Making better conservation decisions

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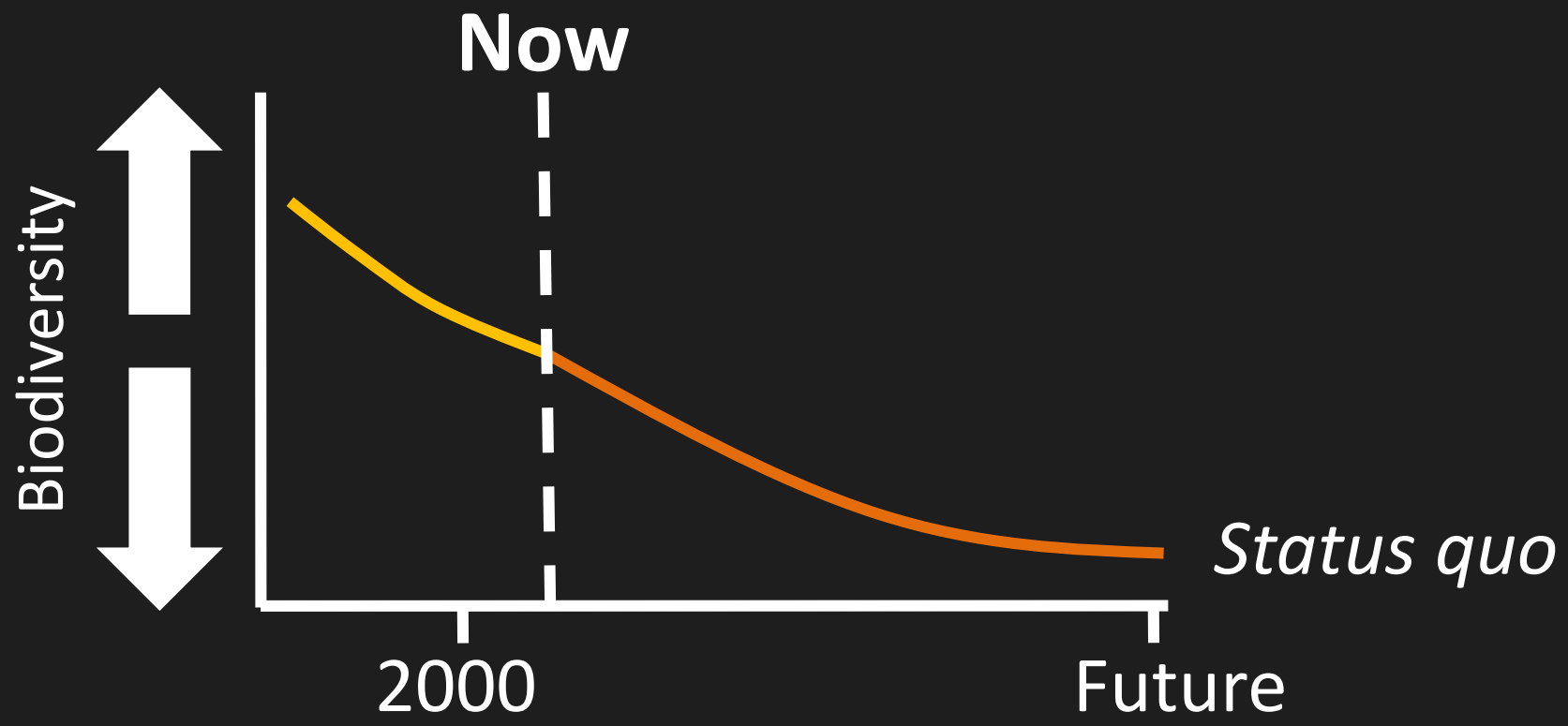
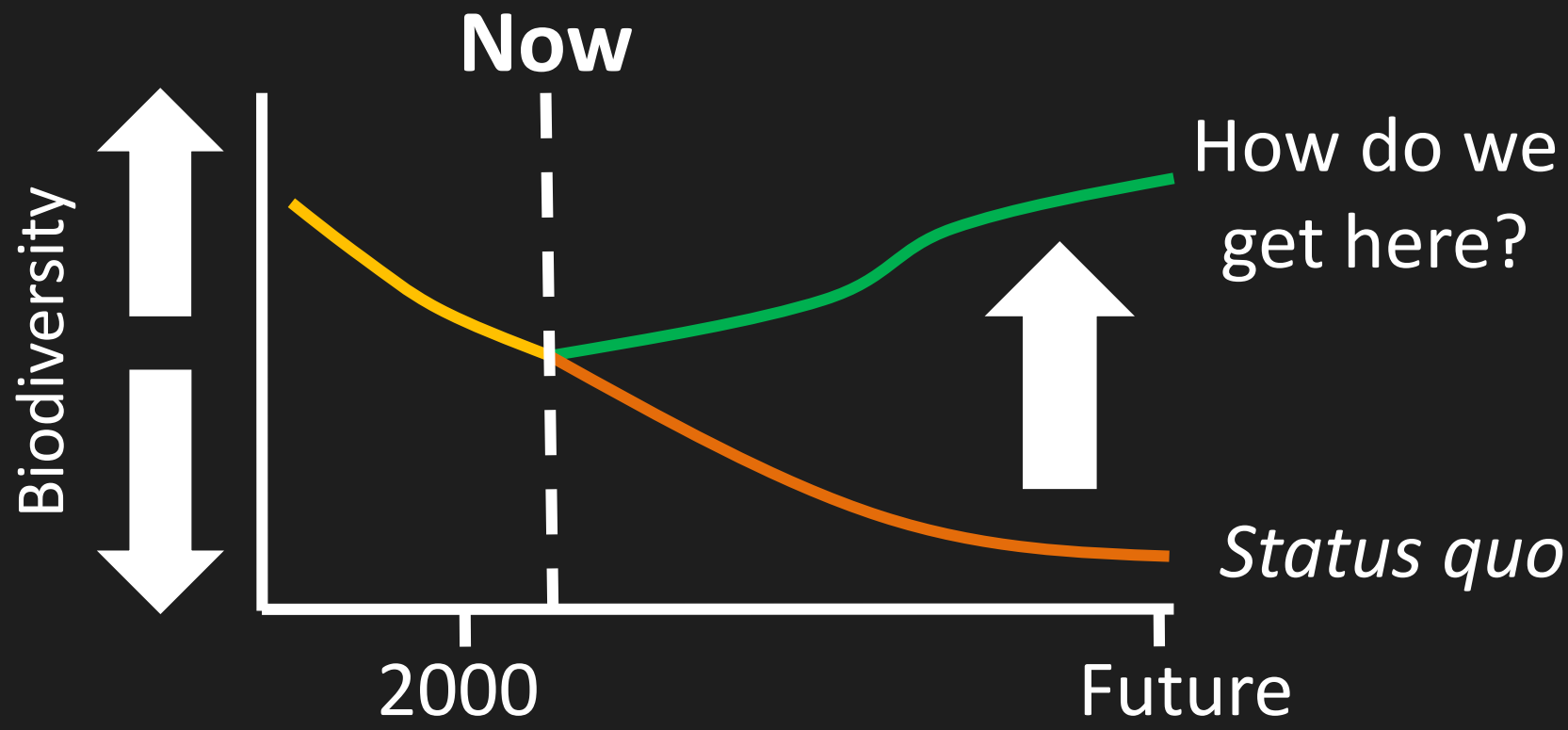
Acknowledgements

Allison Binley
Brandon Edwards
Dobrochna Delsen
Dan Wismer
Hugh Possingham
James Allan
Joseph Bennett
Martin Jung
Marc Edwards
Matthew Strimas-Mackey
Nina Morell
Peter Arcese
Piero Visconti
Richard Schuster
Virgilio Hermoso

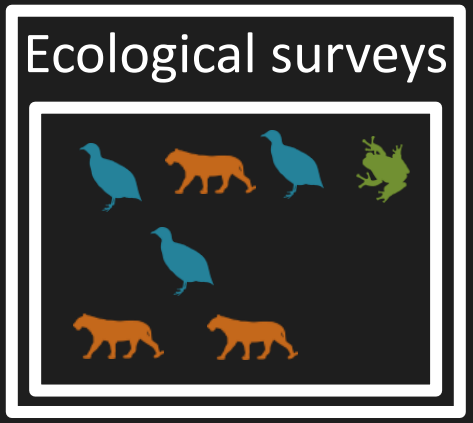

Now
Biodiversity
Status quo
2000
Future

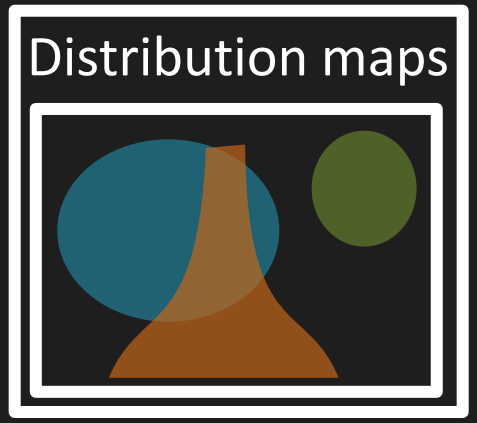

Now
Biodiversity
How do we get here?
Status quo
2000
Future

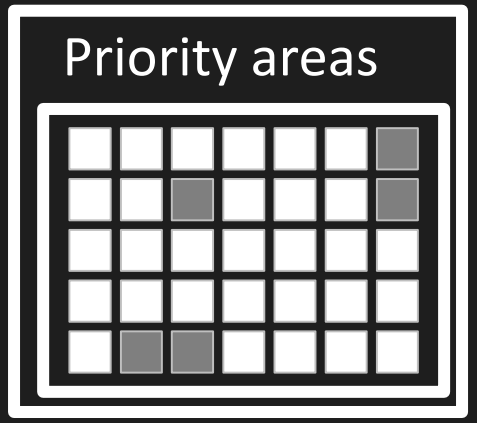
How can we get a better conservation decision?

