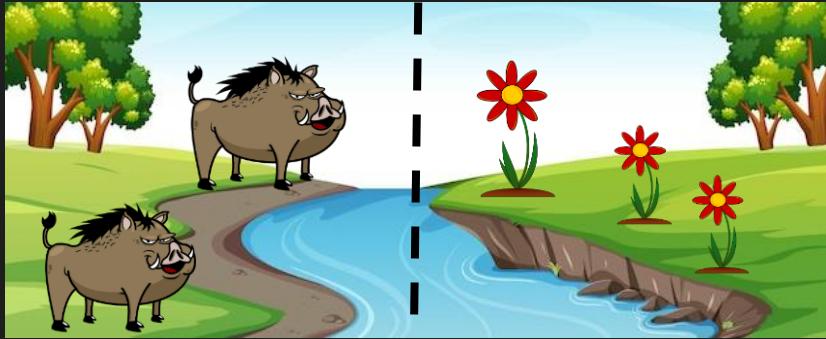


3. Positive conservation outcome?



Conservation is actions in places

1. Area with biodiversity and area impacted by threat



2. Establish protected areas and actions to manage threat



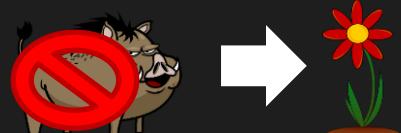
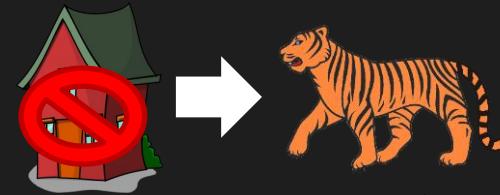
3. Positive conservation outcome



Which threats to abate?



Which threats to abate?



Which threats to abate?



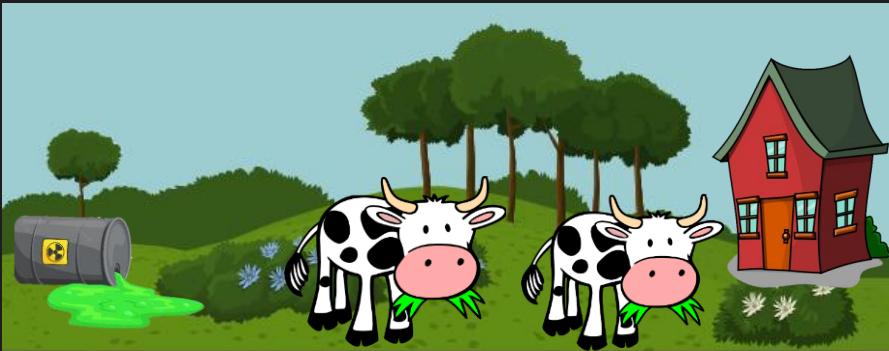
\$1M  → 

\$4M  → 

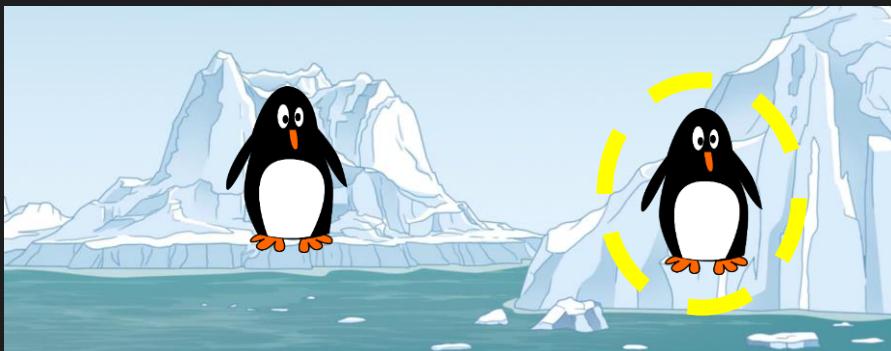
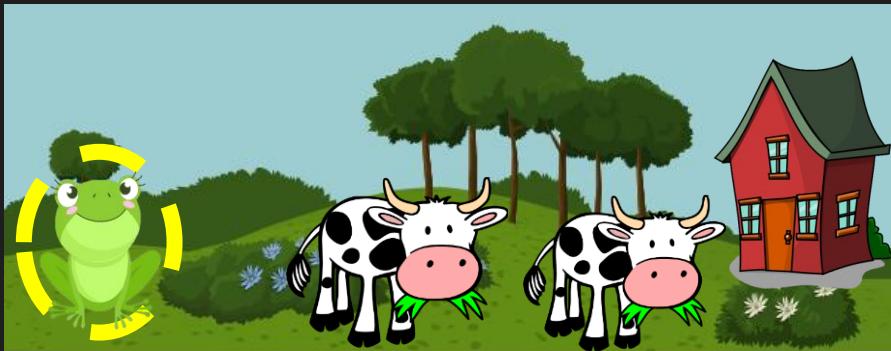
\$2M  → 

\$5M  +  → 

Which places to abate which threats?

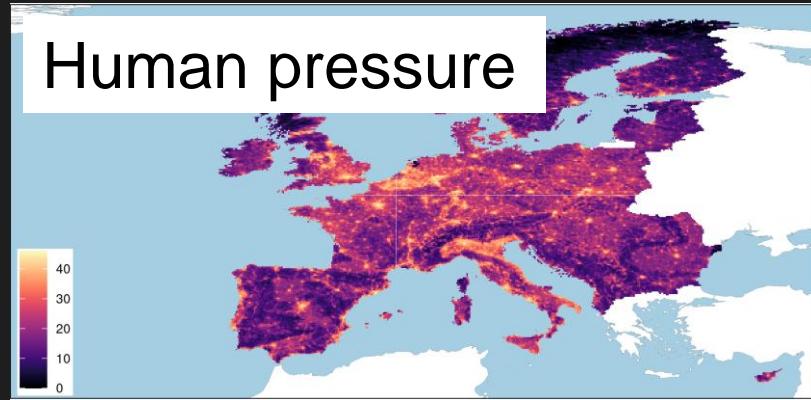


Provide each species with an adequate amount of threat-free habitat



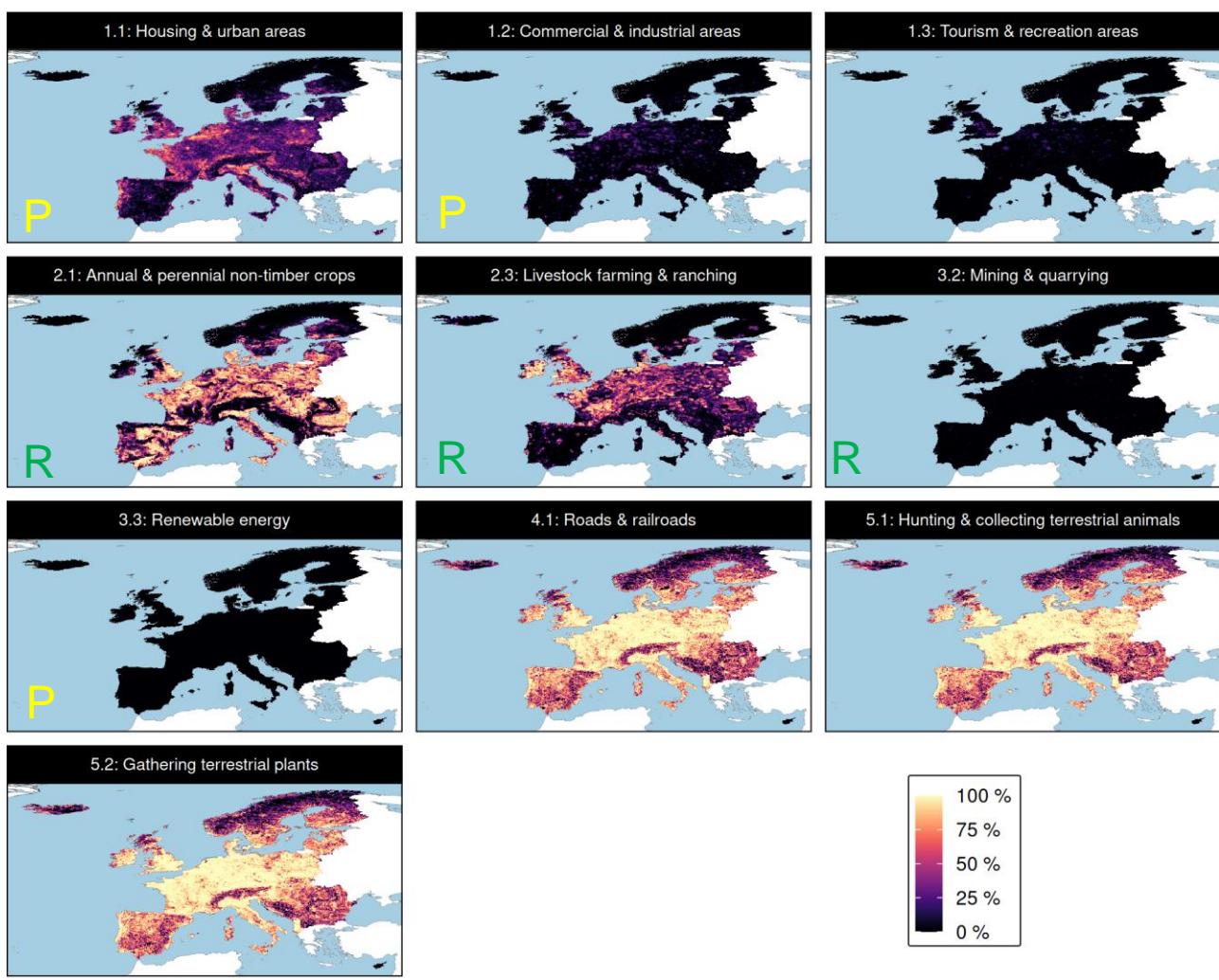
European case study

- Majority of terrestrial vertebrate species
 - 81 amphibian species
 - 386 bird species
 - 151 mammal species
 - 98 reptile species
- 43 countries
- $10 \times 10 \text{ km}$ resolution planning units
- Conservation benefit for a species = amount of threat-free habitat in conservation areas



Threats

- P = Permanent
- R = Restoration
- Management costs modelled using human footprint index as surrogate for opportunity costs



