Development of a MIP for the improvement on efficiency in management plans of threatened species through the use of sensitivity curves

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Outline

Section 1

Introduction

Why to study this?

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- Urgent need to secure the persistence of **species**, with specific **actions** to abate the **threats** that affect them
- Typically, a **binary** approach is used, where a specific action is taken and assumed to eliminate the threat [Auerbach et al., 2014]

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- The fundamental objective is:
  - Determine the most **efficient actions**, in each planning unit, to achieve ecological **targets** at the **minimum cost**
- In addition, some minimum **spatial conditions** are required, such as the connection of selected units and actions performed

Preliminary definitions - 1

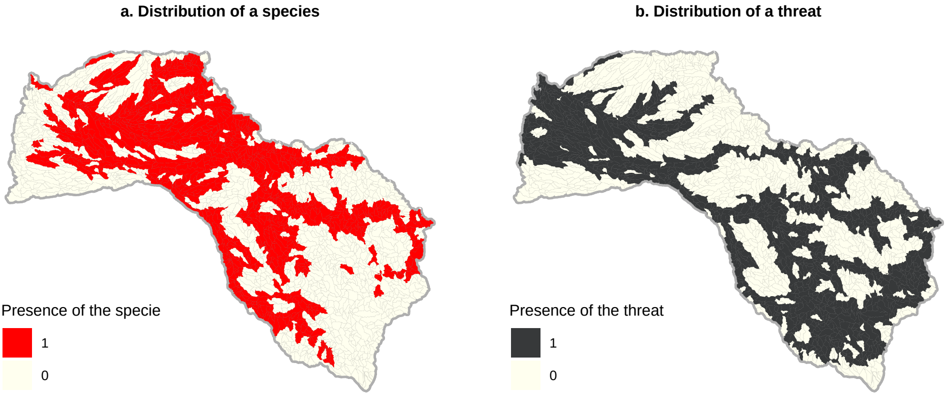

Figure: Graphical representation of the spatial distribution of a fish species (a) and of a major threat (b)

Preliminary definitions - 2

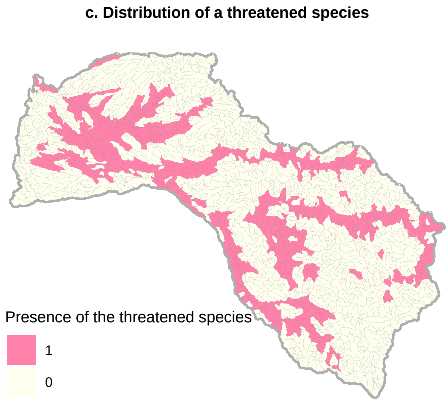

Figure: Graphical representation of the spatial distribution of a threatened fish species.

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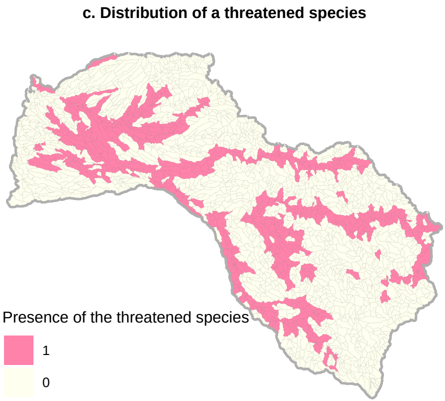

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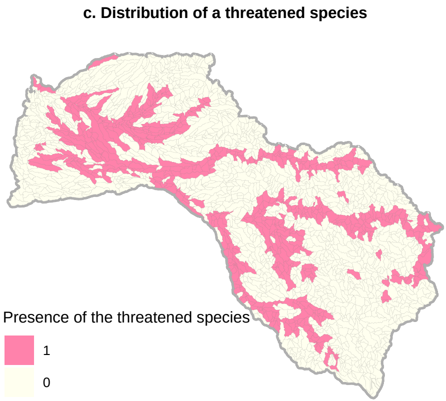

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- Each planning unit, could have a set of species and an other one of threats [Cattarino et al., 2015]