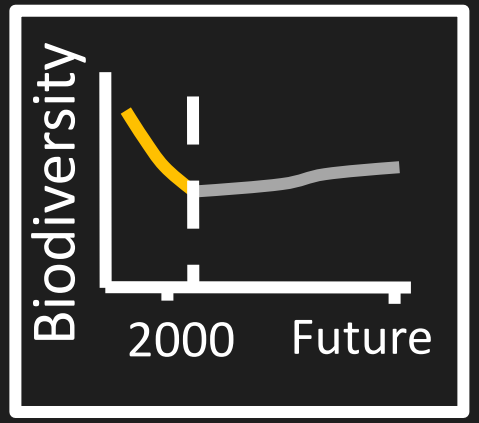
(1) Better algorithms

(2) Better data



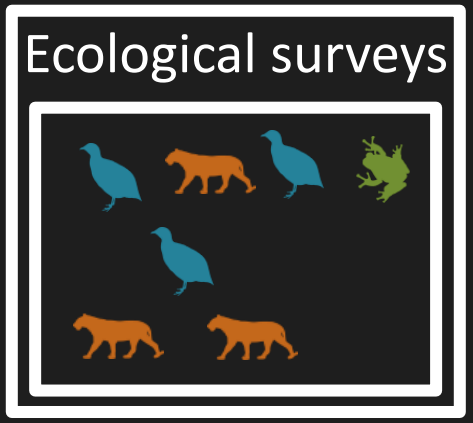


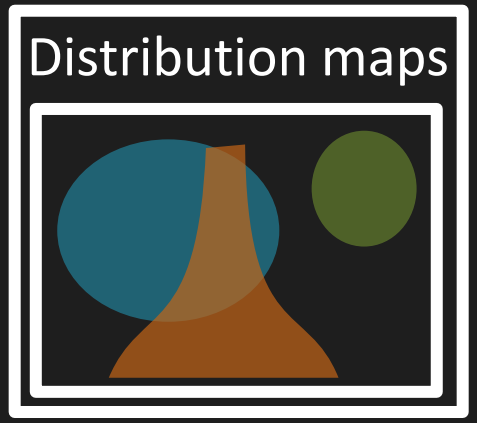


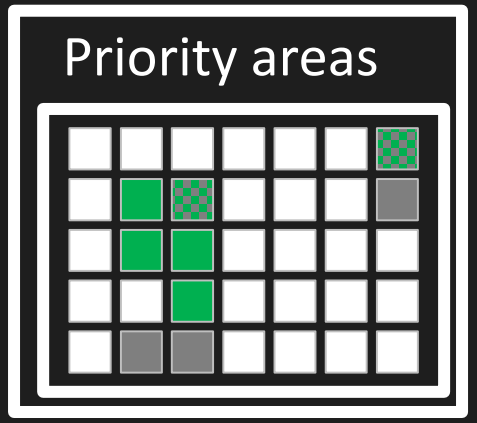


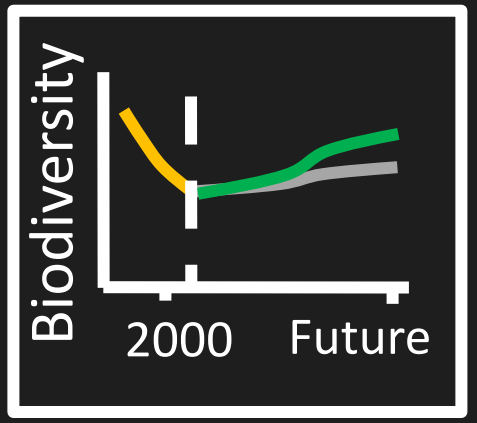
Data → Information → Plan → Outcome

Objectives Constraints









Data → Information → **Plan** → Outcome

Better algorithms

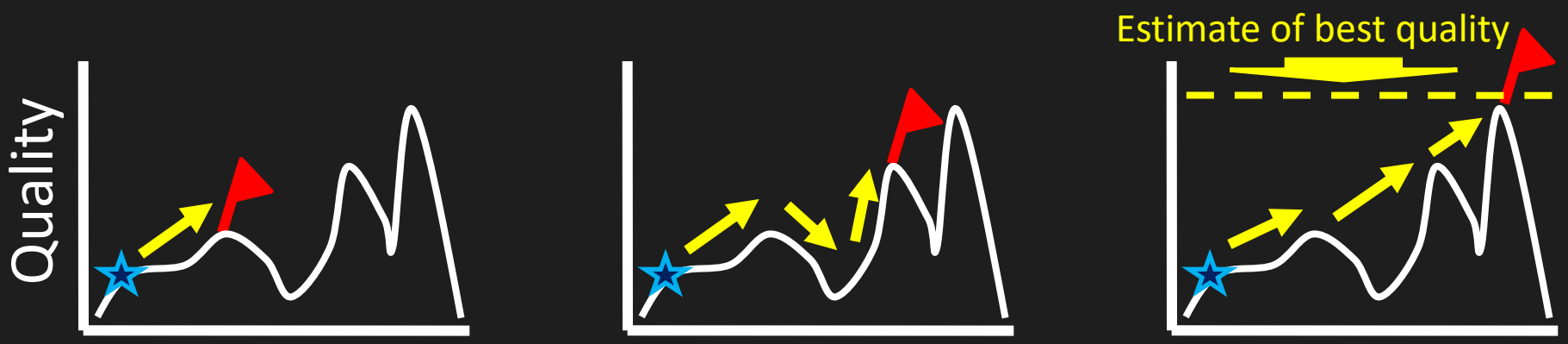
Better outcome

Objectives Constraints

Heuristic algorithm

Meta-heuristic algorithms

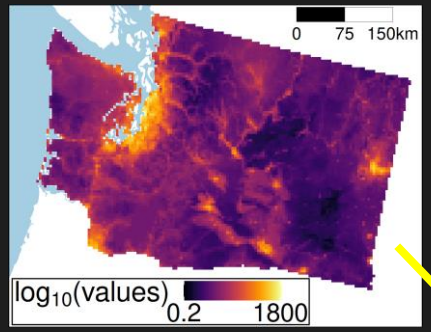
Exact algorithms

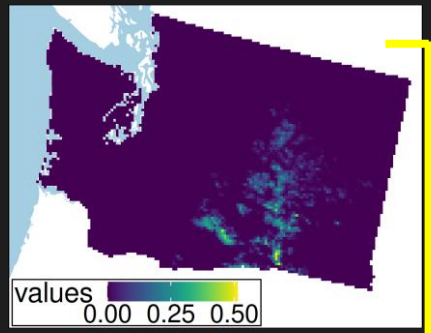


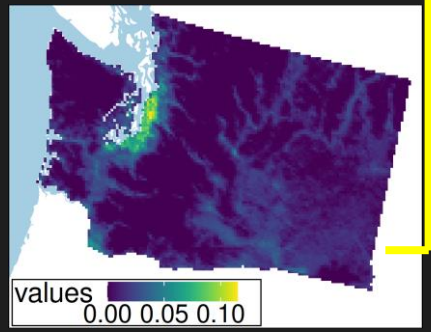
prioritizr: Systematic conservation prioritization in R

- 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

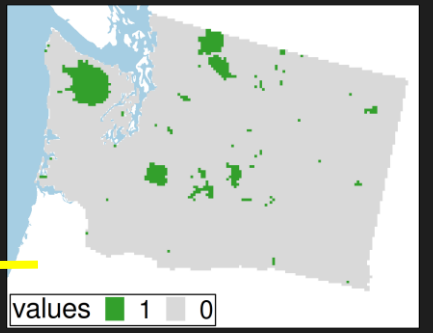
Worked example

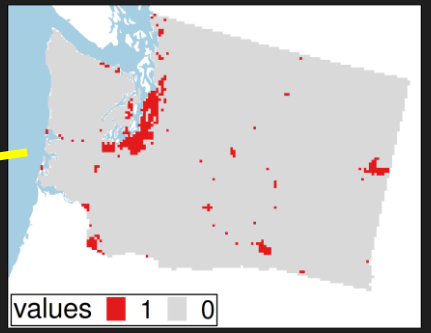







```r
# load packages
library(prioritizr) # package for conservation planning
library(terra)      # package for raster data

# 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")
```



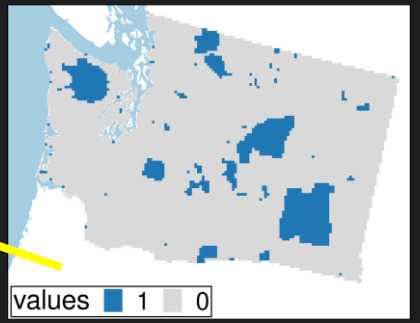


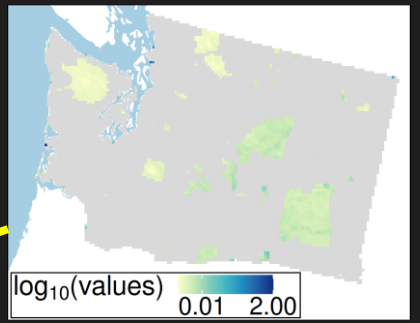
??? *et al.* under review

```r
# 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)
```

??? *et al.* under review

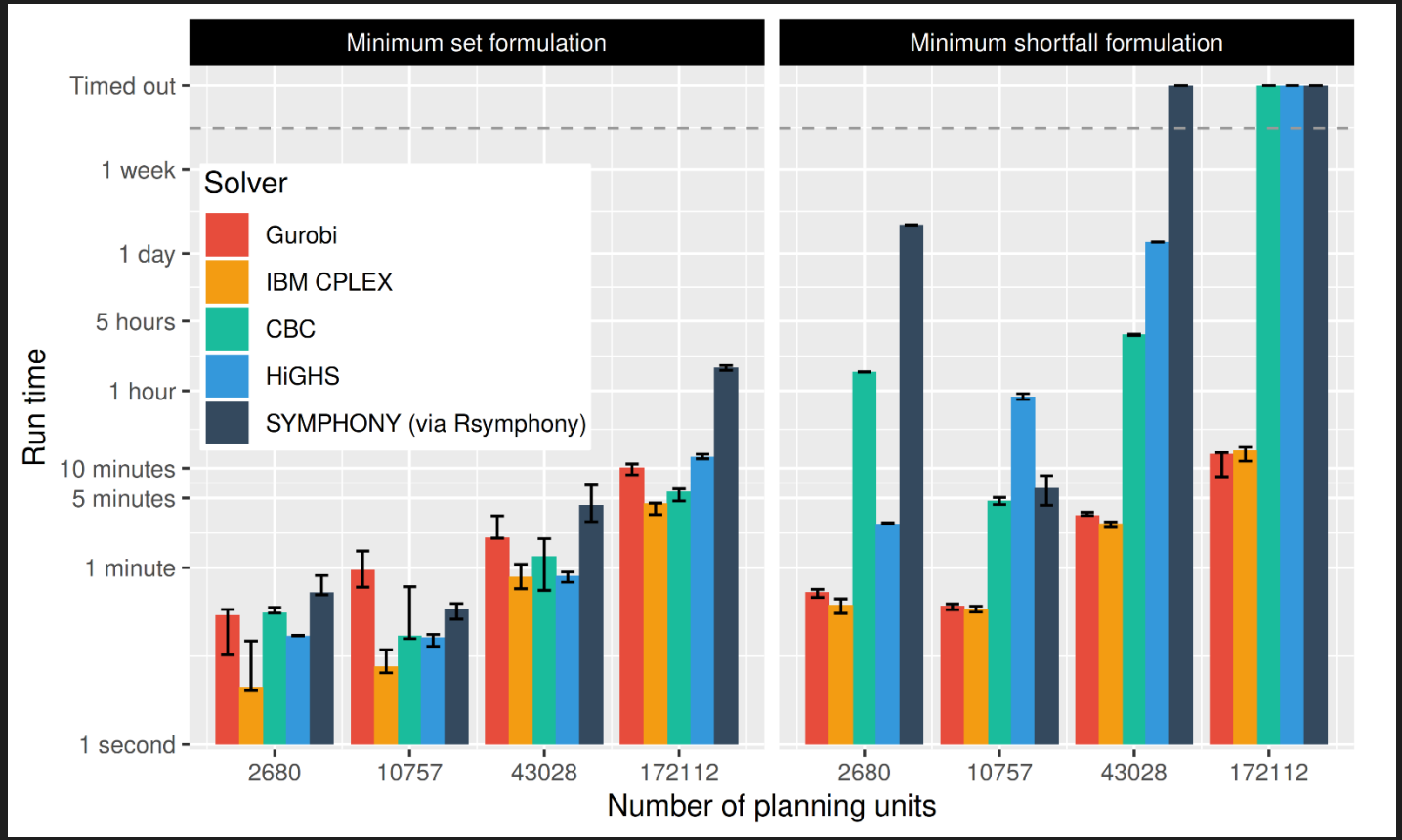
```r
# solve problem
## output raster has binary values indicating if
## each planning unit is (1) selected or (0) not
prioritization <- solve(conservation_planning_problem)

# 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)
```





??? *et al.* under review

Solve problems pretty quickly!



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

??? *et al.* under review

Where to work

https://ncc.carleton.ca

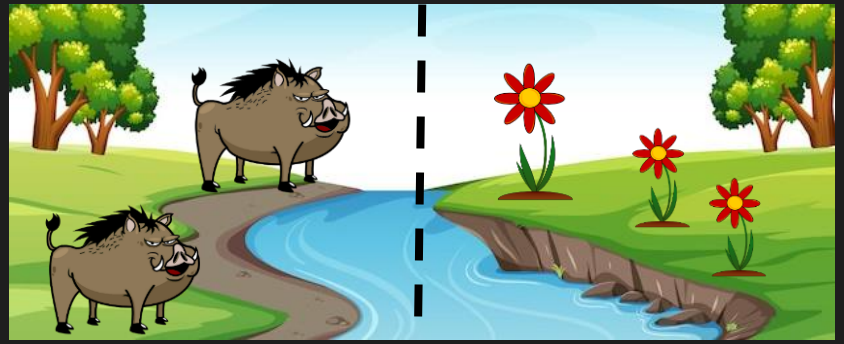
How can we get a better conservation decision?

(1) Better algorithms

(2) Better data

Conventional conservation planning

1. Area with biodiversity and area impacted by threat

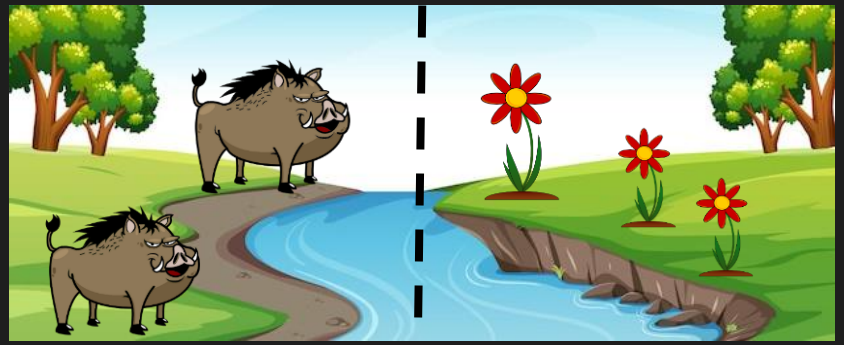


2. Establish protected area to safeguard biodiversity

3. Positive conservation outcome?

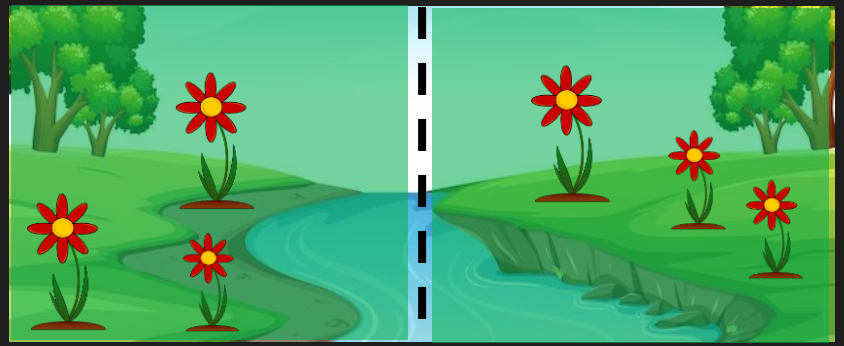
Conservation is actions in places

1. Area with biodiversity and area impacted by threat



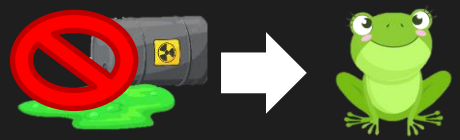
2. Establish protected areas and actions to manage threat

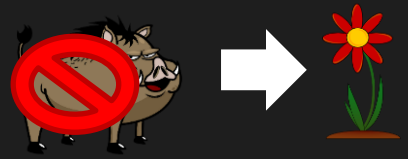
3. Positive conservation outcome

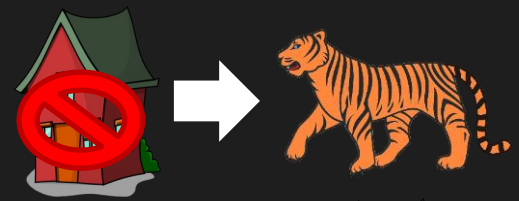


Which threats to abate?

Which threats to abate?

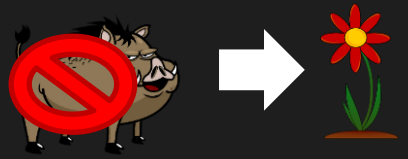


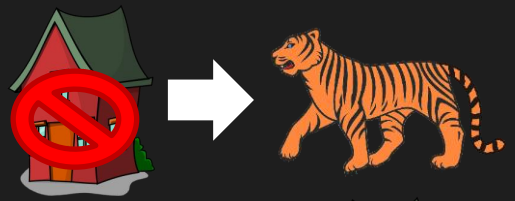




Which threats to abate?