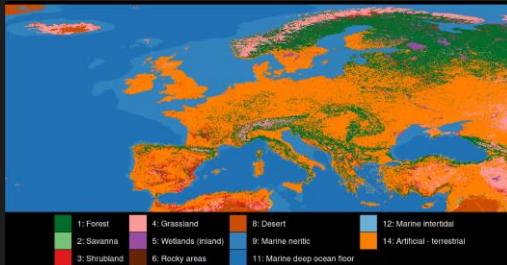
Mapping suitable habitat for species



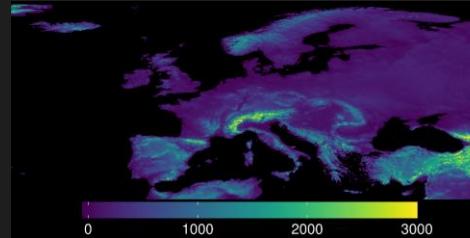
Species

- habitat types
- elevational limits
- threat impacts

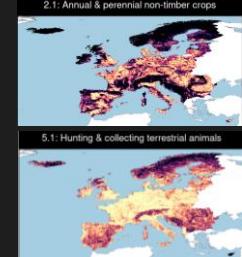
Current land cover



Elevation



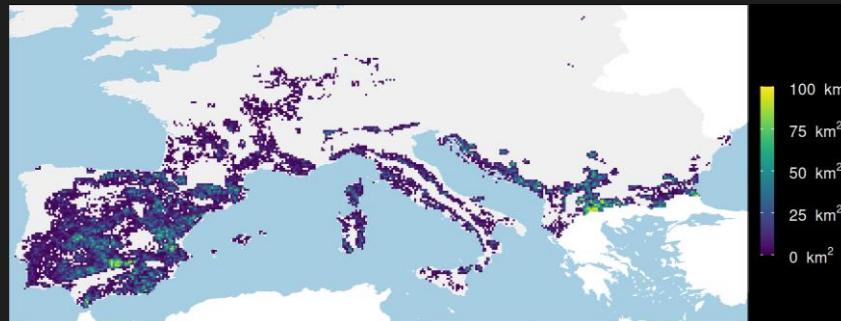
Threats



Woodchat Shrike



Area of threat-free habitat

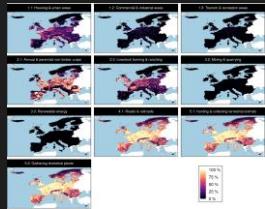
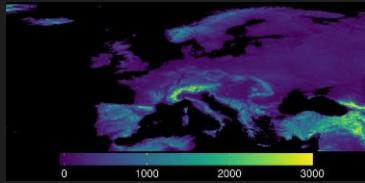


Mapping consequences of managing threats

Species



Elevation



Threats

Current land cover



Potential natural vegetation



Woodchat Shrike



What if?

Existing habitat



Restore croplands



Restore croplands
& stop hunting

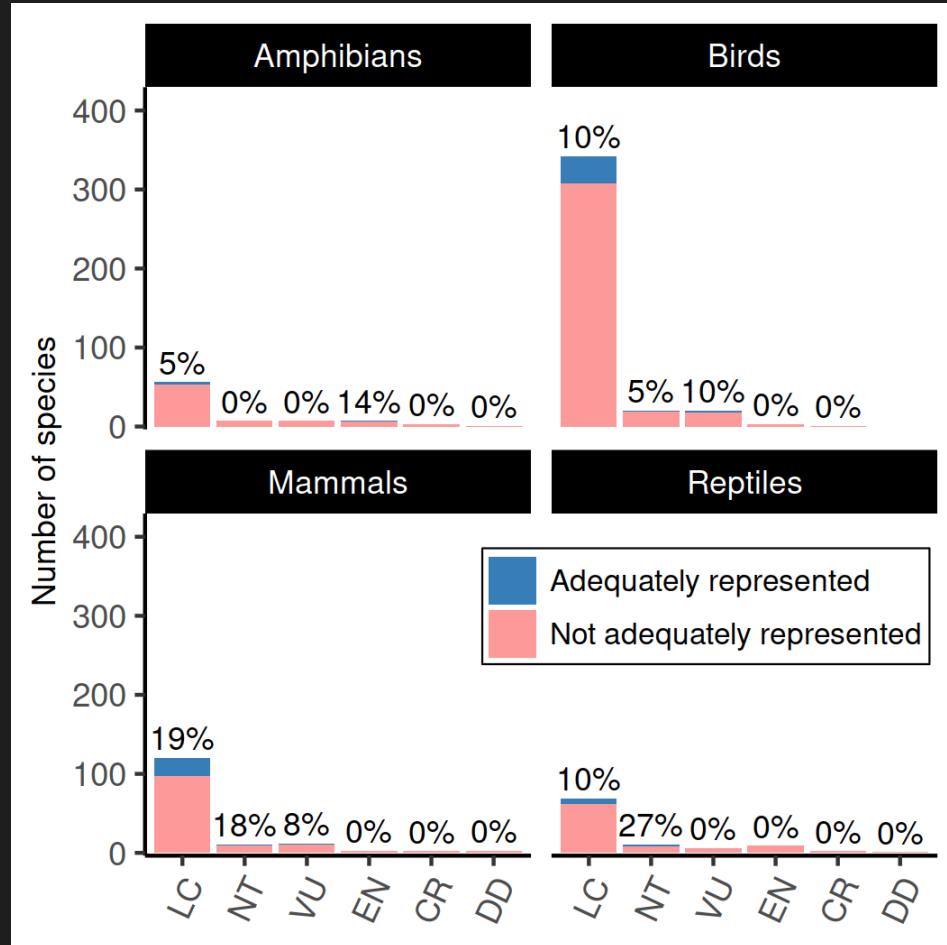


Stop hunting



Existing protected areas

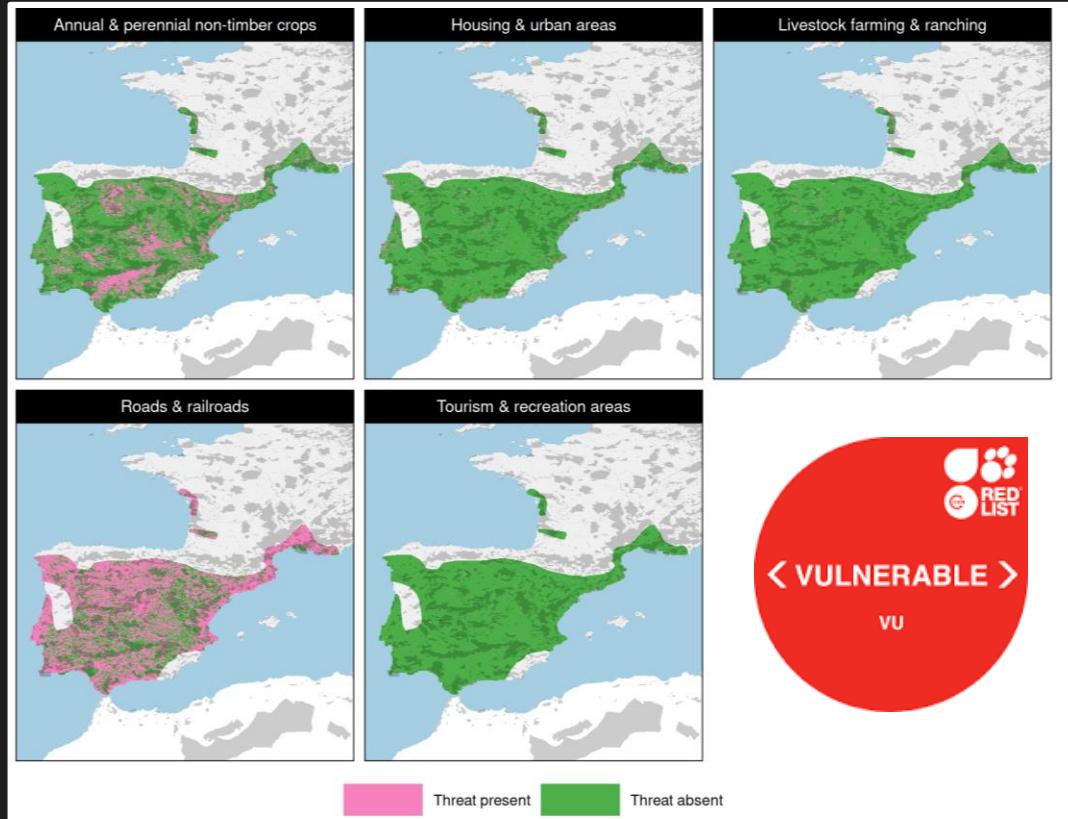
- 77 (11%) species adequately represented when accounting for threats
- Only 4 of 61 critically endangered species adequately represented when accounting for threats
- If we didn't account for threats, then instead of 77 species, we would mistakenly think 137 species (19%) are adequately represented