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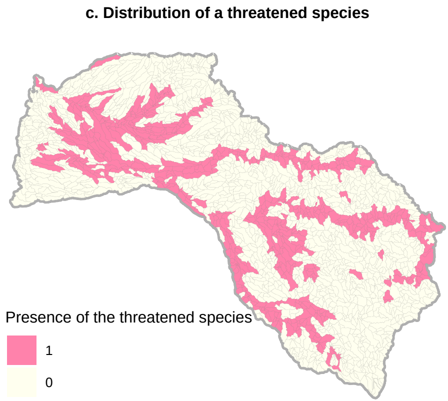

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- In a multi-action planning for threat management:
- Each planning unit, could have a set of species and an other one of threats [Cattarino et al., 2015]
- Where and what conservation actions should be done to minimize the cost of management?

Section 2

Methods

Case study: Mitchell River catchment, northern Australia

- Total area: **71,630 km^2**, divided into **2316 planning units** (hydrologically defined sub-catchment)

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- **45 freshwater fish species** in the study area
- **4 important threats** in the catchment are studied

Case study: Mitchell River catchment, northern Australia

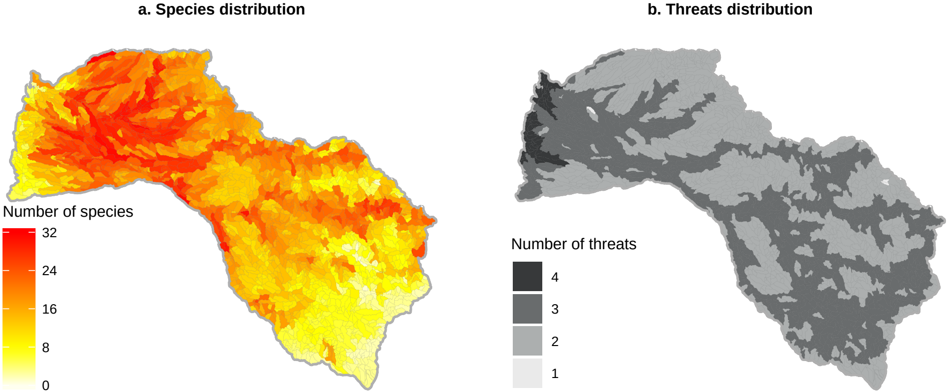


Figure: Graphical representation of the spatial distributions of the 45 species of fish (a) and of the four major threats (b) analyzed in the case study

Threats

- **4 major threats**:
  - Water buffalo (Bubalis bubalis)
  - Cane toad (Bufo marinus)
  - River flow alteration (caused by impoundments, channels for water extractions and levee banks)
  - Grazing land use

Actions

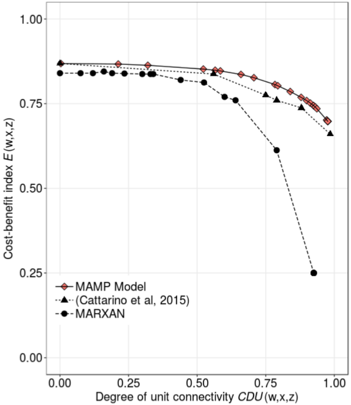
- **4 conservations actions for remediating each specific threat**:
  - Shooting for buffalo control
  - Chemical or biological treatment for cane toad control
  - Removal of dams or redesign of levee banks for flow-regime restoration
  - Pasture fencing and stewardship programs for grazing management

Monitoring and land adquisition

- **Before implementing each specific action:**
  - We need to buy the planning unit
  - We need to monitor if the threat is present in that unit.