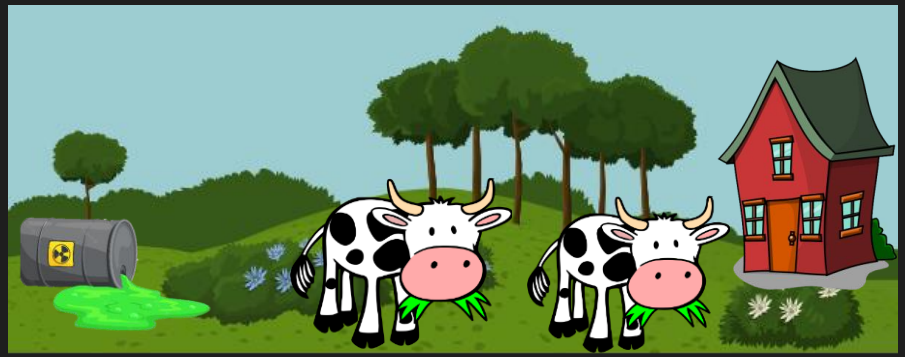
$1M 

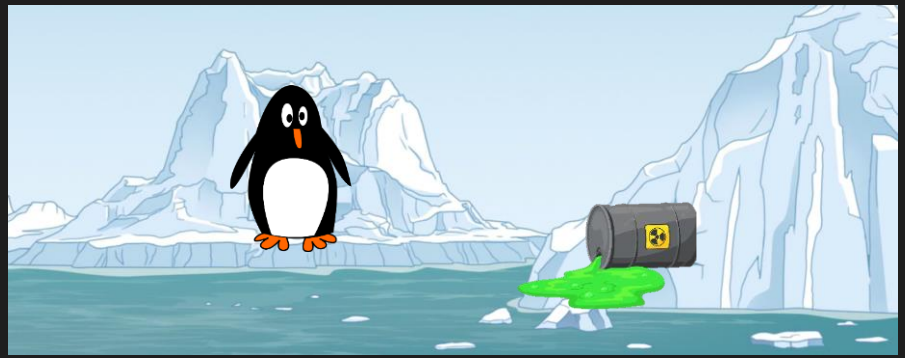
$2M 

$4M 

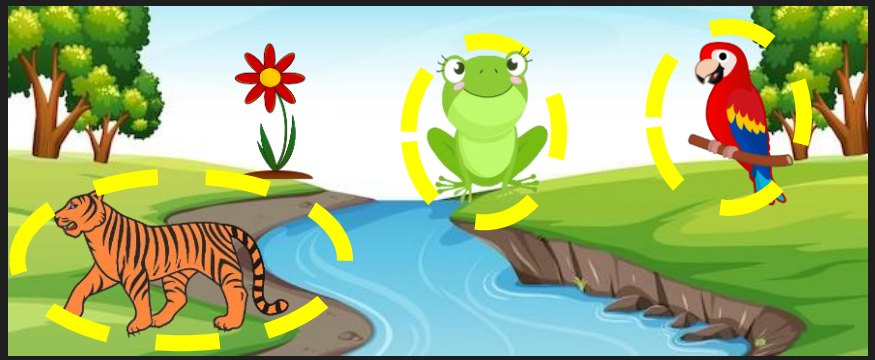
$5M 

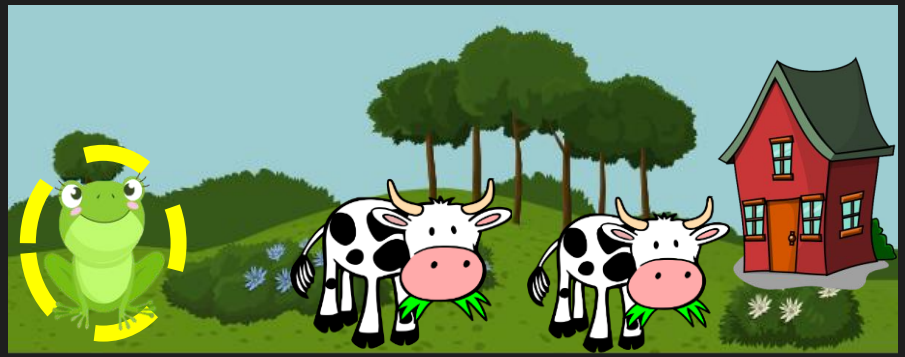
Which places to abate which threats?

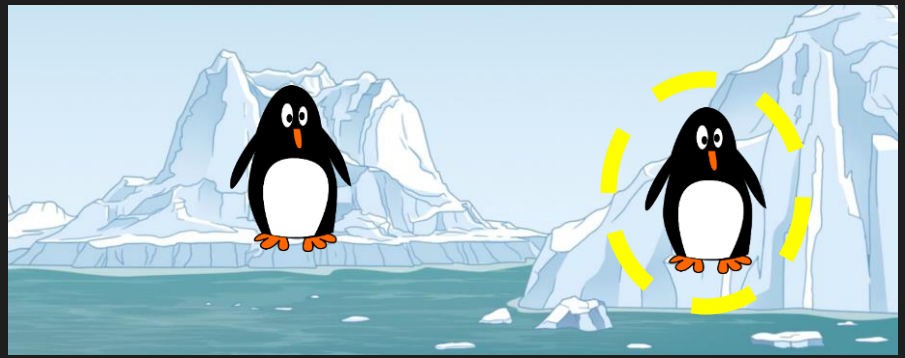




Provide each species with an adequate amount of threat-free habitat

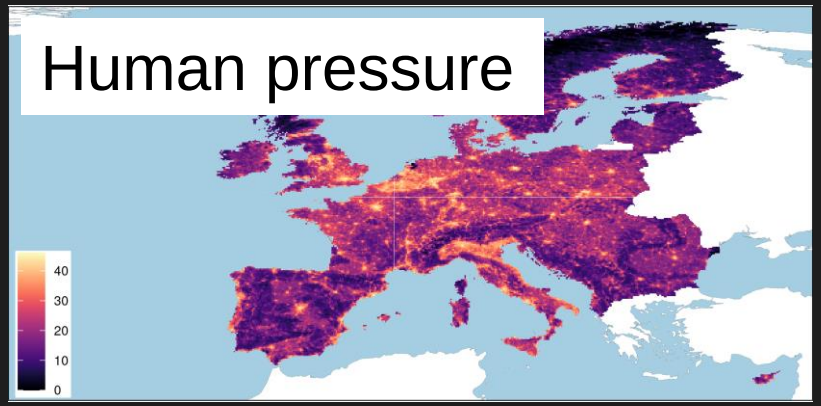


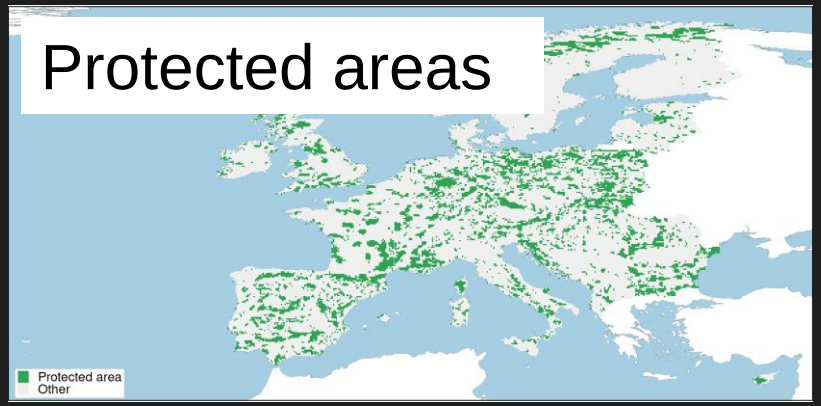




European case study

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





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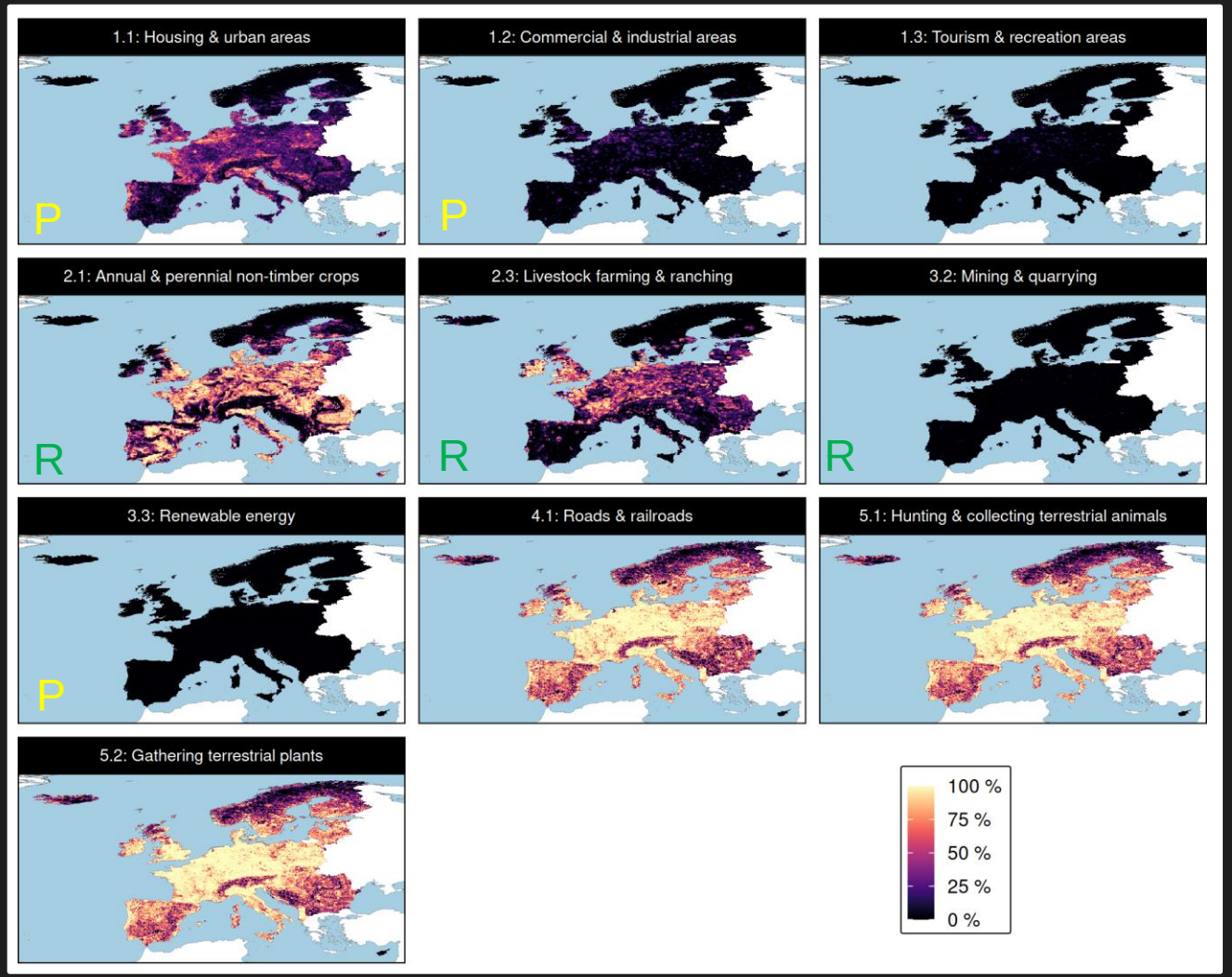
Threats

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



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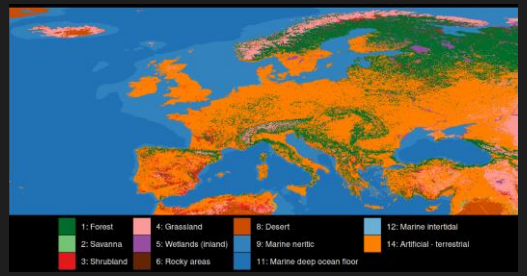
Mapping suitable habitat for species

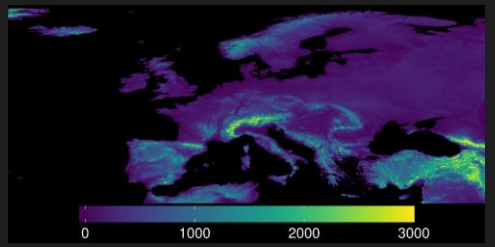
Species

- habitat types
- elevational limits
- threat impacts

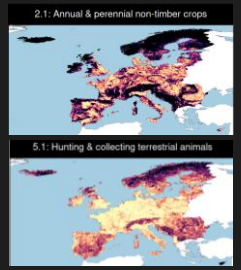
Current land cover



Elevation

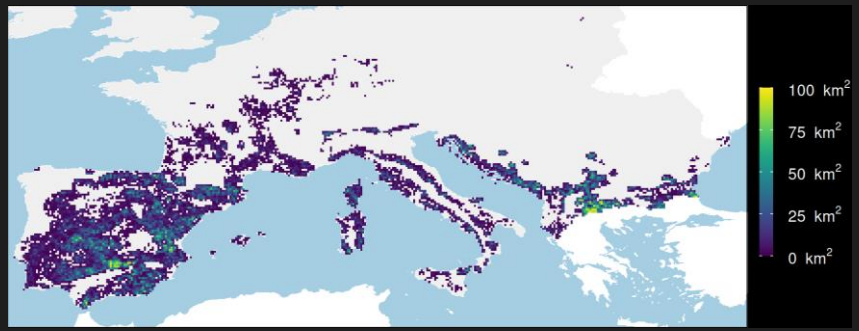


Threats



Woodchat Shrike

Area of threat-free habitat



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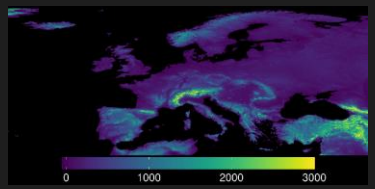
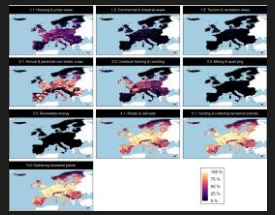
Mapping consequences of managing threats

Species

Elevation



Threats



Current land cover

Potential natural vegetation

Woodchat Shrike

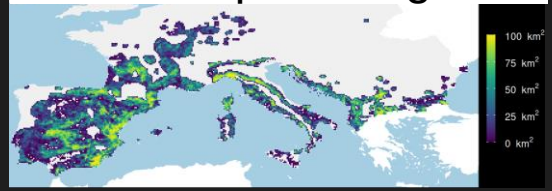
What if?