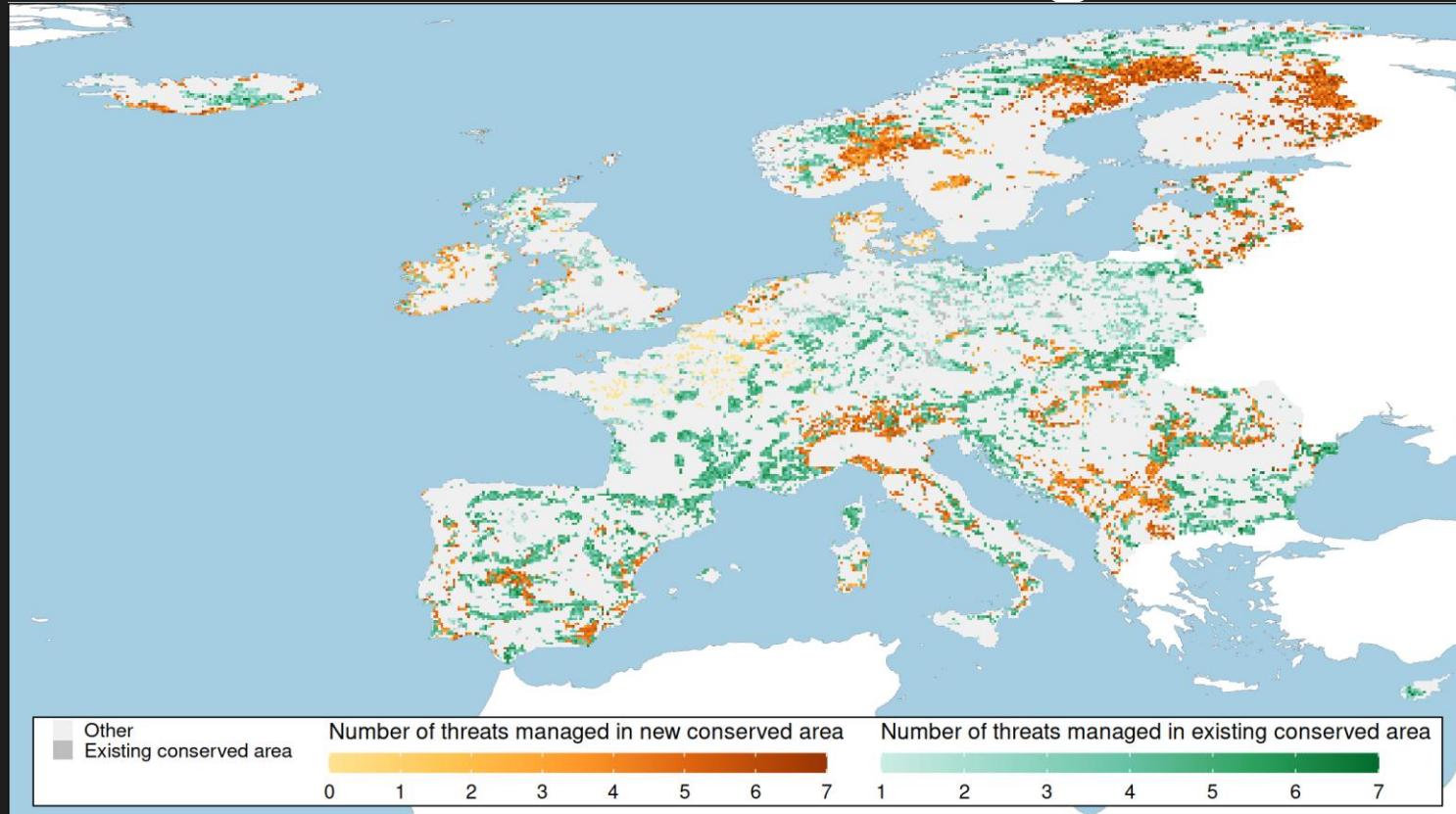


Pelobates cultripes

- 13% of current habitat covered by protected areas
- 10% representation target
- Only 6% covered by protected areas that are free from threats that impact this species

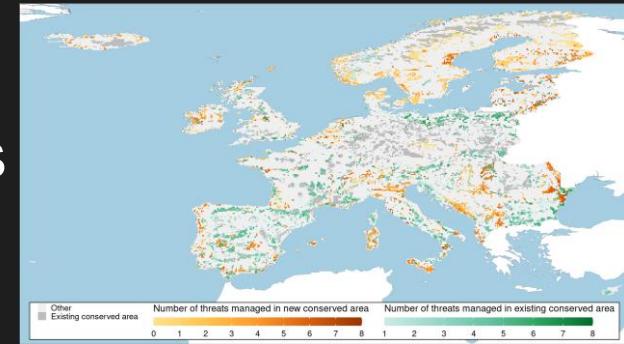


Prioritization to manage threats



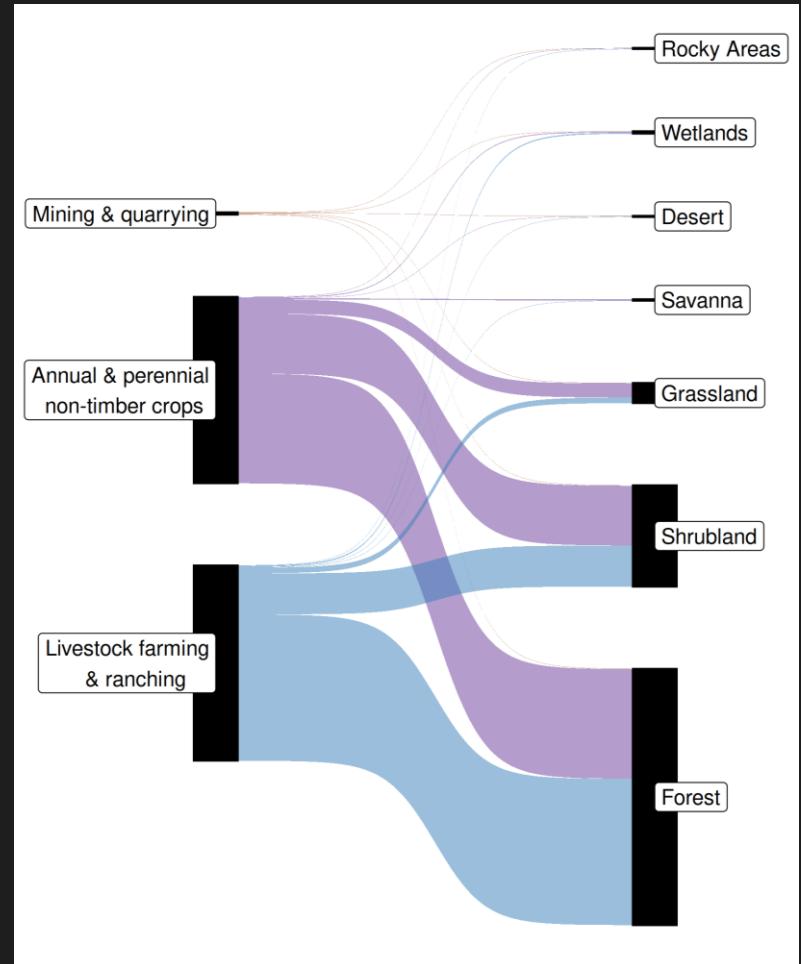
Prioritization to manage threats

- Total system $\leq 30\%$ of each country
- Adequately represent 325 (45%) species
- 66% of priority areas managing inside existing conserved areas
- 32% of priority areas establishing new protected areas and managing threats
- 2% of priority areas simply protecting remnant habitat



Habitat restoration

- Of the 7 threats that could be managed, 3 associated with restoration actions
- 65% of priority areas involved restoring habitat inside protected areas
- 33% of priority areas involved restoring habitat in newly established protected areas
- 28% of Europe's land prioritized for habitat restoration
- EU pledged to restore 20%



Make better conservation decisions by using...

1. Better algorithms
2. Cost-effective data



jeffrey.hanson@uqconnect.edu.au



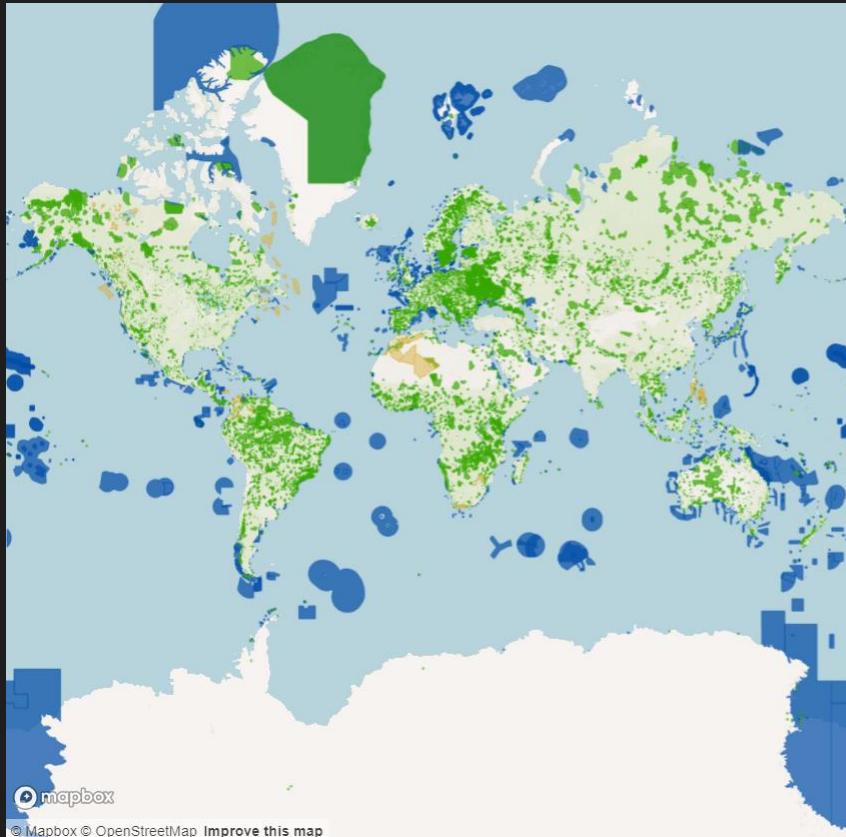
github.com/jeffreyhanson



jeffrey-hanson.com



World database on Protected Areas (WDPA)

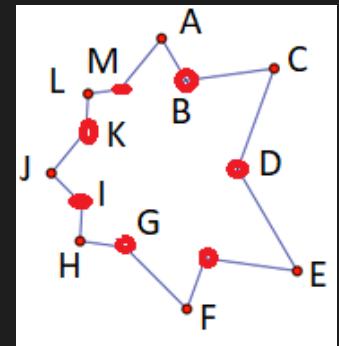
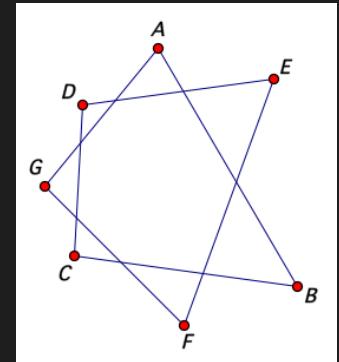


- 267 countries
- 268,721 terrestrial protected areas
- 18,638 marine protected areas
- IUCN management categories

But data needs cleaning...