What has been done so far

- Marxan [Watts et al., 2009] and Marxan with zones [Levin et al., 2013]
- An algorithm based on Simulated Annealing [Cattarino et al., 2015].
- A MIP approach for multi-action planning for threat management [Salgado & Alvarez-Miranda et al., 2018, submitted to Elsevier]



Adding another dimension

- Normally, a **binary** approach is used
  - Whether we implement an **action** or not
- **Continuous responses** by species against their corresponding threats
- Different forms of curves to represent species with higher or lower levels of **sensitivity** to their threats

Levels of effort for the actions

- It is beneficial to use levels of **effort**, and we use **4 degrees**
  - i Zero level effort
  - ii 33% effort (low)
  - iii 66% effort (intermediate)
  - iv 100% effort (high)
- A lower number of levels requires a **smaller amount of data**, and therefore the implementation of the model becomes **simpler** and more attractive.

Response curves

Two dimensions:

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- **Threat intensity**:
  i For the **binary** scenario, it is whether the threat is **present** or not
  ii For the **continuous** responses, it is the **degree** of the remaing threat

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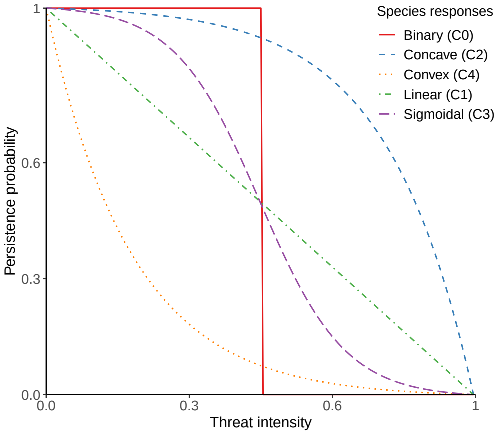

Figure: Graphical representation of the species persistence probability according to the threat intensity

Response curves - Transitivity

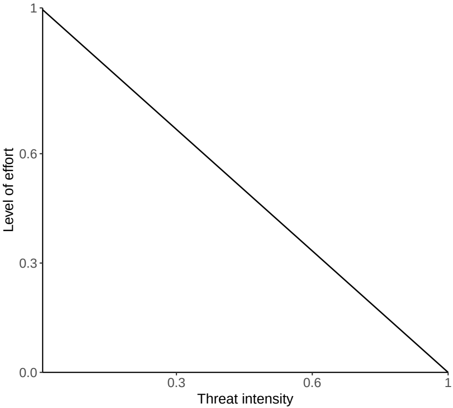

Figure: Graphical representation of the level of effort made according to the remaining threat intensity

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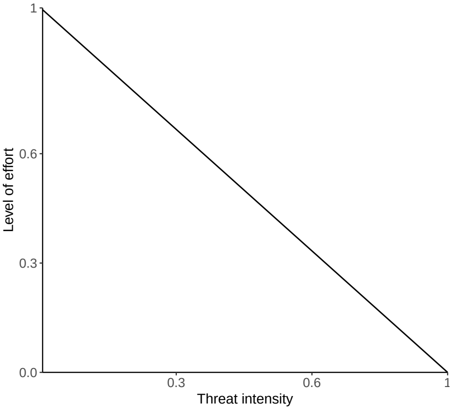

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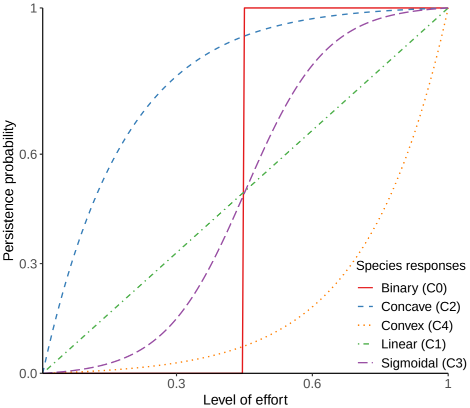

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Some parameters

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- **Penalty factor** for the selected **units fragmentation** (β_u) and for the **actions fragmentation** (β_a)