Existing habitat

Restore croplands

Stop hunting

Restore croplands & stop hunting



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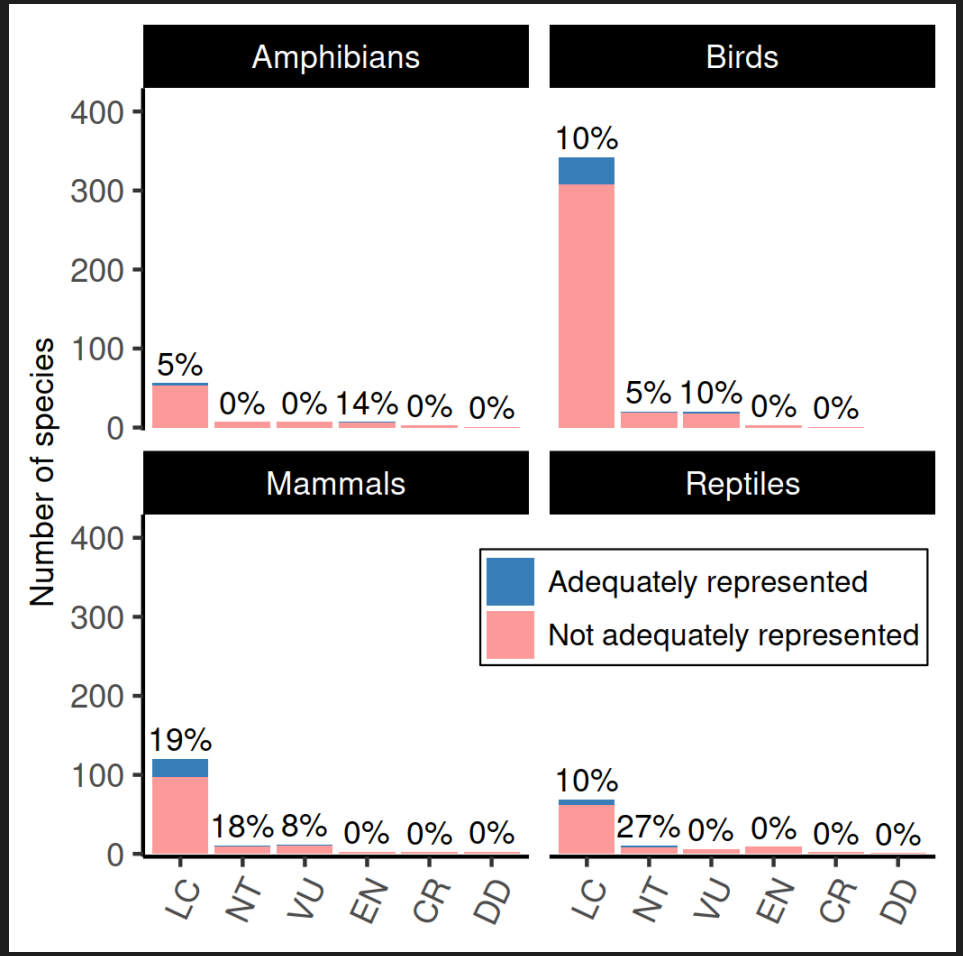
Existing protected areas

- 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



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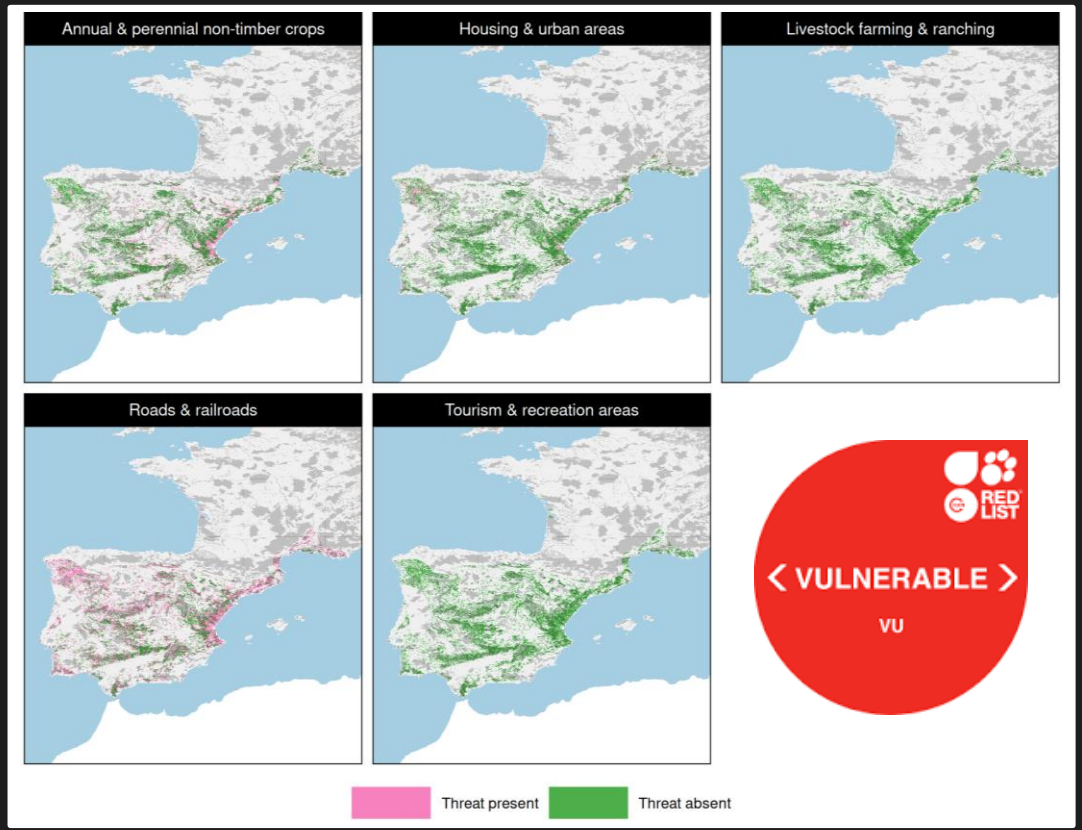
Pelobates cultripes

- 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



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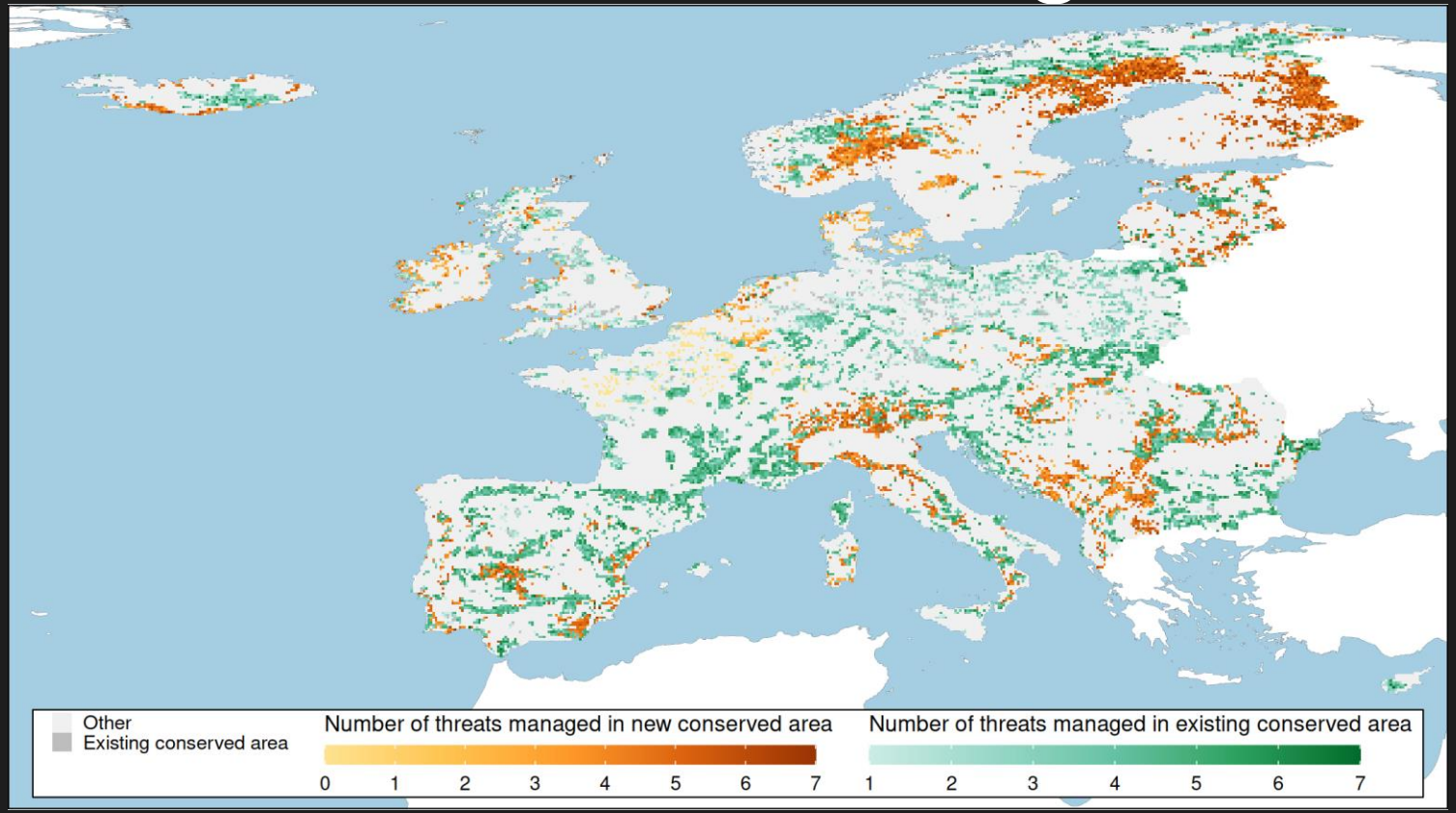
Prioritization to manage threats



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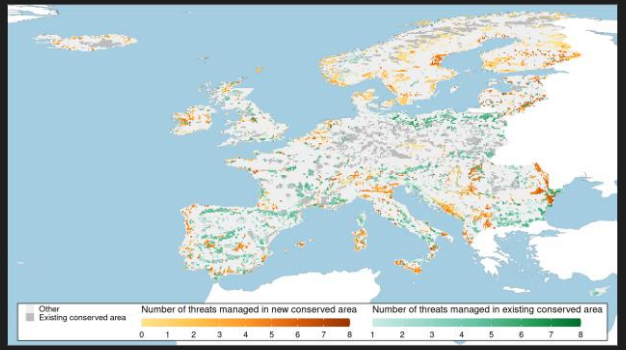
Prioritization to manage threats

- Total system ≤ 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



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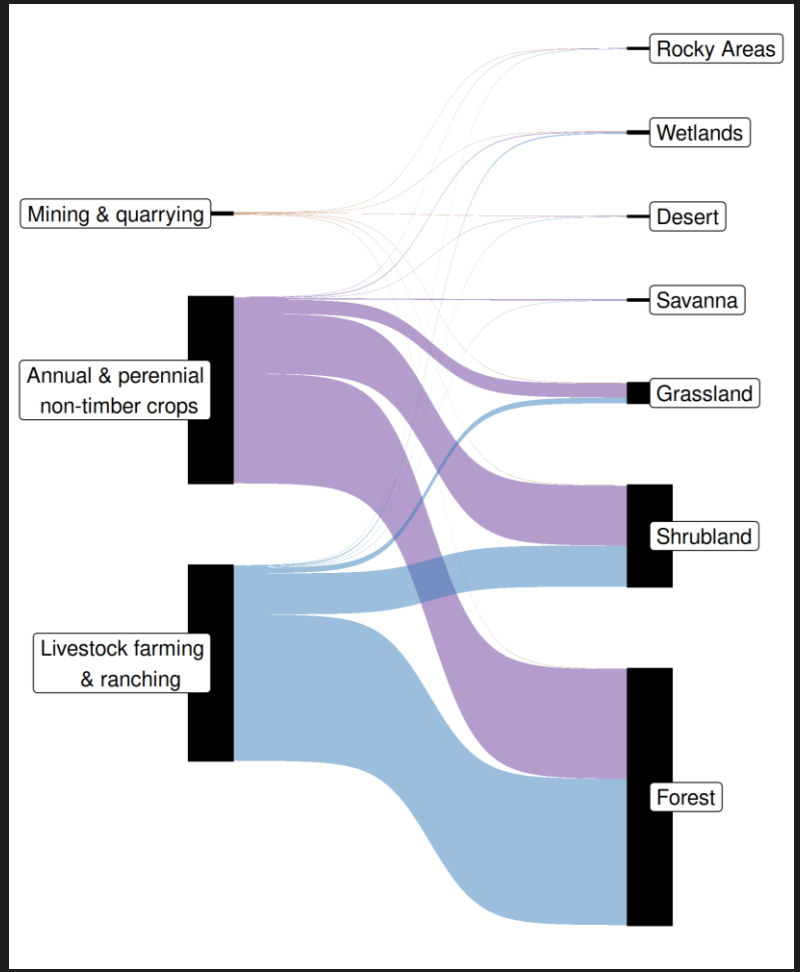
Habitat restoration

- 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%



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Make better conservation decisions by using…