- Invalid geometries
- Protected areas that aren't implemented
- Protected areas represented only as points
- Protected areas that cross the dateline
- Protected areas that don't really do much
- Removing slivers
- Erase for overlapping areas

Self-intersections

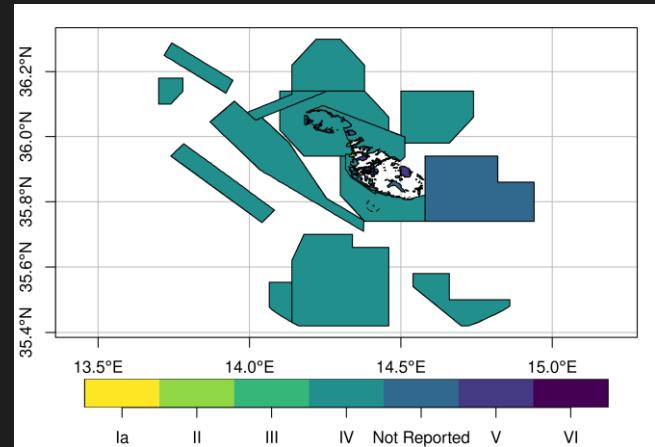


wdpar: Interface to the World Database on Protected Areas

```
# (i) load package
library(wdpar)
#> Loading required package: sf
#> Linking to GEOS 3.10.2, GDAL 3.4.1, PROJ 8.2.1; sf_use_s2() is TRUE

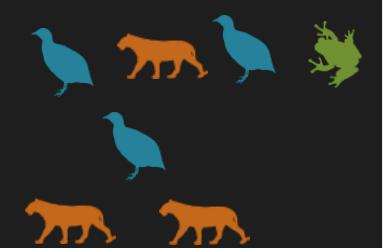
# (ii) download data
d <- wdpa_fetch("Malta")

# (iii) clean data
d <- wdpa_clean(d)
#> ✓ initializing [75ms]
#> ✓ retaining only areas with specified statuses [41ms]
#> ✓ removing UNESCO Biosphere Reserves [62ms]
#> ✓ removing points with no reported area [37ms]
#> ✓ wrapping dateline [425ms]
#> ✓ repairing geometry [1.1s]
#> ✓ reprojecting data [65ms]
#> ✓ repairing geometry [583ms]
#> ✓ further geometry fixes (i.e. buffering by zero) [144ms]
#> ✓ repairing geometry [506ms]
#> ✓ snapping geometry to tolerance [101ms]
#> ✓ repairing geometry [564ms]
#> ✓ formatting attribute data [31ms]
#> ✓ removing slivers [122ms]
#> ✓ calculating spatial statistics [116ms]
```

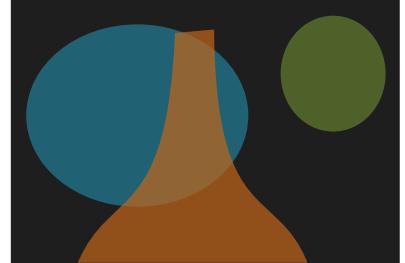


Is more data
always better?