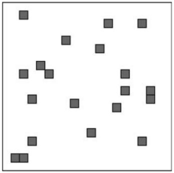

Figure: Fragmentated units

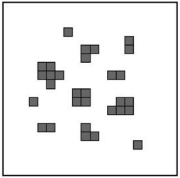

Figure: Connected units

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- For the **two costs** involved, we used that the greater the area to be monitored or treated, the greater the associated cost.
- **Actions costs** $c_{i,k}^{n}$:
  - i For a **null** effort level, a cost equal to **zero** is associated
  - ii For the **low** level, a 33% from the area α_i
  - iii For the **intermediate** level, a 66% of the area α_i
  - iv For the **high** level, the total surface area α_i
- To adjust to the real costs, the **monitoring cost** c_i was reduced to a value of 20% of the surface area α_i

MIP formulation of the effort management planning problem, oriented to multi-conservation actions

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- w_i: **binary** variable that indicates if the planning **unit i** is selected to be **monitored**, and to be part of the reserve

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Two **decision** variables are defined to solve the problem:

I w_i: **binary** variable that indicates if the planning **unit i** is selected to be **monitored**, and to be part of the reserve

II $x^n_{i,k}$: **binary** variable that determines whether or not an **action k** is performed, in planning **unit i** and in intensity **level n**

MIP formulation of the effort management planning problem, oriented to multi-conservation actions

$$\min \sum_{i\in I} w_i c_i + \sum_{i\in I}\sum_{k\in K_i}\sum_{n\in N} x^n_{i,k} c^n_{i,k} + \beta_u \sum_{i\in I} \sum_{\substack{j\in I:\\ \exists d_{i,j}>0}} w_i(1-w_j)\frac{1}{d^2_{i,j}} \qquad (1)$$

$$\text{s.t.} \sum_{n\in N} x^n_{i,k} = w_i, \qquad \forall k \in K_i, \forall i \in I \qquad (2)$$

$$\sum_{n\in N} x^n_{i,k} = 0, \qquad \forall k \notin K_i, \forall i \in I \qquad (3)$$

$$\sum_{\substack{i\in I_s:\\ |K_i|>0}} B_{i,s}\alpha_i + \sum_{\substack{i\in I_s:\\ |K_i|=0}} F_{i,s}\alpha_i \geq T_s, \qquad \forall s \in S \qquad (4)$$

$$w_i, x^n_{i,k} \in \{0,1\}, \qquad \forall i \in I, \forall k \in K, \forall n \in N \qquad (5)$$

$$F_{i,s} \in [0,1], \qquad \forall i \in I_s, \forall s \in S \qquad (6)$$

Extended model

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$$\beta_a \sum_{i \in I} \sum_{\substack{j \in I: \\ \exists d_{i,j} > 0}} \sum_{k \in K_i \cap K_j} \sum_{n \in N \setminus \{0\}} x_{i,k}^{n} (1 - \sum_{m \in N \setminus \{0\}} x_{j,k}^{m}) \frac{1}{d_{i,j}^2}$$

Description of the experiment

Name of the parameters	Assigned values
Contribution target to the ecological benefit (T_s)	{110, 220, 440, 880, 1760, 3520, 7040, 14080, 24160} km^2
Unit fragmentation penalty factor (β_u)	{15}
Action fragmentation penalty factor (β_a)	{0, 3, 7, 11, 15, 19, 23}

Table: Summary of the parameters used to solve the experiments for the case study of the Mitchell River catchment

Composition of the functions used for the responses

Curve type	Associated function $r^n_{k,s}(x)$
Binary	0 if $x < 1$, 1 if $x = 1$
Concave	$\frac{1-e^{ax}}{1-e^{a}}$
Convex	$\frac{e^{ax}-1}{e^{a}-1}$
Linear	x
Sigmoidal	$\frac{(1+e^{-b(x-0.5)})^{-1}-(1+e^{0.5b})^{-1}}{(1+e^{-0.5b)})^{-1}-(1+e^{0.5b})^{-1}}$

Nota 1: x is used instead of $\sum_{n\in N} x^n_{i,k} e_n$.

Nota 2: Parameters a and b are constant.