1. Better algorithms
2. Cost-effective data

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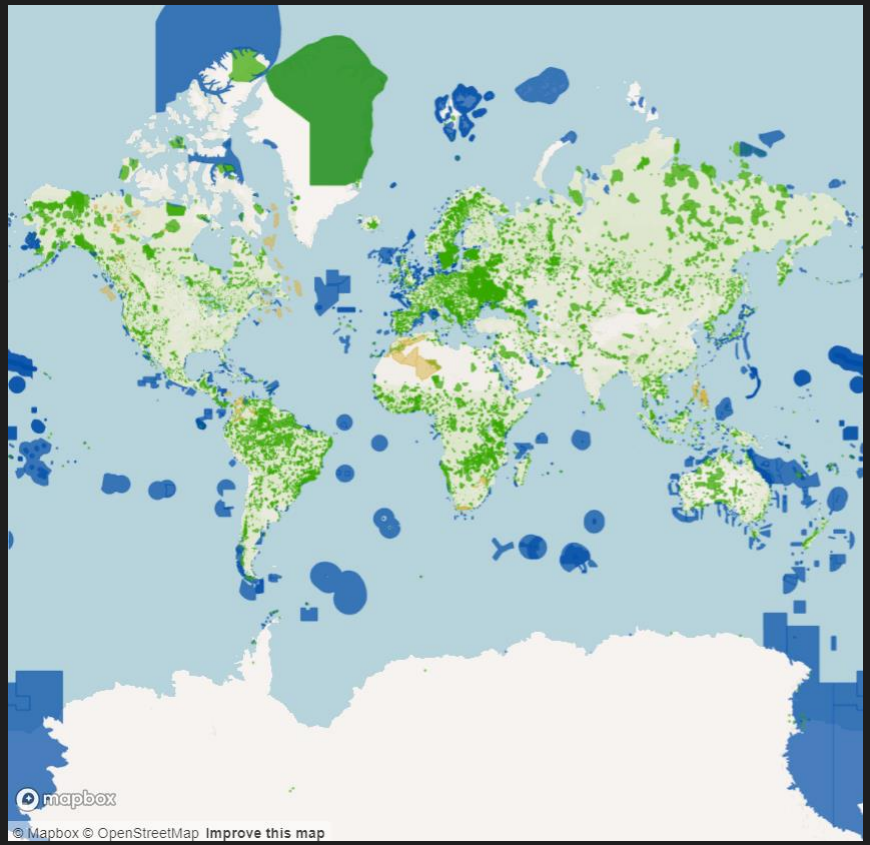
github.com/jeffreyhanson

jeffrey-hanson.com

World database on Protected Areas (WDPA)

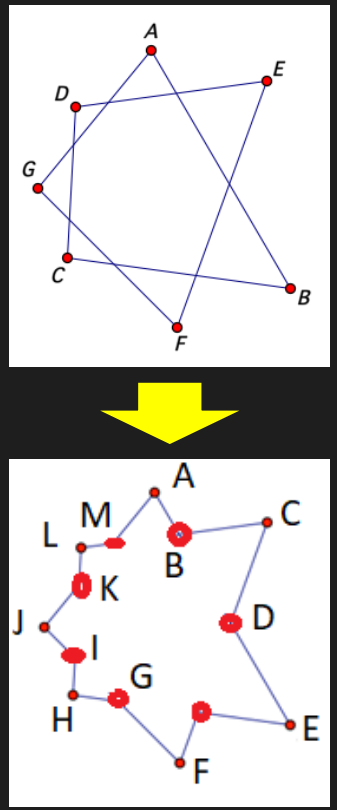


- 267 countries
- 268,721 terrestrial protected areas
- 18,638 marine protected areas
- IUCN management categories

But data needs cleaning…

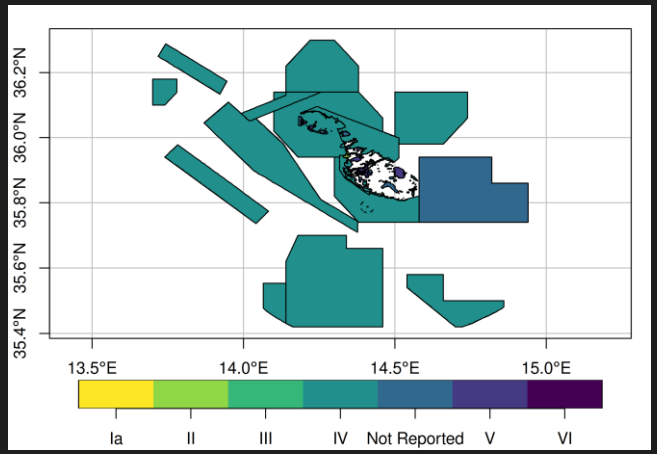
- Invalid geometries
- Protected areas that aren't implemented
- Protected areas represented only as points
- Protected areas that cross the dateline
- Protected areas that don't really do much
- Removing slivers
- Erase for overlapping areas

Self-intersections

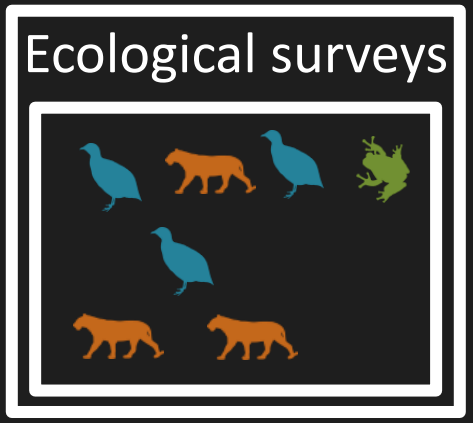


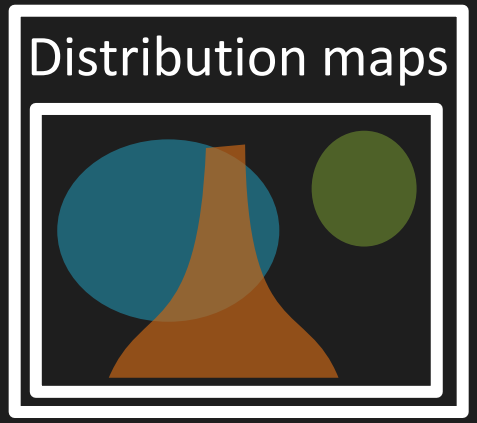
wdpar: Interface to the World Database on Protected Areas

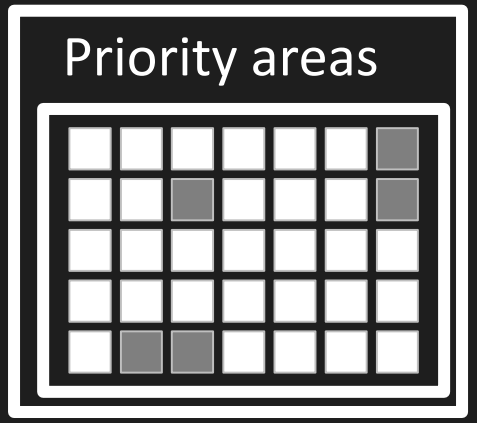
```
# (i) load package
library(wdpar)
#> Loading required package: sf
#> Linking to GEOS 3.10.2, GDAL 3.4.1, PROJ 8.2.1; sf_use_s2() is TRUE

# (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]
```

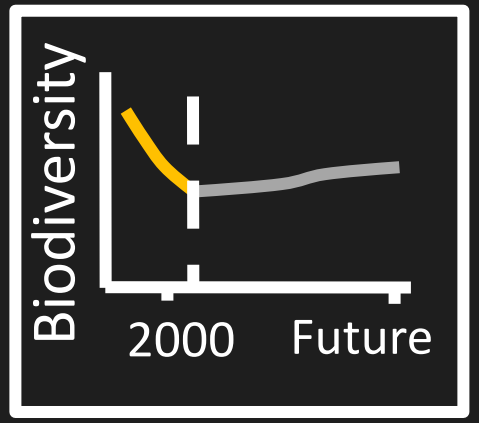


Is more data always better?