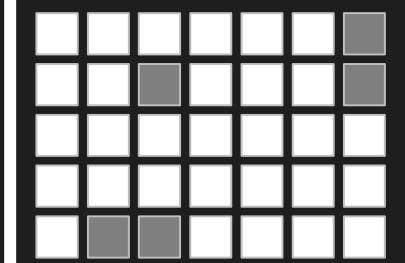
Ecological surveys



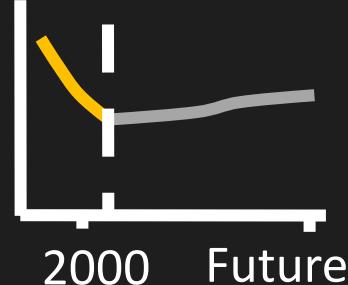
Distribution maps



Priority areas

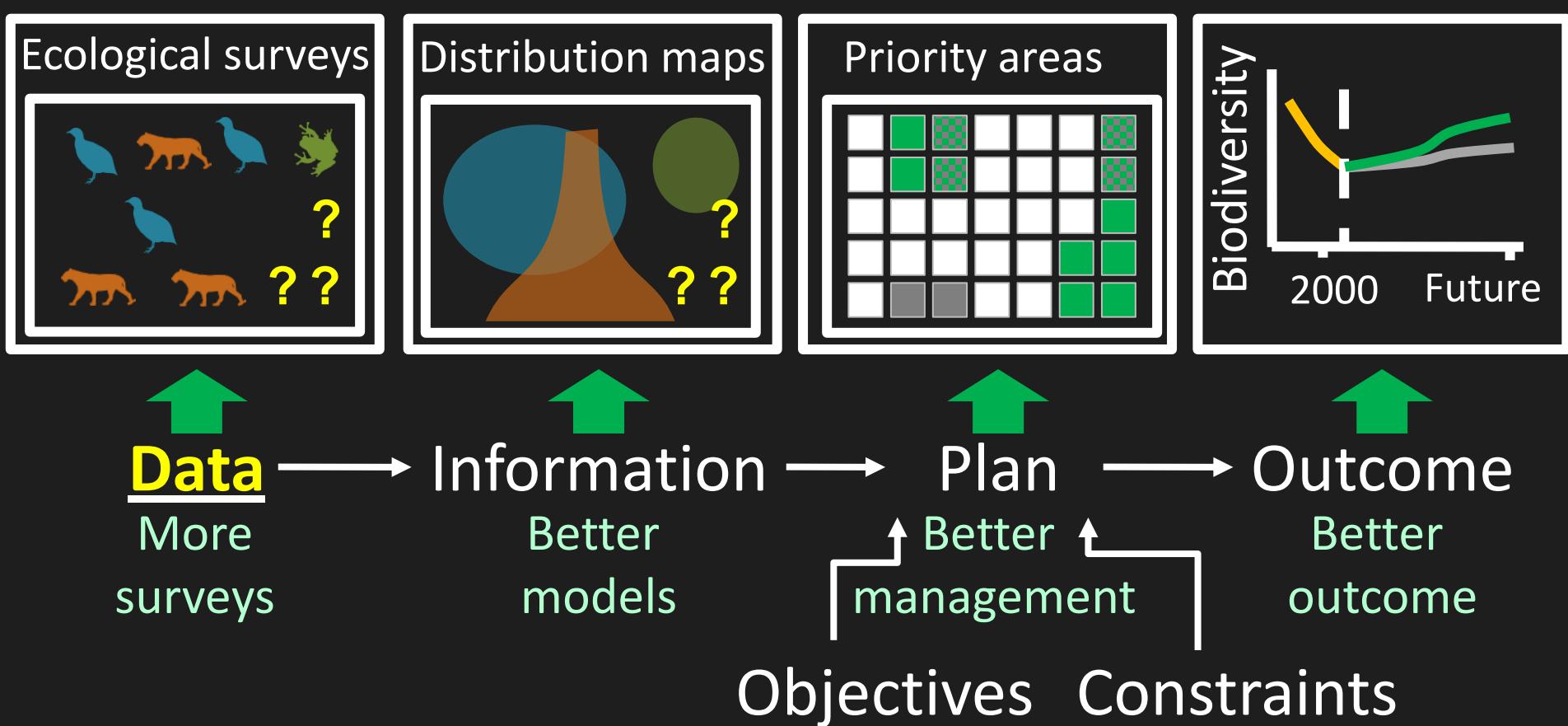


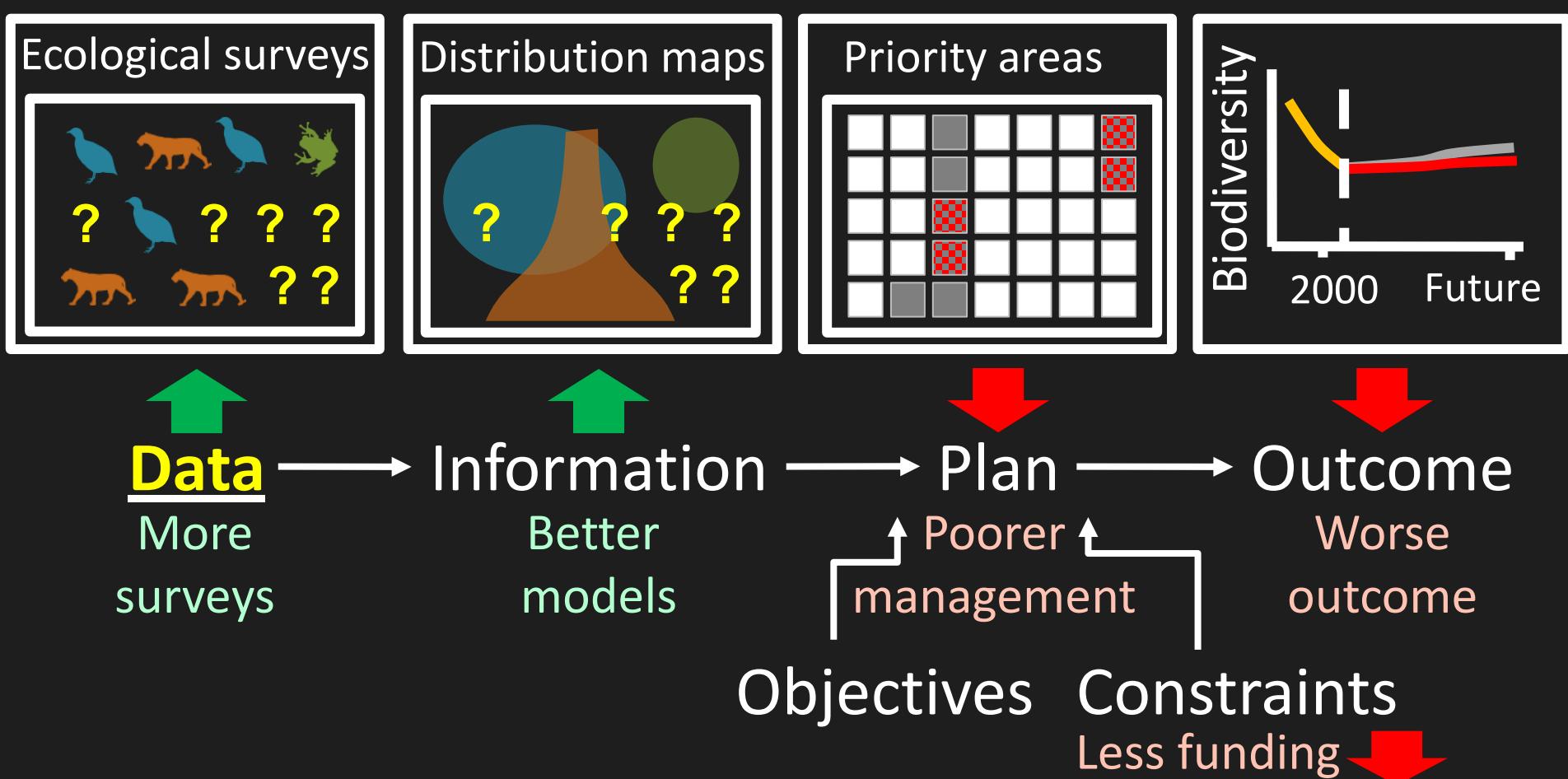
Biodiversity



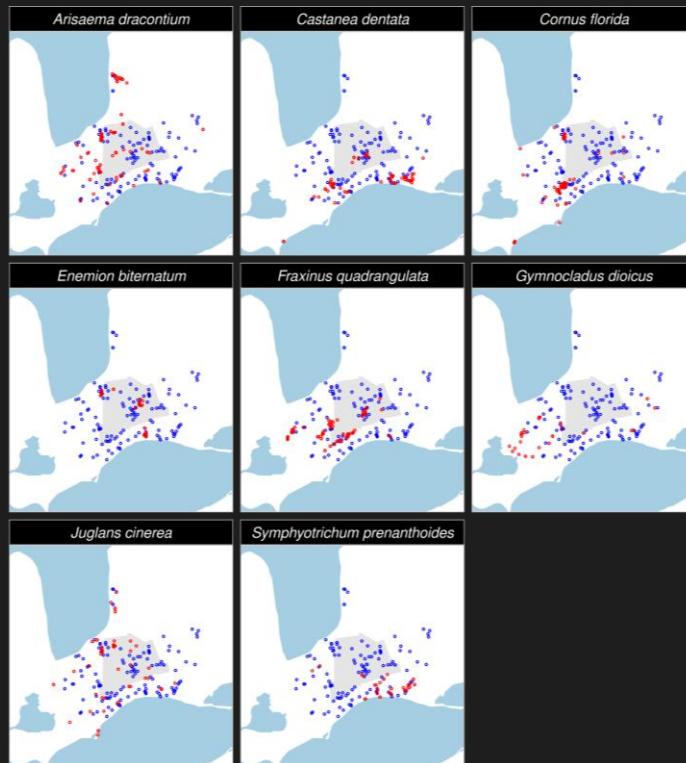
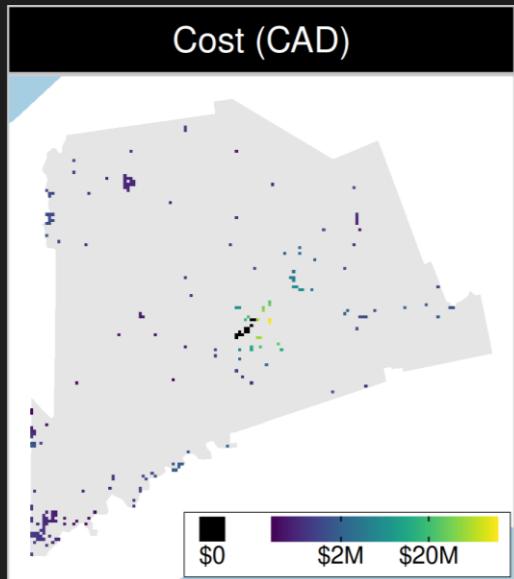
Data → Information → Plan → Outcome





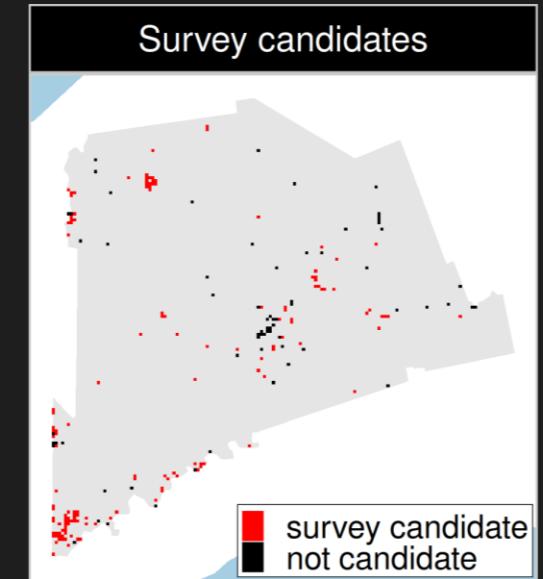


Study system: Middlesex county, Canada



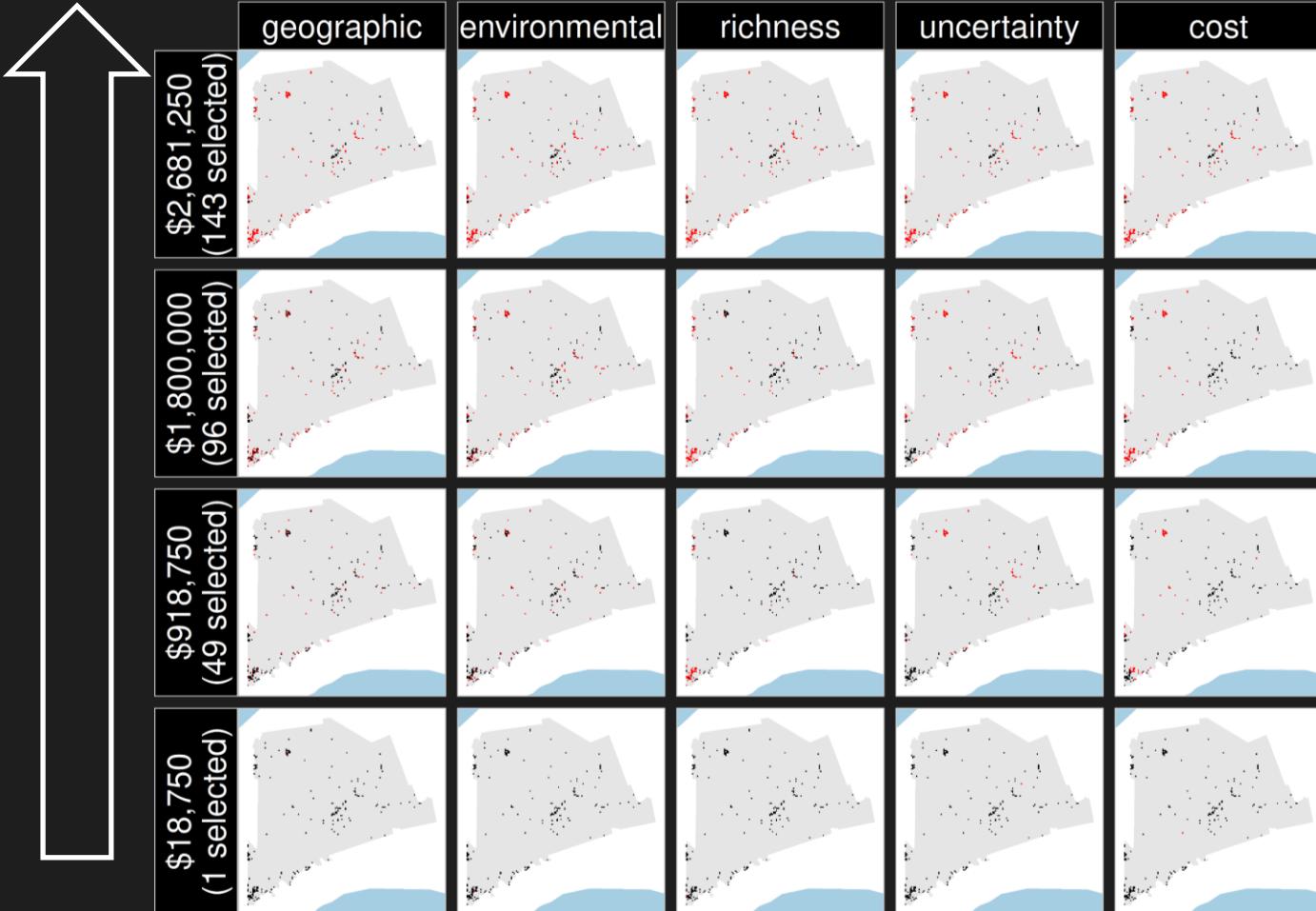
8 imperiled plant species

199 places that could potentially be acquired for protected area establishment



143 places that could potentially be surveyed to improve existing data

Number of places selected for surveys
(amount of funds allocated for collecting extra data)