Table: Summary of the functions used to represent the response curves, which relate the level of effort chosen to a probability of persistence associated with each species

Definition of indicators

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  - i "Cost-benefit ratio": ratio of total protected area and real cost of the management plan. ($\frac{km^2}{\$}$)
  - ii "Actions connectivity degree": division between the average fragmentation of each action k and the theoretical maximum fragmentation for each action k.

Section 3

Results

Resolution time

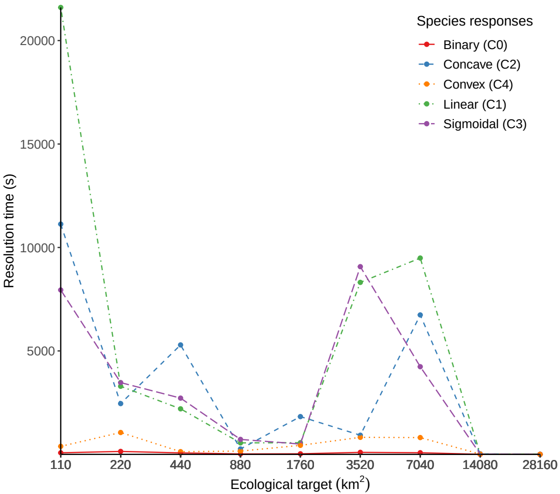


Figure: Graphical representation of the resolution times obtained by solving the instances related to the five response curves

GAP

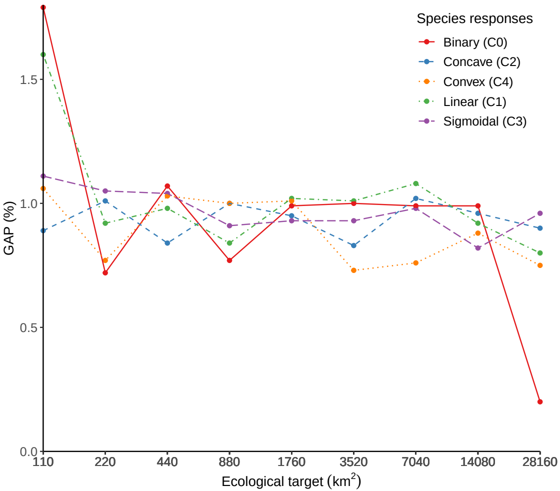


Figure: Graphical representation of the GAPs obtained by solving the instances related to the five response curves

Benefit-Cost Ratio ($\frac{km^2}{\$}$)

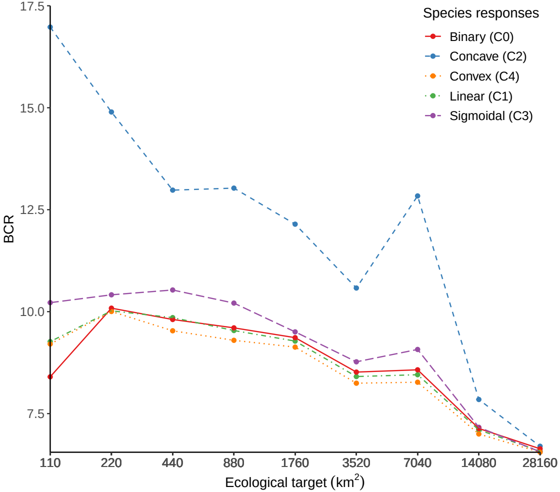


Figure: Graphical representation of the BCR obtained by solving the instances related to the five response curves