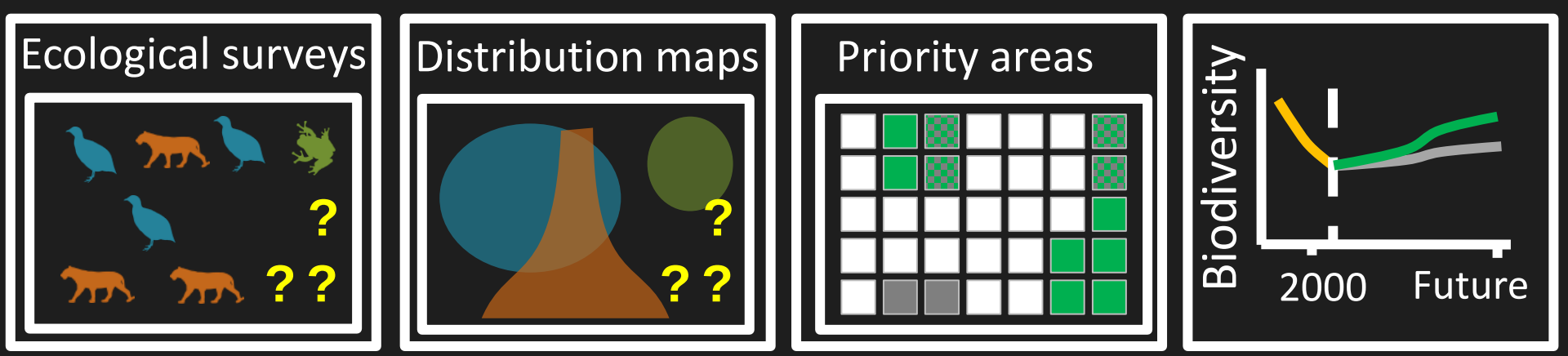






Data → Information → Plan → Outcome

Objectives Constraints



Data → Information → Plan → Outcome

More surveys

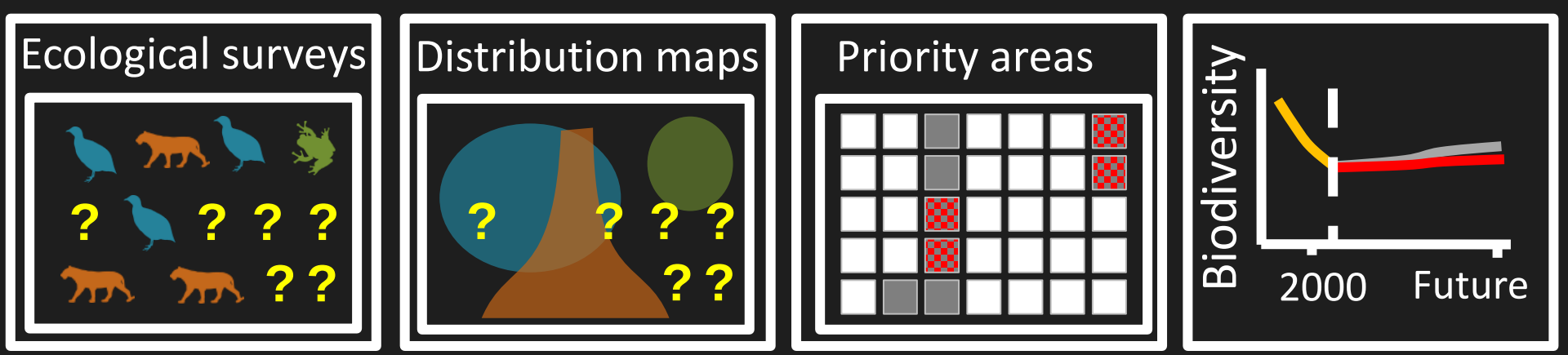
Better models

Better management

Better outcome

Objectives

Constraints



Data → Information → Plan → Outcome

More surveys

Better models

Poorer management

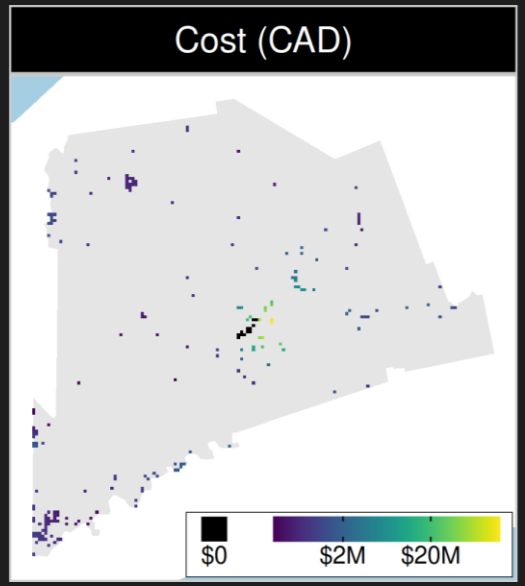
Worse outcome

Objectives

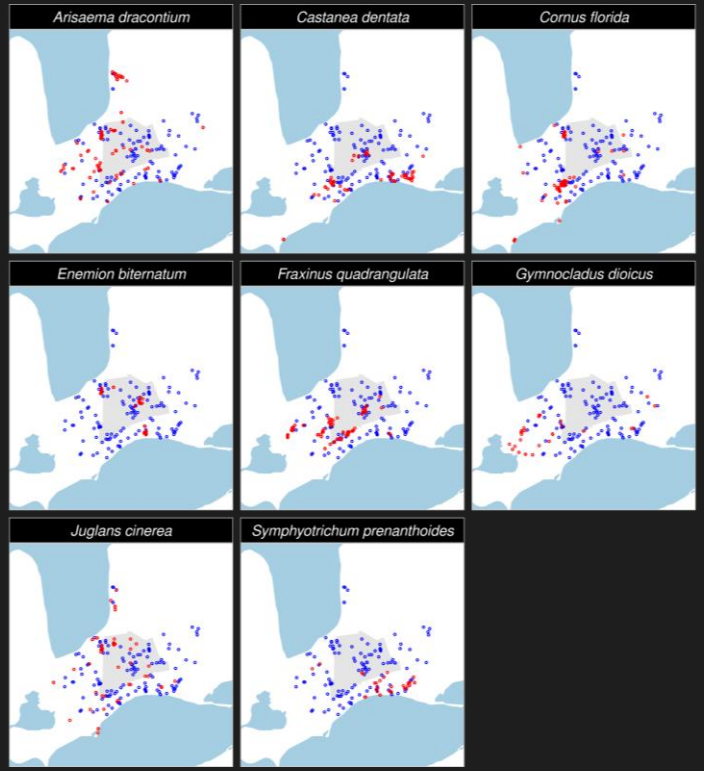
Constraints

Less funding

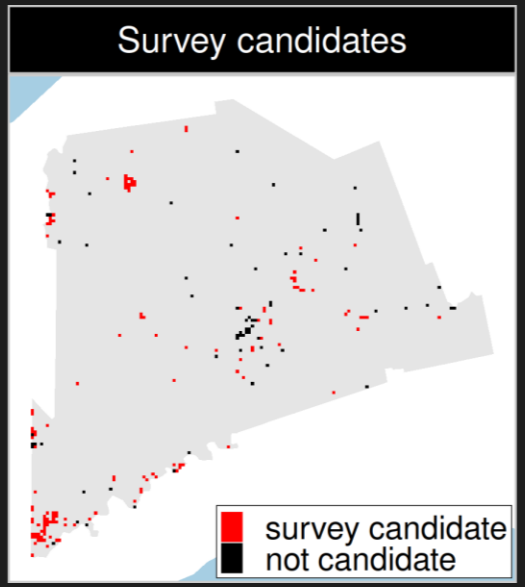
Study system: Middlesex county, Canada



199 places that could potentially be acquired for protected area establishment



8 imperiled plant species



143 places that could potentially be surveyed to improve existing data

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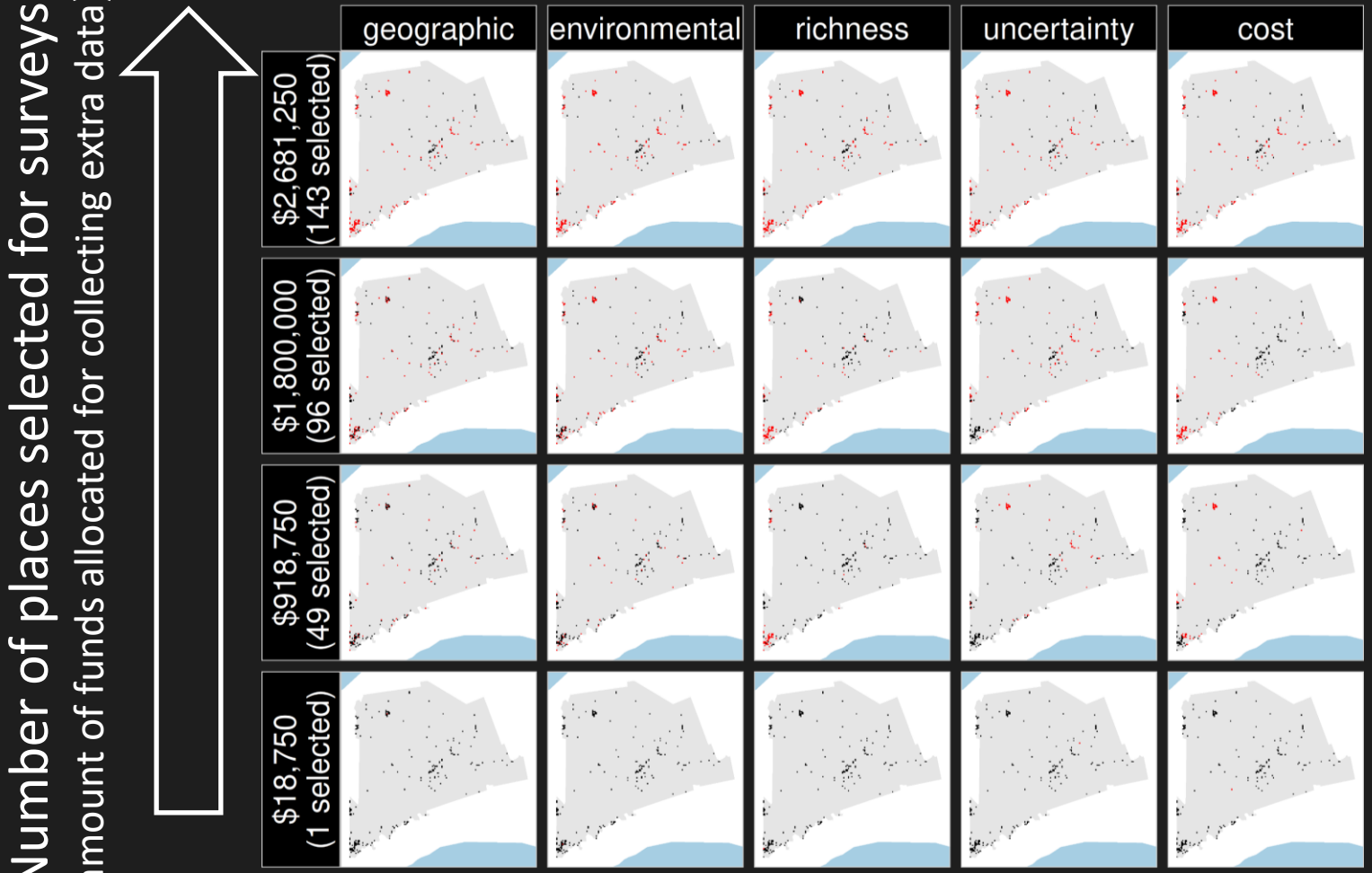

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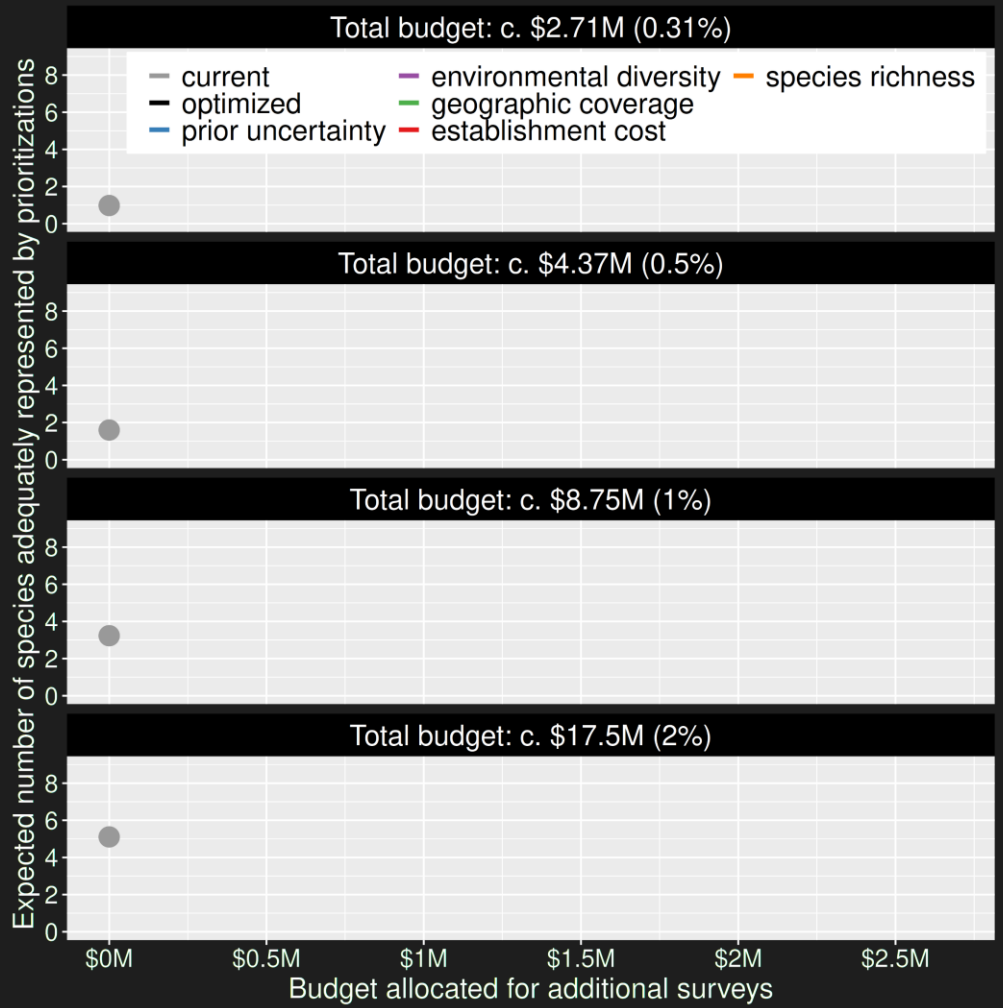
Value of information

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



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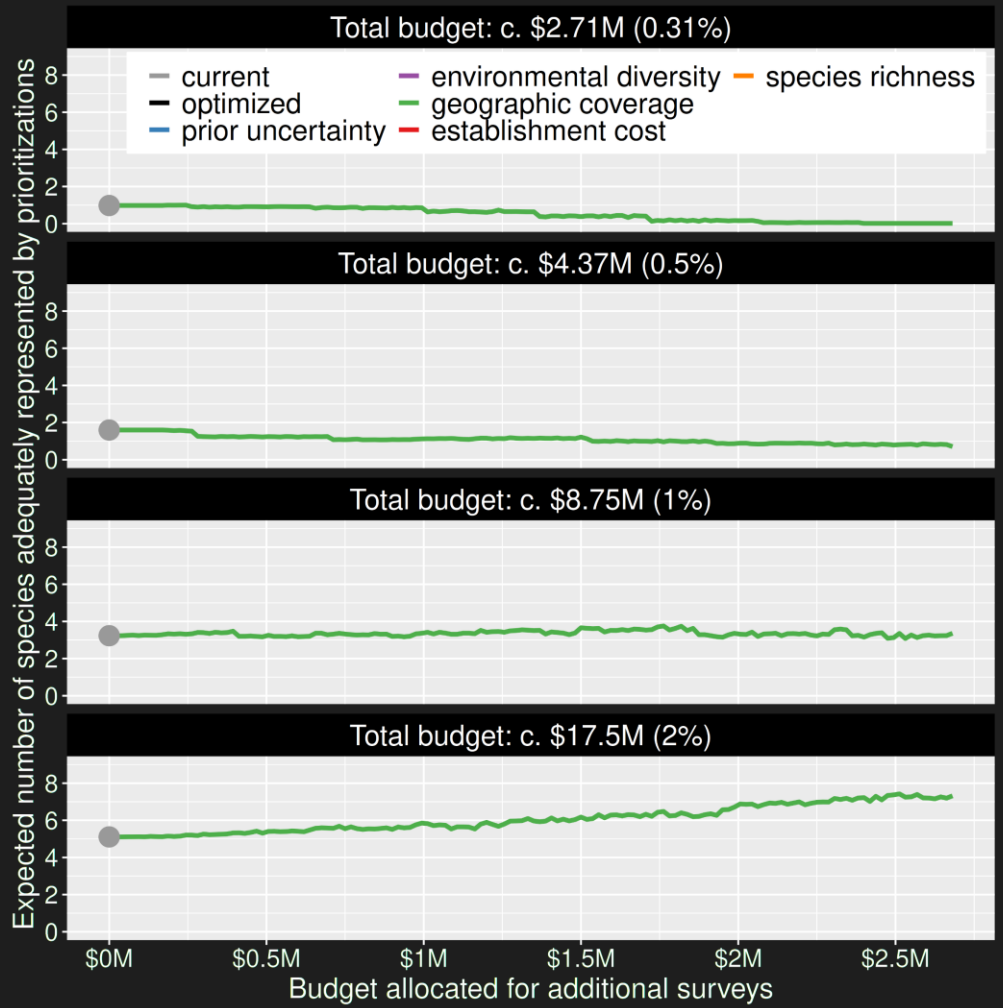
Value of information

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



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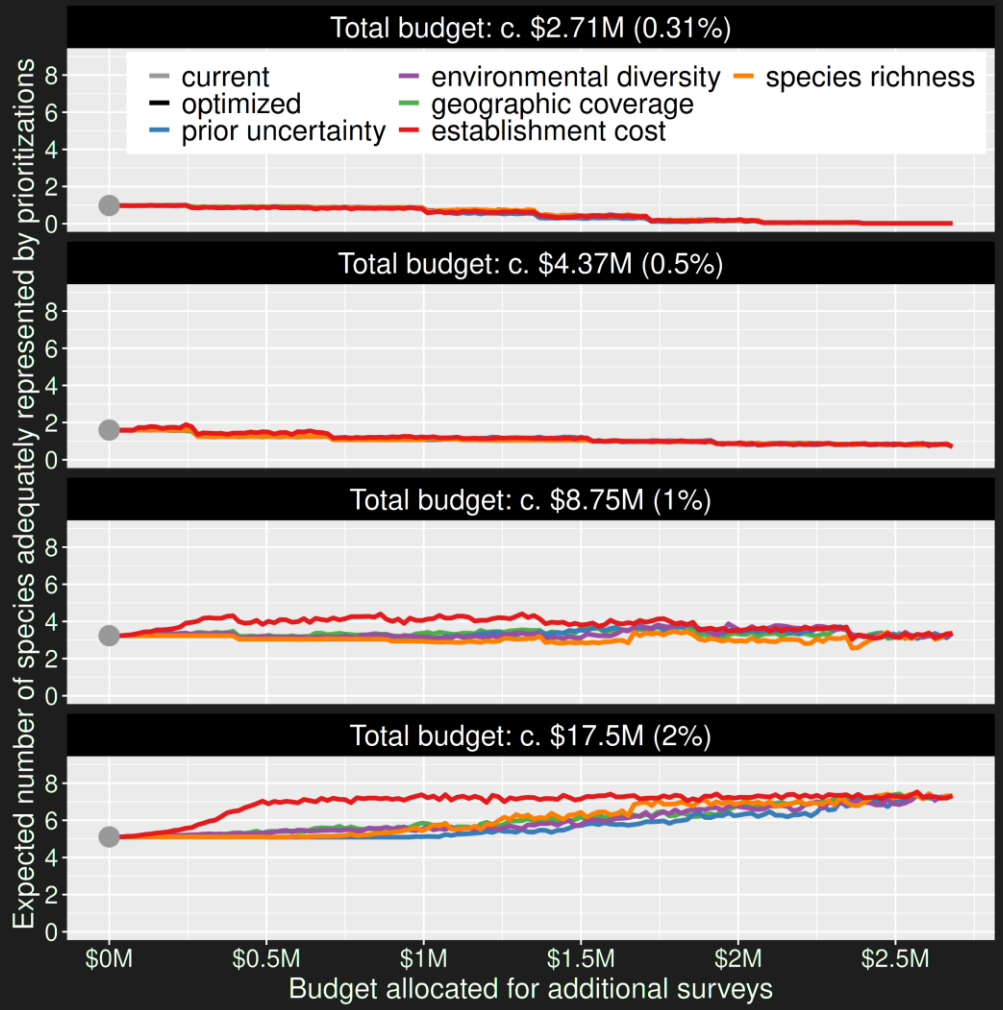
Value of information