Different approaches for designing survey schemes



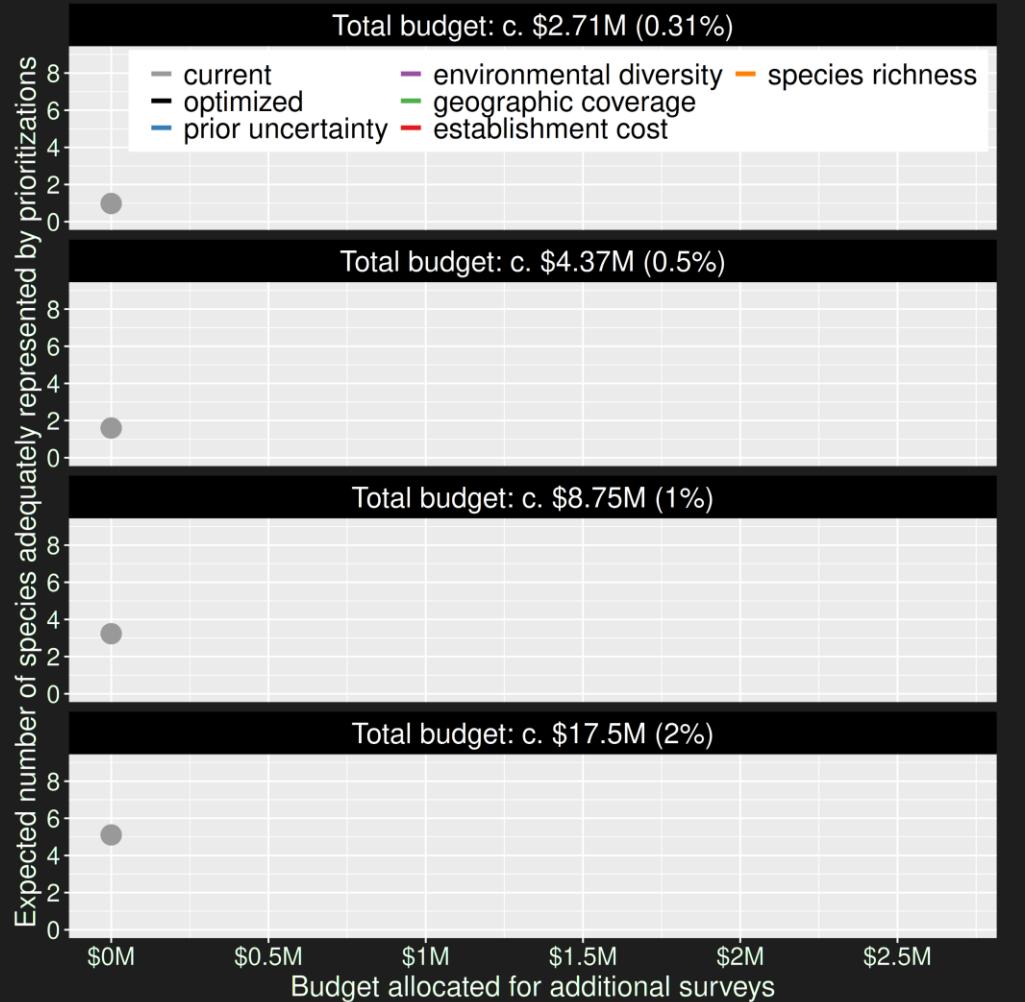
Selected
for survey



NOT selected
for survey

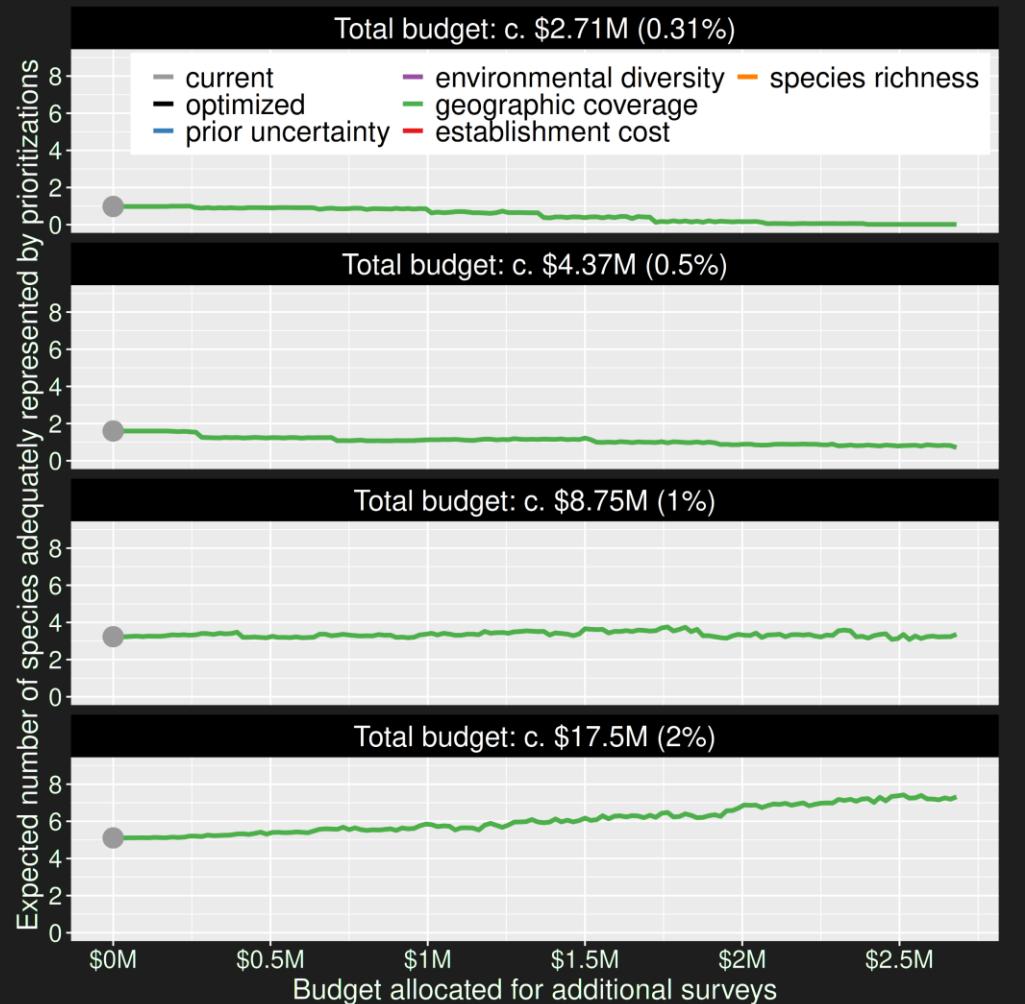
Value of information

- Existing data leads to positive outcomes
- More budget means better outcomes



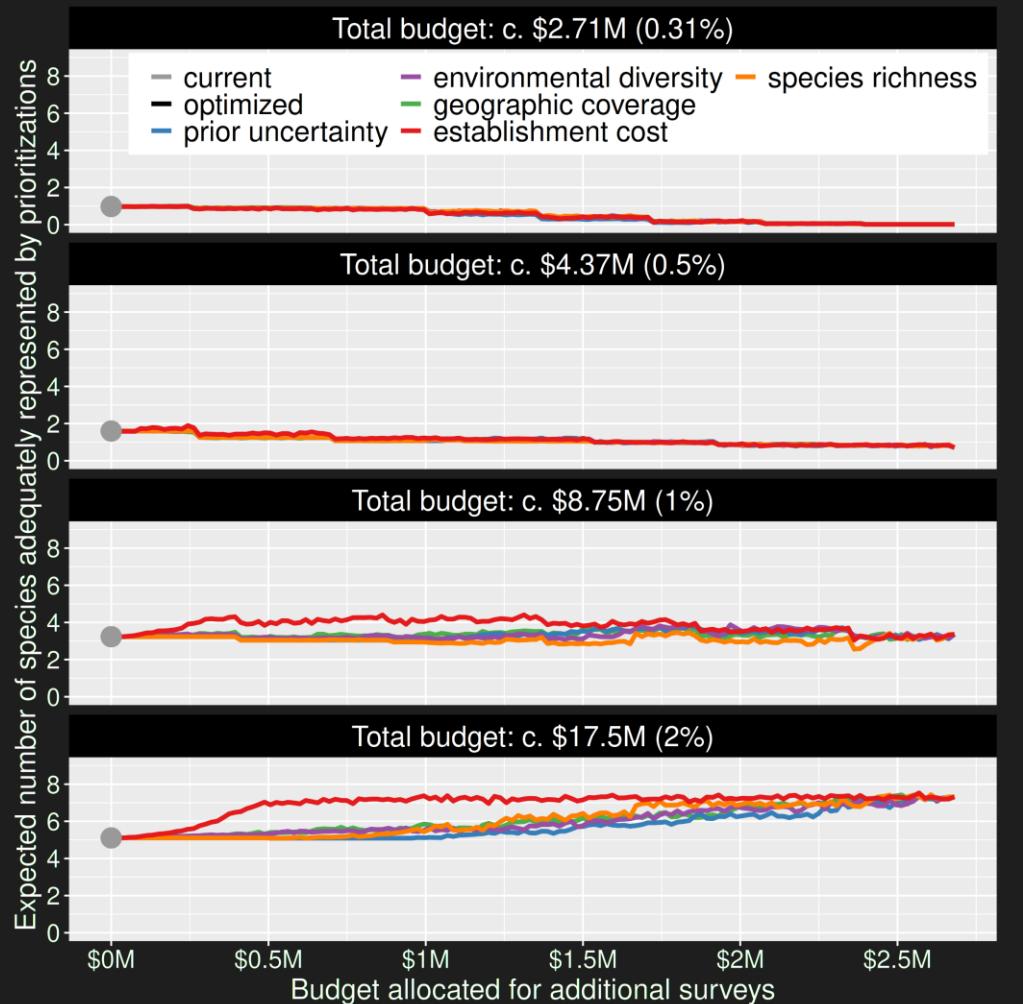
Value of information

- Allocating funds for gathering more data can mean worse outcomes
- Allocating funds for gathering more data can mean better outcomes too