Differences through the illustration of maps - 1

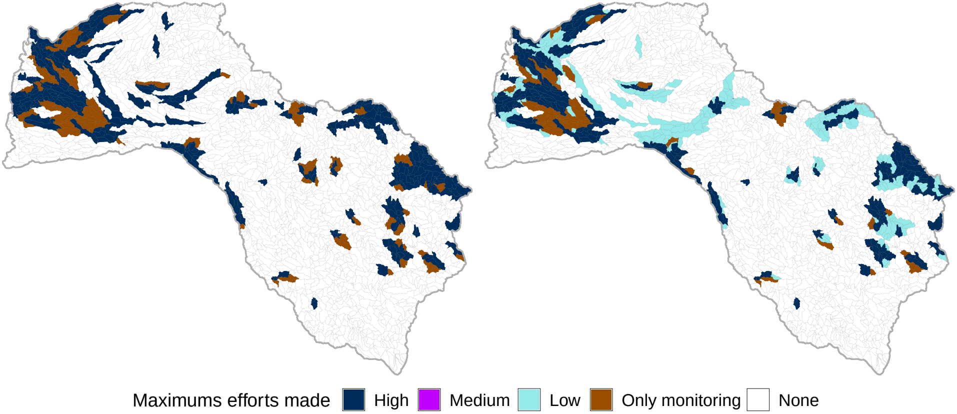


Figure: Graphical representation of the maximum efforts spatial distribution, for an objective of 3520 km^2, using a degree of global connectivity equal to 15, a degree of connectivity of actions equal to 11 and evaluated for the **binary** and **concave** responses

Differences through the illustration of maps - 2

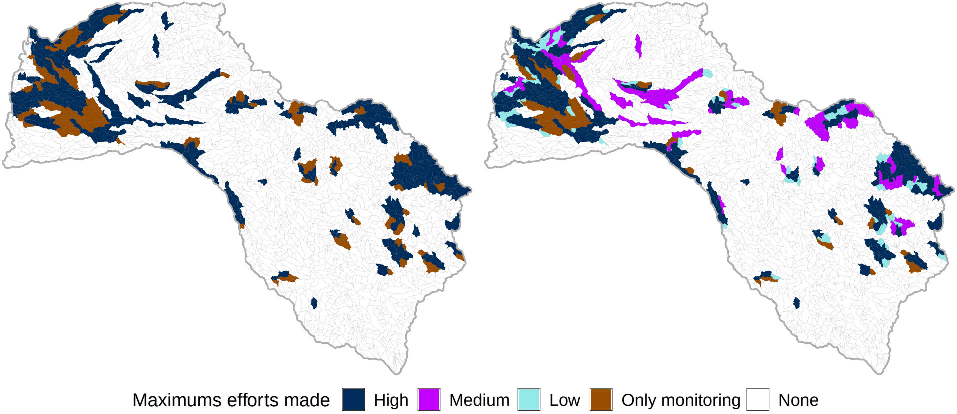


Figure: Graphical representation of the maximum efforts spatial distribution, for an objective of 3520 km^2, using a degree of global connectivity equal to 15, a degree of connectivity of actions equal to 11 and evaluated for the **binary** and **sigmoidal** responses

Second experiment

- To analyze the behavior of the costs associated with each response curve when the degree of penalty is increased (Actions fragmentation)
- Seven values for the degrees of penalty between 0 and 23
- Ecological target of the species equal to 3520 km^2

Resolution time

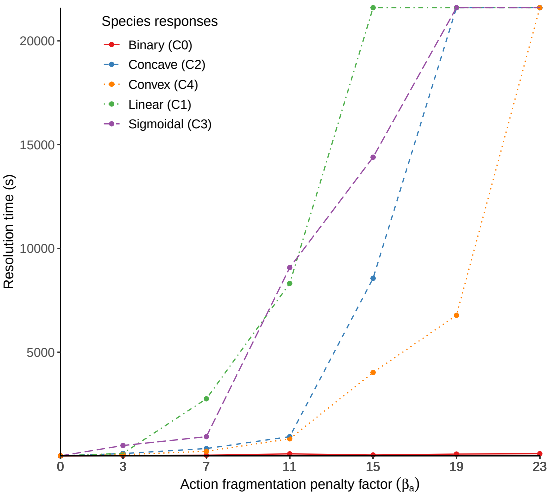


Figure: Graphical representation of the resolution times obtained when solving the instances for the actions fragmentation penalty factor β_a