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



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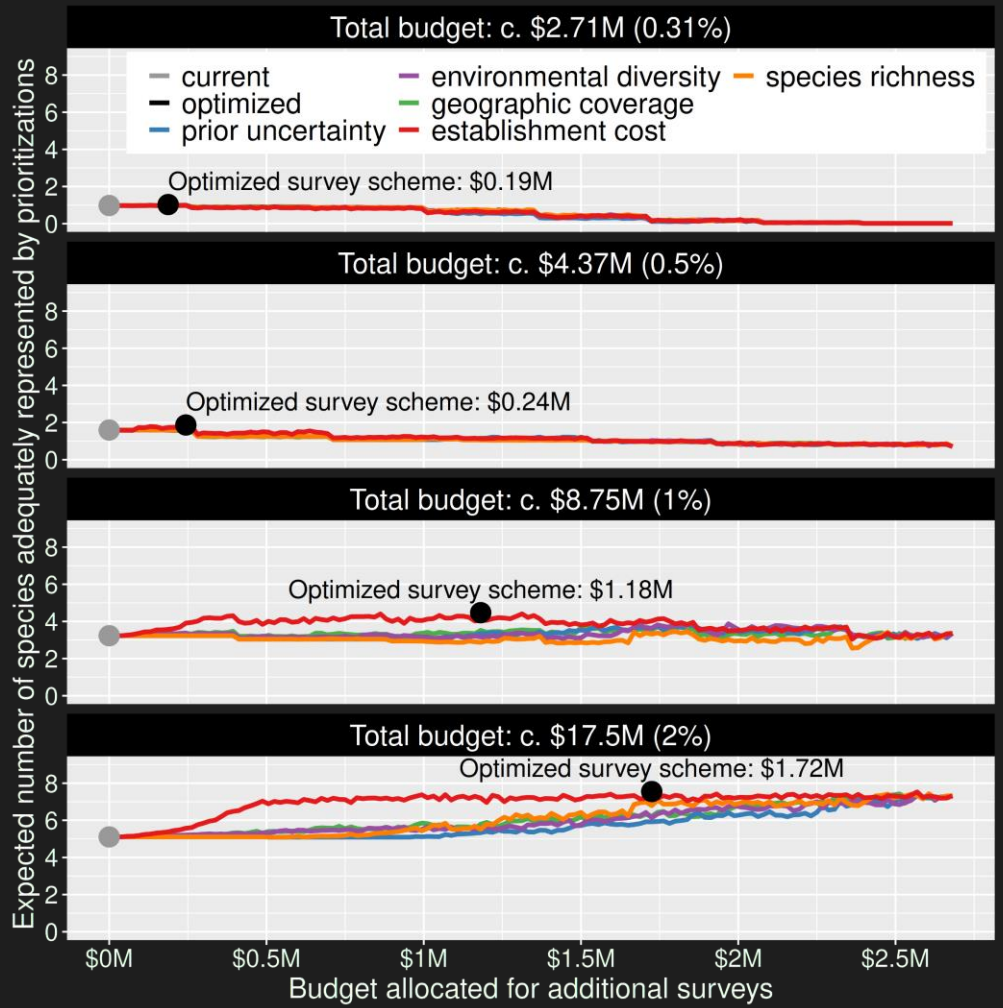
Value of information

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



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How can we get a better conservation decision?

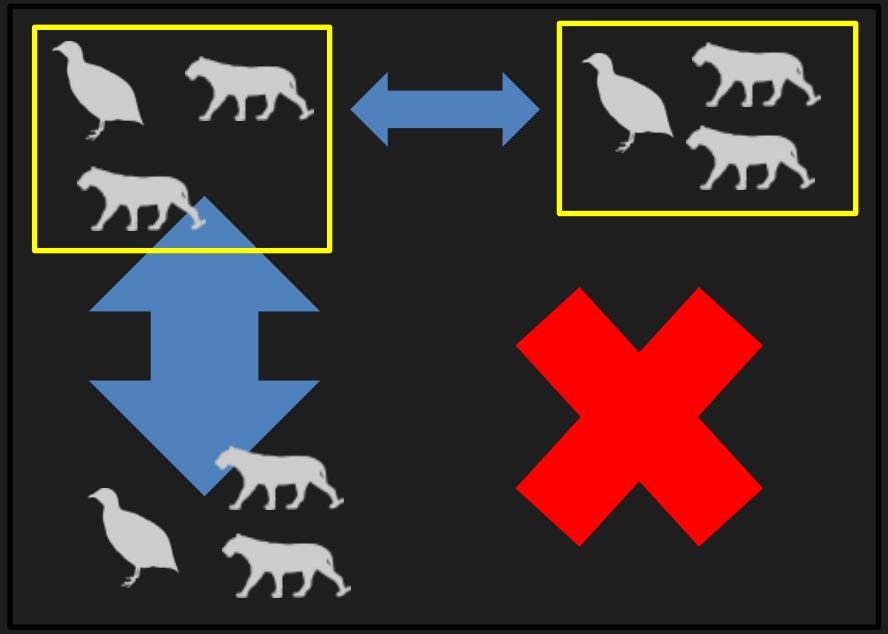
(1) Better algorithms

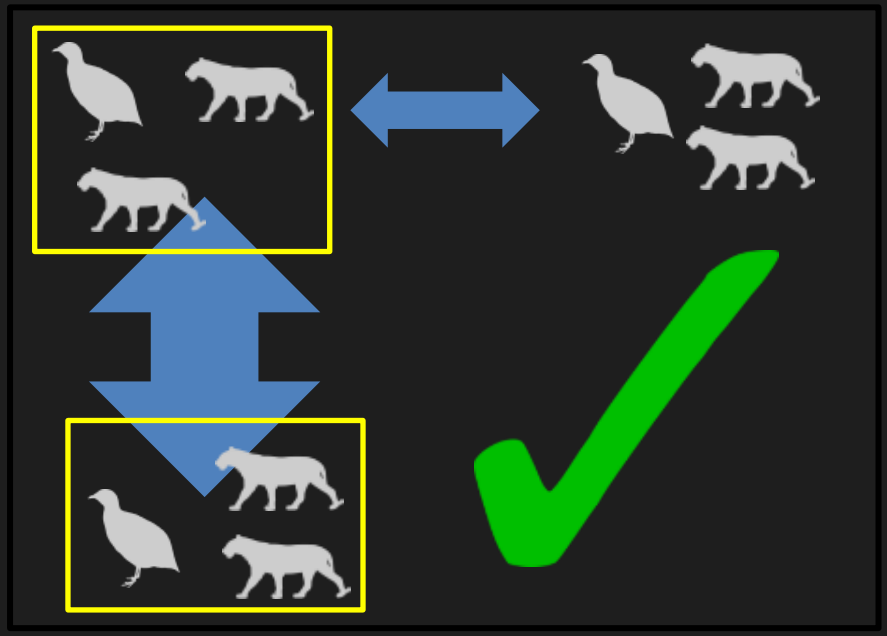
(2) Better data

(3) Better surrogates

Connectivity in reserve design

movement of individuals and genes between populations





*All else being equal

But getting connectivity data is hard

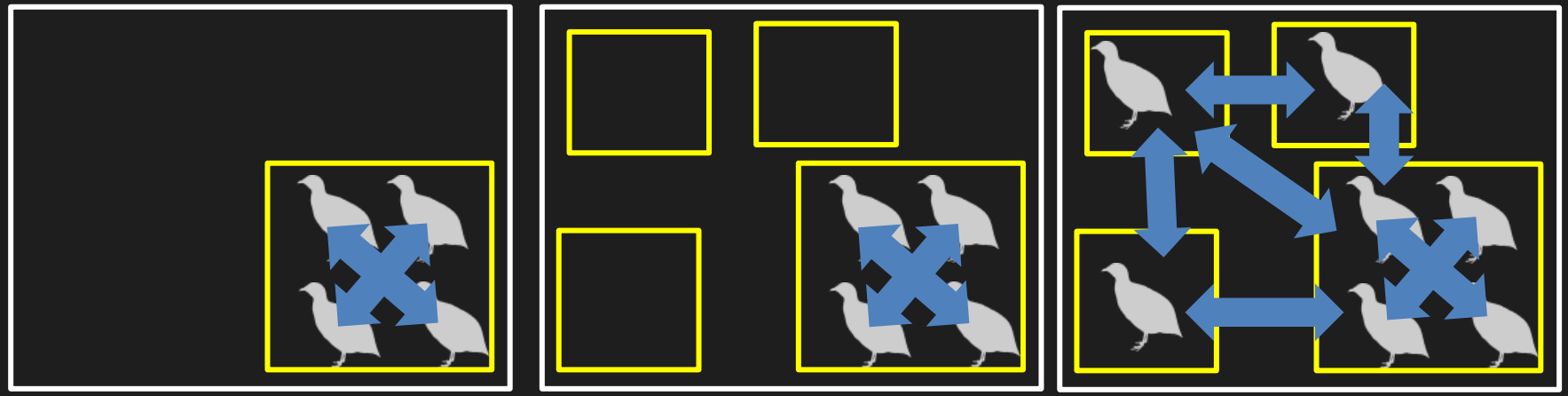
Animal telemetry

Molecular ecology

Rules of thumb for connectivity

More habitat = More connectivity

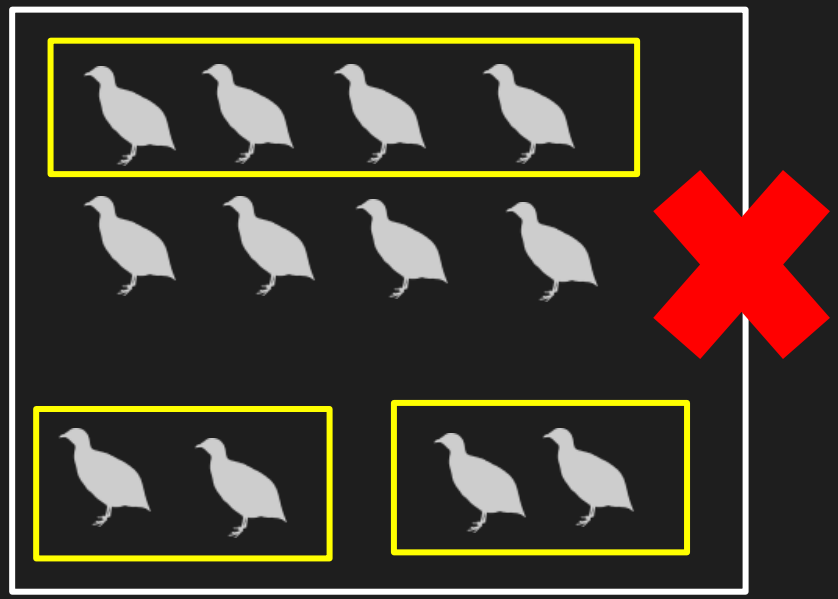
- Total area protected
- Species representation