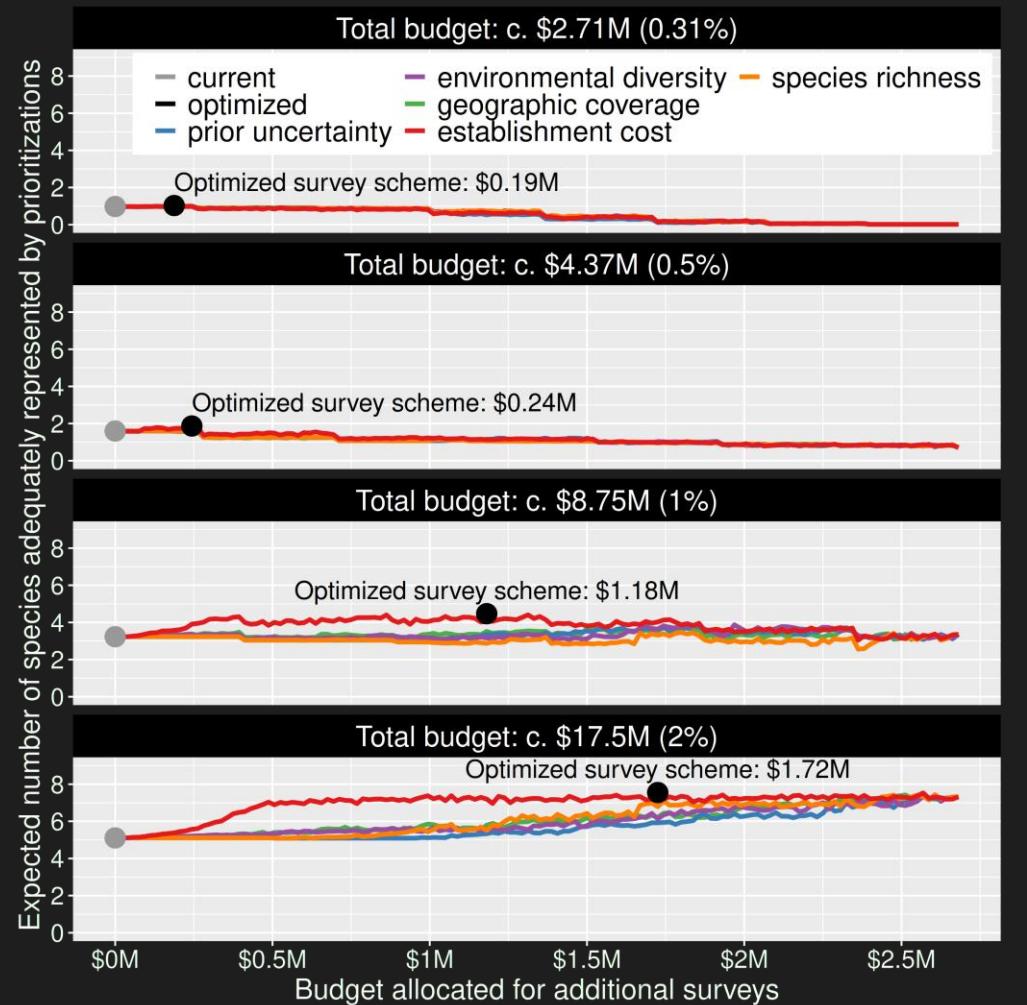
Value of information

- Conventional approaches for gathering additional evidence have different performance
- Performance of these approaches depends on available funds
- All of them could lead to worse outcomes



Value of information

- Directly maximizing return on investment is best method for additional data
- This considers objectives and constraints that underpin conservation plans and their success

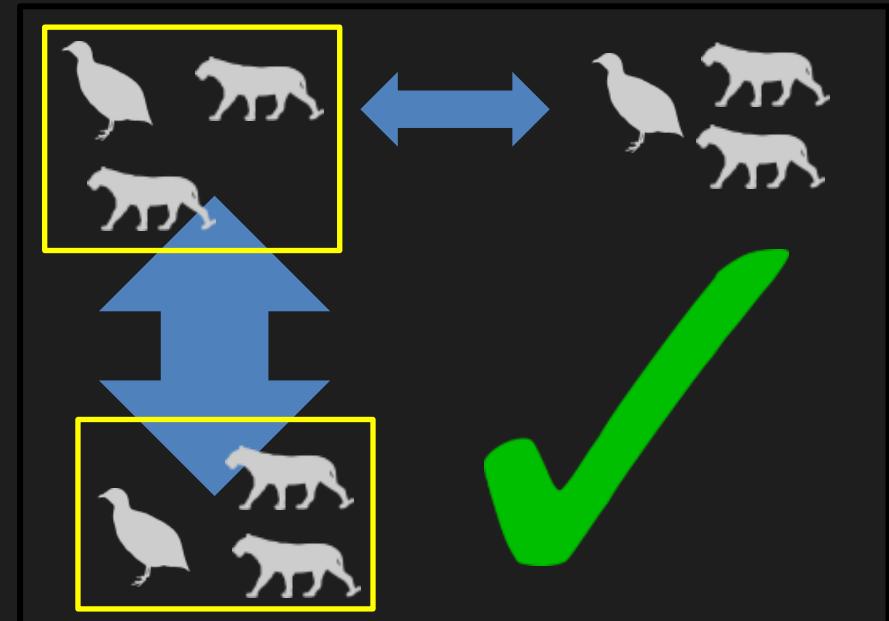
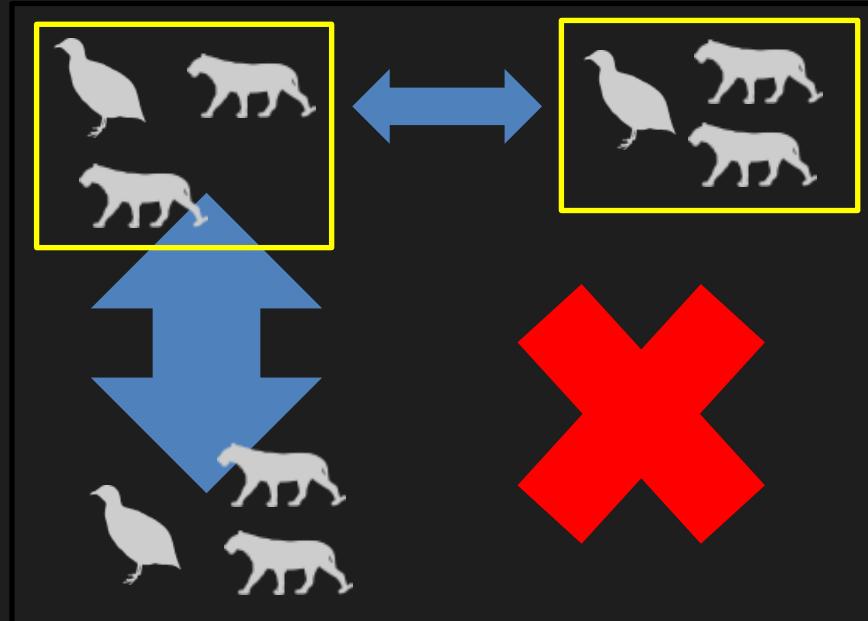


How can we get a better conservation decision?

- (1) Better algorithms
- (2) Better data
- (3) Better surrogates

Connectivity in reserve design

movement of individuals and genes between populations



*All else being equal

But getting connectivity data is hard

Animal telemetry



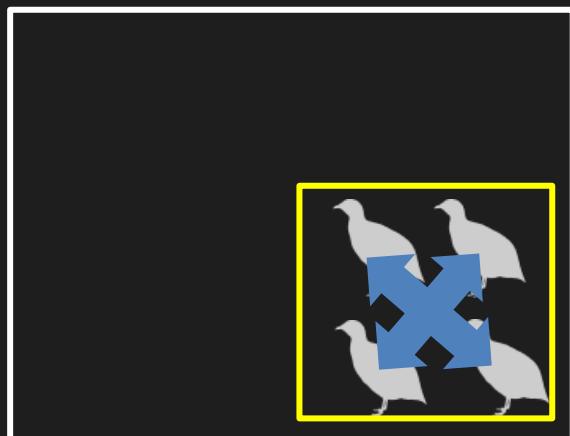
Molecular ecology



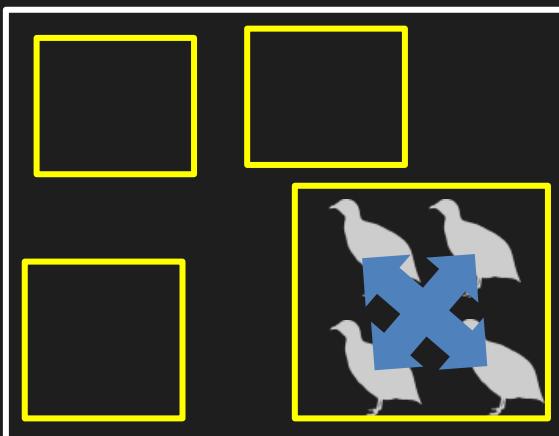
Rules of thumb for connectivity

More habitat = More connectivity

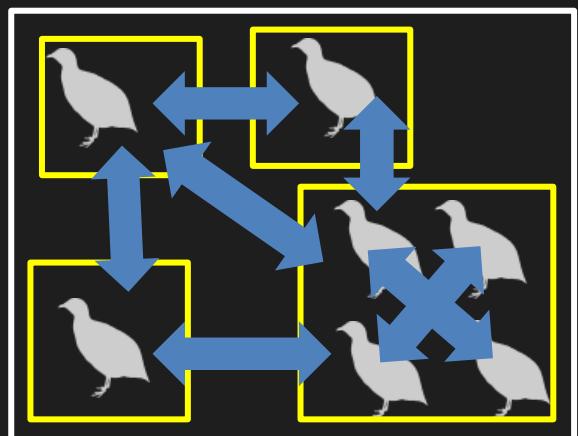
- Total area protected
- Species representation



Now



Soon

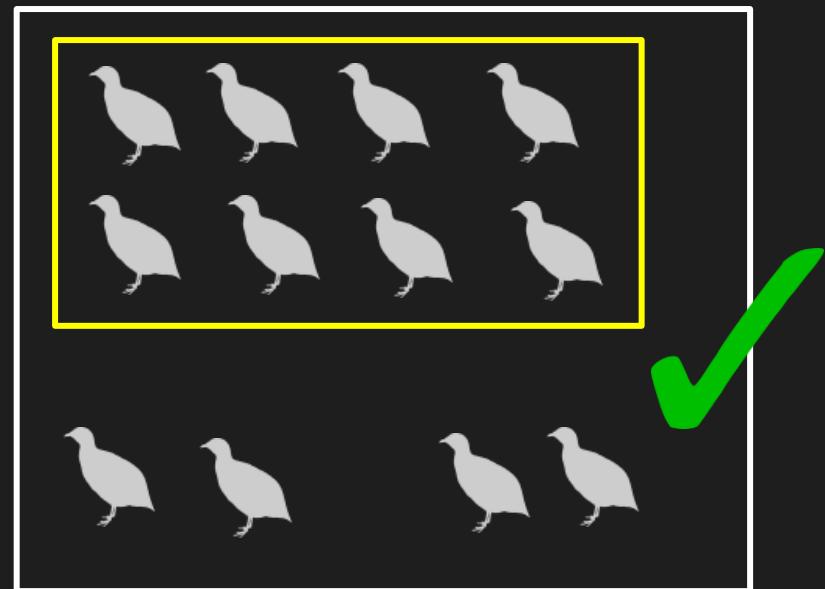
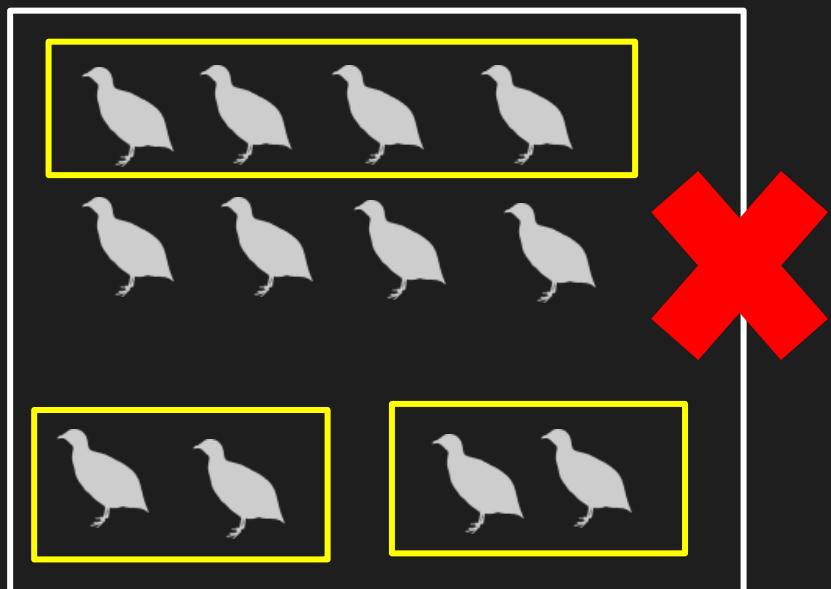