Resolution time and GAP

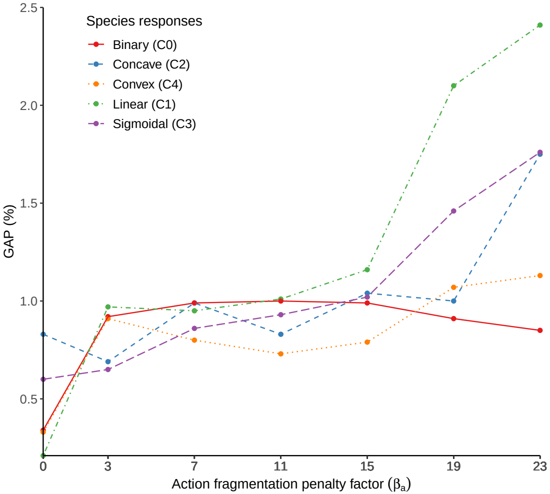


Figure: Graphical representation of the GAPs obtained when solving the instances for the actions fragmentation penalty factor β_a

Benefit-Cost Ratio

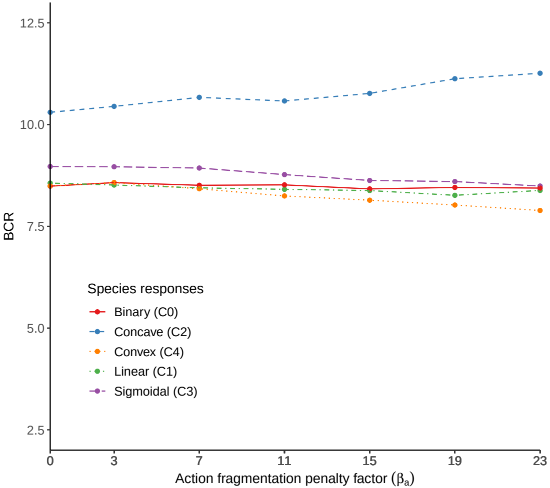


Figure: Graphical representation of the BCR obtained when solving the instances for the actions fragmentation penalty factor β_a

Actions connectivity degree

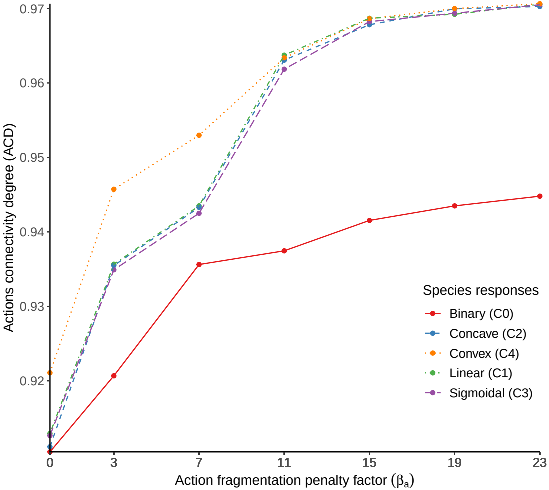


Figure: Graphical representation of the ACD obtained when solving the instances for the actions fragmentation penalty factor β_a