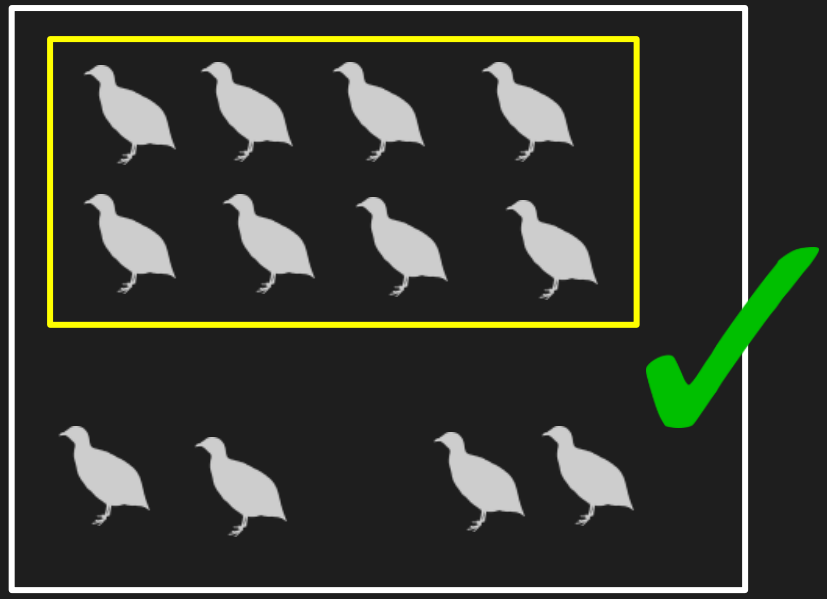


Rules of thumb for connectivity

More spatial clustering = More connectivity

- Boundary length

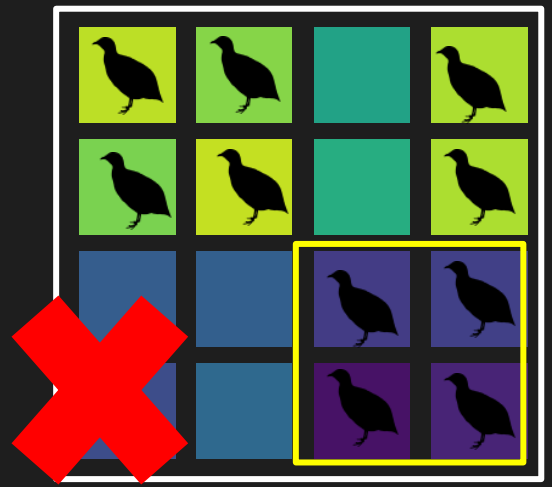


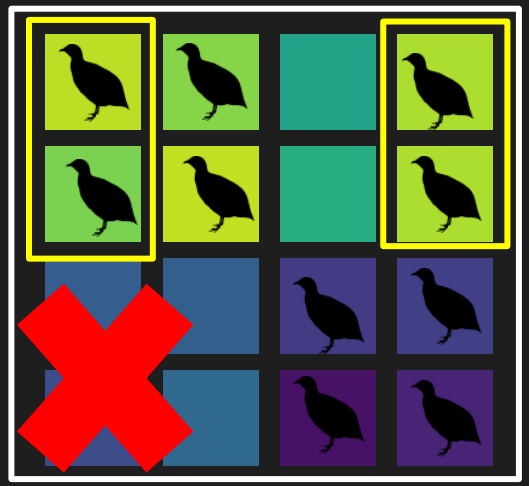


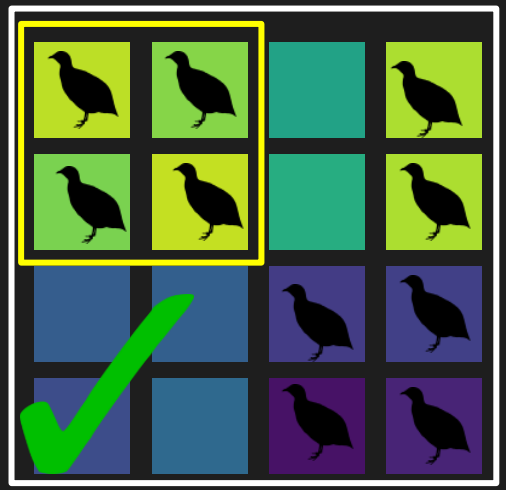
Rules of thumb for connectivity

Protect clusters of low resistance = More connectivity

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







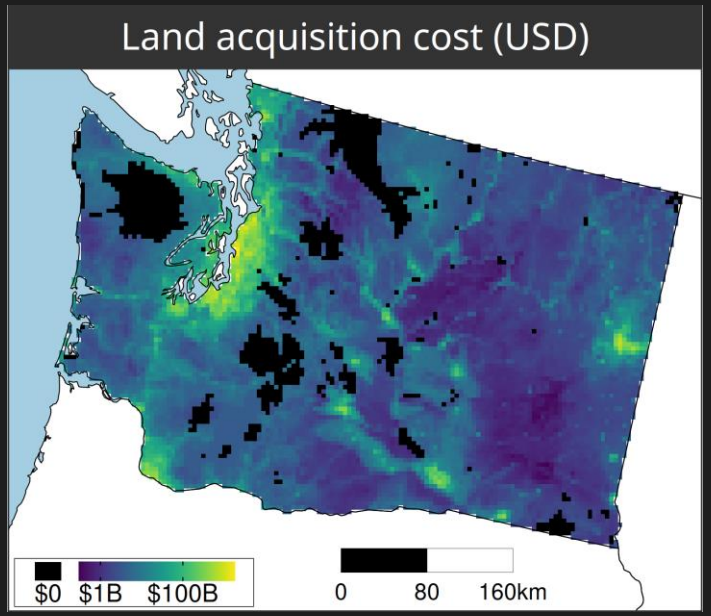
High resistance

Low resistance

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



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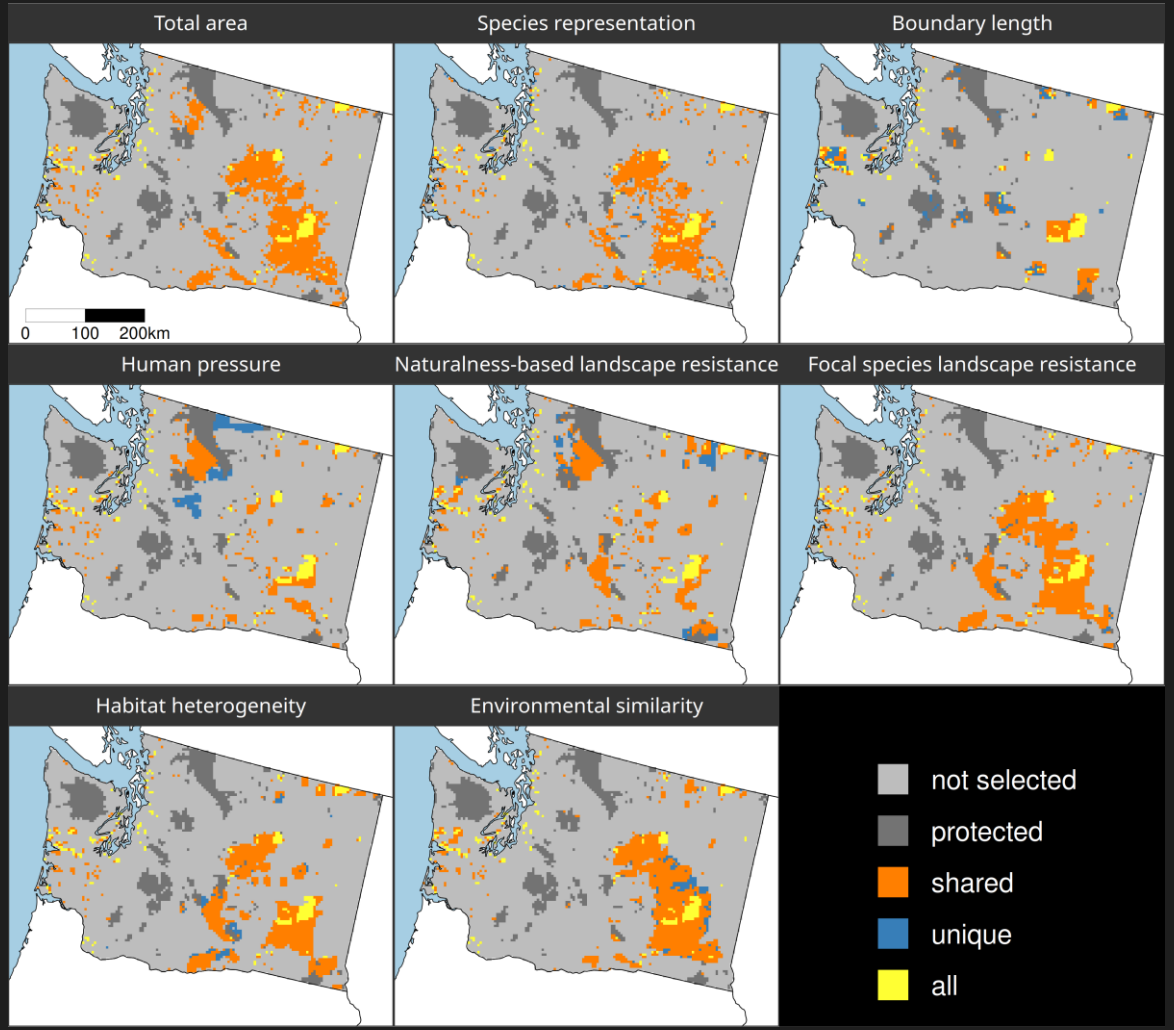
- Different connectivity approaches produce different prioritizations
- Different connectivity approaches can yield similar prioritizations



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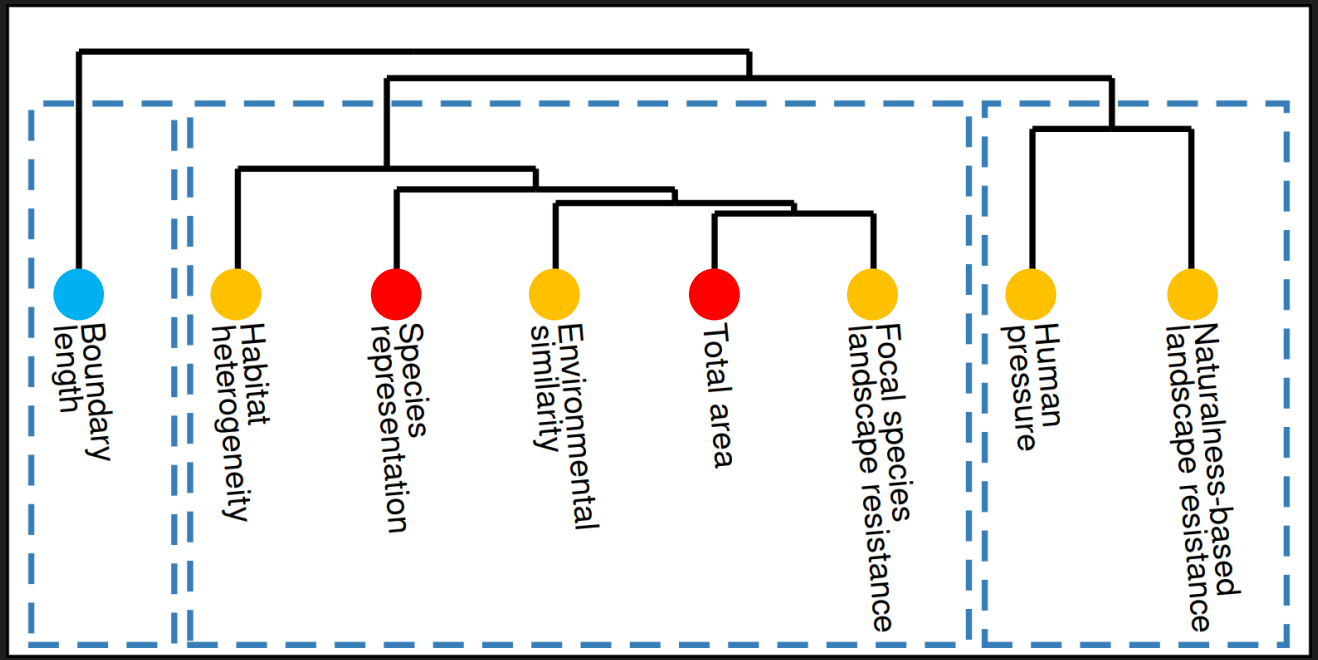
How do the prioritizations compare?



Approach

- Habitat-based
- Spatial clustering
- Resistance-based

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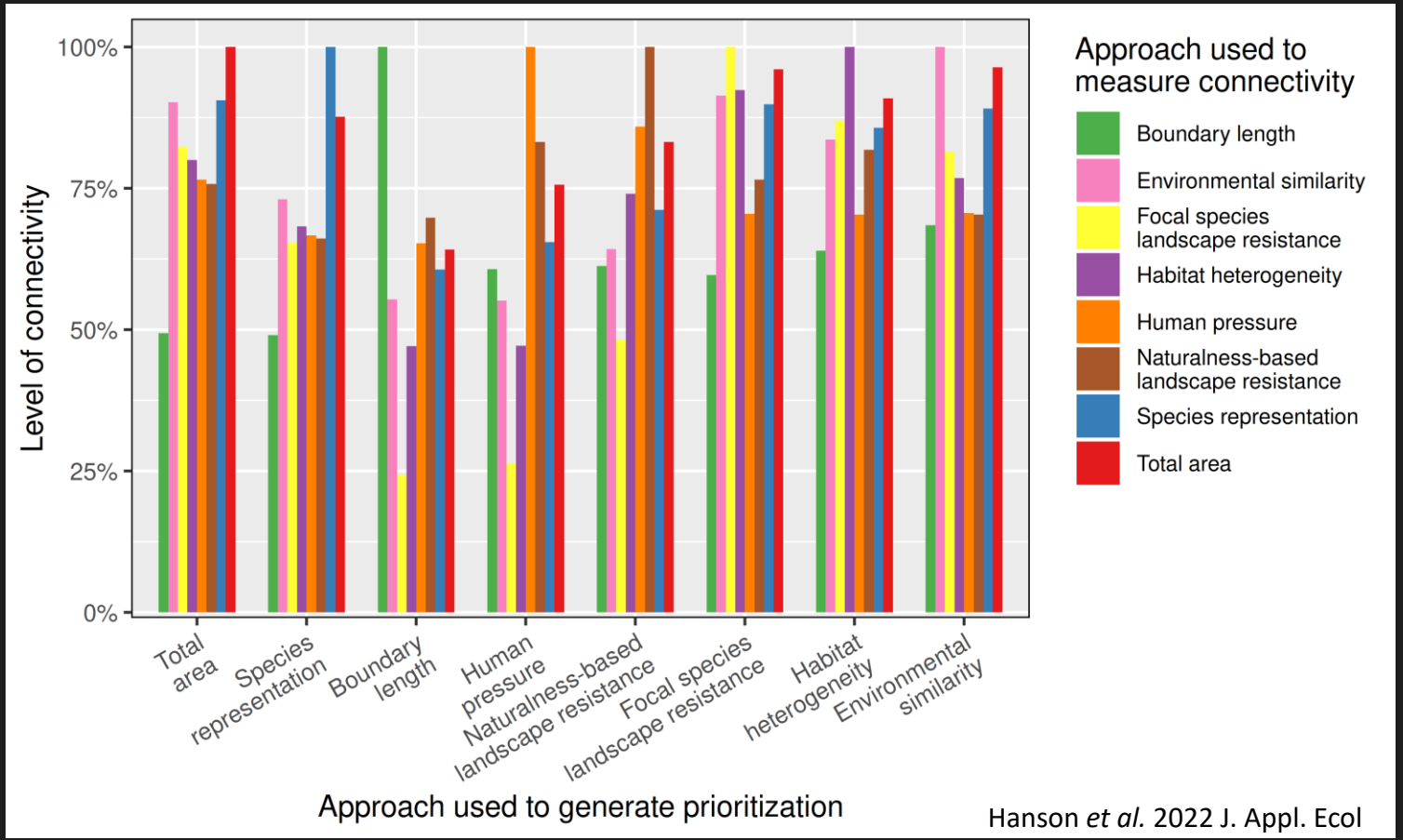
No obvious winner



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