Later

Rules of thumb for connectivity

More spatial clustering = More connectivity

- Boundary length



Rules of thumb for connectivity

Protect clusters of low resistance = More connectivity

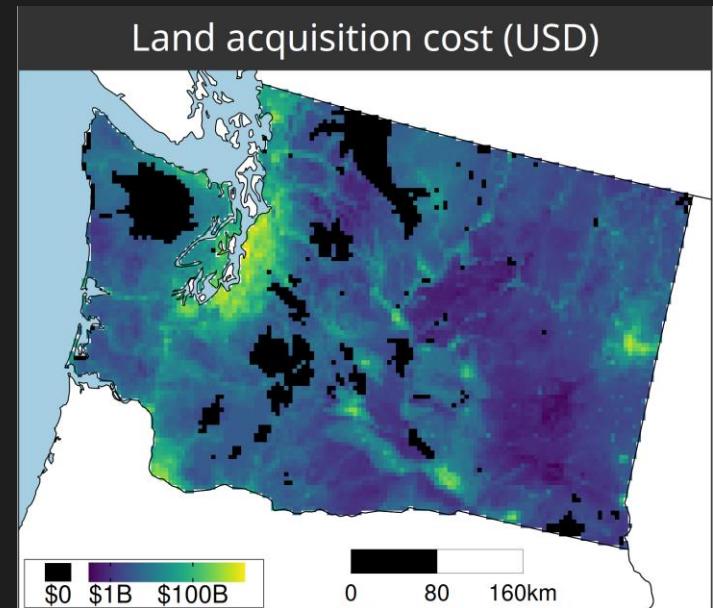
- Human pressure
 - Naturalness based landscape resistance
 - Focal species landscape resistance
- Habitat heterogeneity
 - Environmental similarity



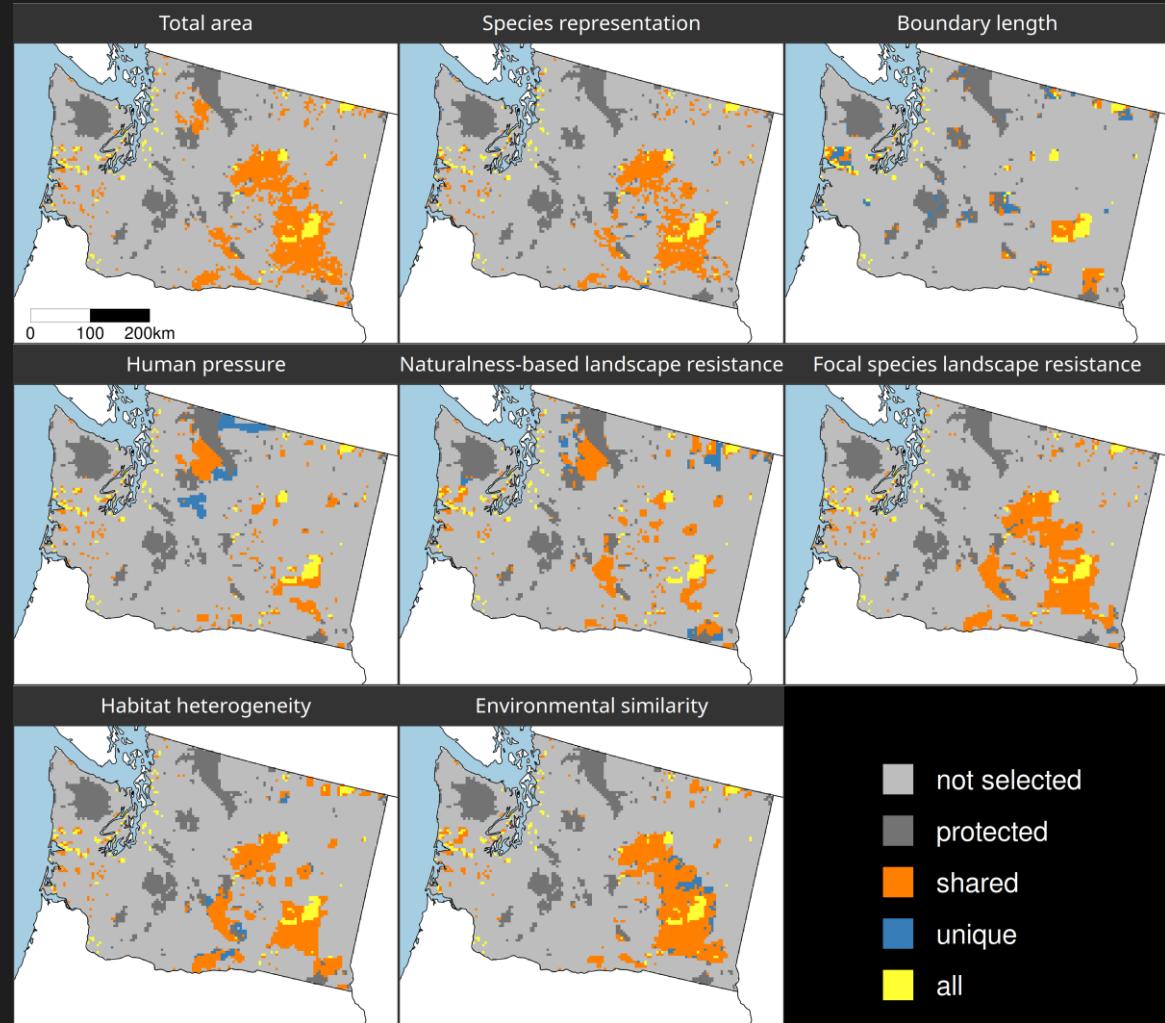
A comparison of approaches for including connectivity in systematic conservation planning

Washington State, USA

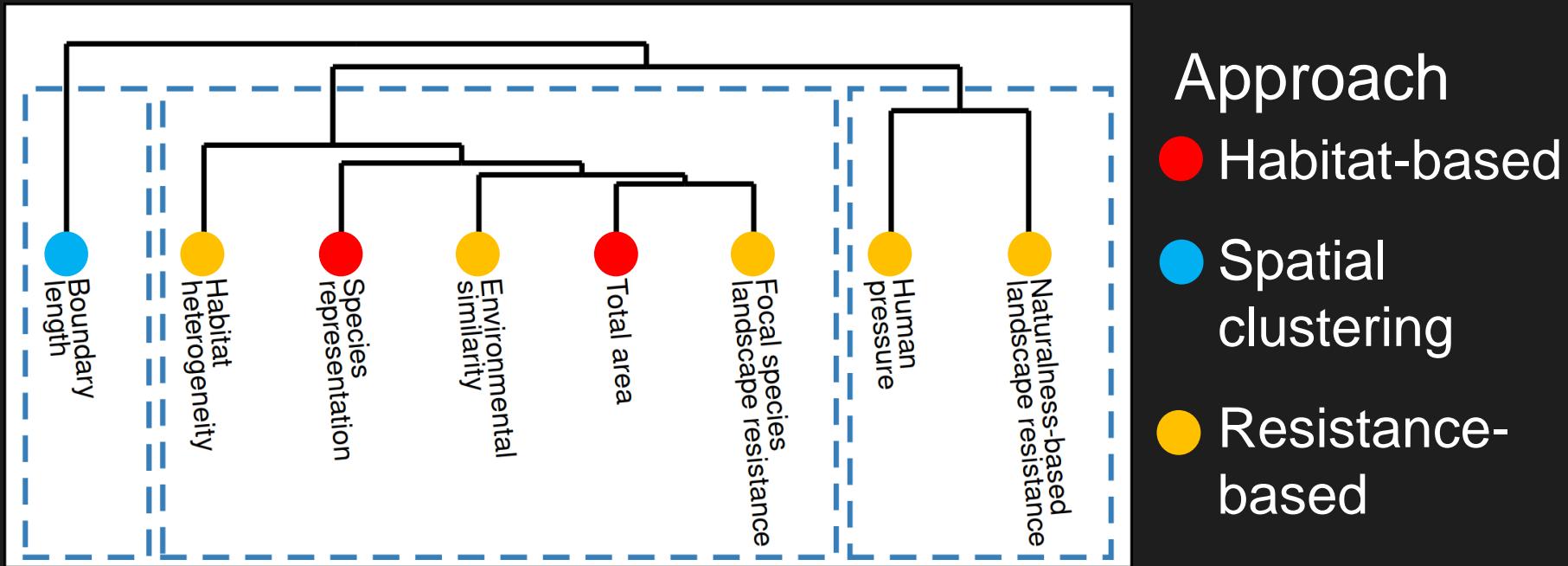
- 261 bird species
- Land acquisition costs
- Existing protected areas
- Multiple land-uses
- Multiple eco-systems



- Different connectivity approaches produce different prioritizations
- Different connectivity approaches can yield similar prioritizations



How do the prioritizations compare?



No obvious winner