Connectivitty differences through the illustration of maps - 1

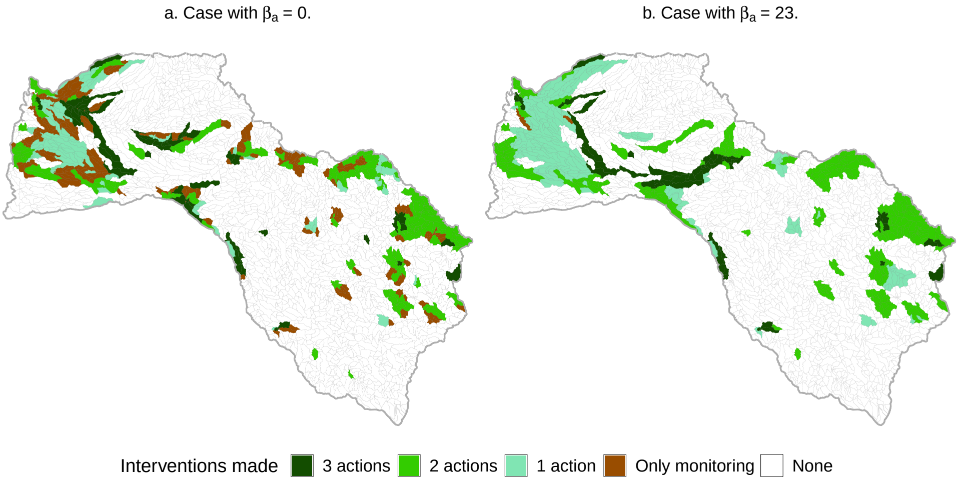
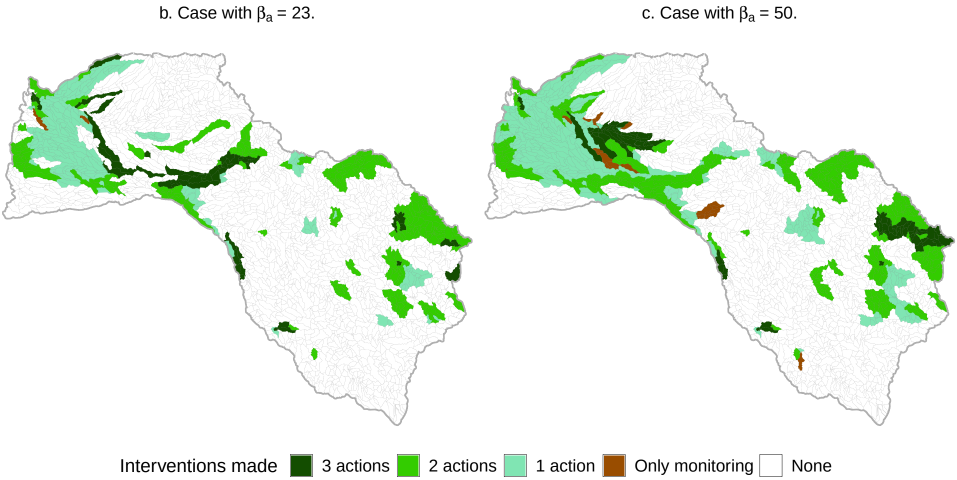


Figure: Graphical representation of the interventions spatial distribution, for an objective of 3520 km^2 and a degree of global connectivity of 15

Connectivitty differences through the illustration of maps - 2



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Section 4

Conclusions

Scope and limitations of the study

- **Mixed integer optimization** model, which finds sites and **levels** of efficient **efforts** of conservation actions, considering **multiple threats** and relying on the different **response curves** of the species

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- **Mixed integer optimization** model, which finds sites and **levels** of efficient **efforts** of conservation actions, considering **multiple threats** and relying on the different **response curves** of the species
- MIP gives **flexibility** to eventually modify the objective function, incorporate new restrictions and perform sensitivity analysis to measure the impacts of each parameter on the indicators of the management plan
- Due to the type of problem faced, each of these improvements requires the **incorporation** of a large number of **variables** and **equations** that lead to **exponentially** resolution times

Analysis of how response curves affect efficiency

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Analysis of how response curves affect efficiency

- Gains in **efficiency** (RCB) depending on the **shape** of the response curve. Sigmoidal and concave response curves can achieve targets using **lower effort** levels
- When considering a convex curve, the model loses a bit of efficiency by virtue of **connecting** more the conservation **actions** exercised
- The binary case generate **high values** of penalty for actions **fragmentation**, and the value of the objective function is greater than for the convex case

Principal conclusions

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- When demanding a **higher connectivity** level for the **actions**, efficiency levels remained almost the **same** and **continuous** responses achieved more **connected** solutions than the **binary**
- We can **efficiently** identify the optimum **effort** to be allocated to **multiple interventions**, and **where** to perform them, to combat the existing **threats**

Future work

- It would be of great interest to study the **impact** of adding **uncertainty** to the responses curves
- This work can be extended by considering a new dimension of **time**, making a dinamic approach
- Finally, a future research could be oriented to analize the variation of the species **density** within each planning unit as the remaining threats are not erradicated

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