# A MIP Approach for Multi-Action Planning for Threat Management


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## Communicating risks in decisión support systems
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## Solsona, Spain

# Outline

- **Introduction and Motivation**
  - Conservation Planning Relevance
  - Conservation Planning Tools
  - Existing MIP approaches
- **A MIP Approach for Multi-Action Planning for Threat Management**
  - Multi-Action Planning for Threat Management
  - MIP Model Definition
  - A MIP-based extension
- **Case Study: Mitchell River Catchment**
  - General information
  - Species and threats distribution
- **Computational Results**
  - Cost efficiency and degree of connectivity
  - Comparison with Marxan and Cattarino et al. 2015' results
  - Results of the extended model
- **Conclusions**

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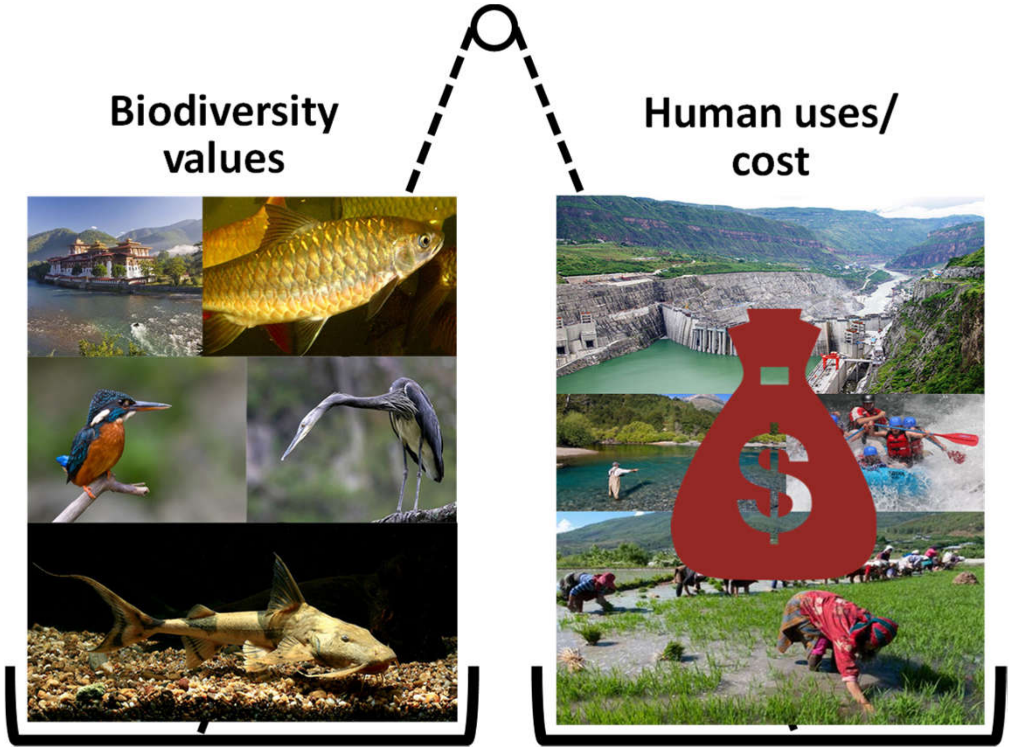
# Introduction: Conservation Planning Relevance

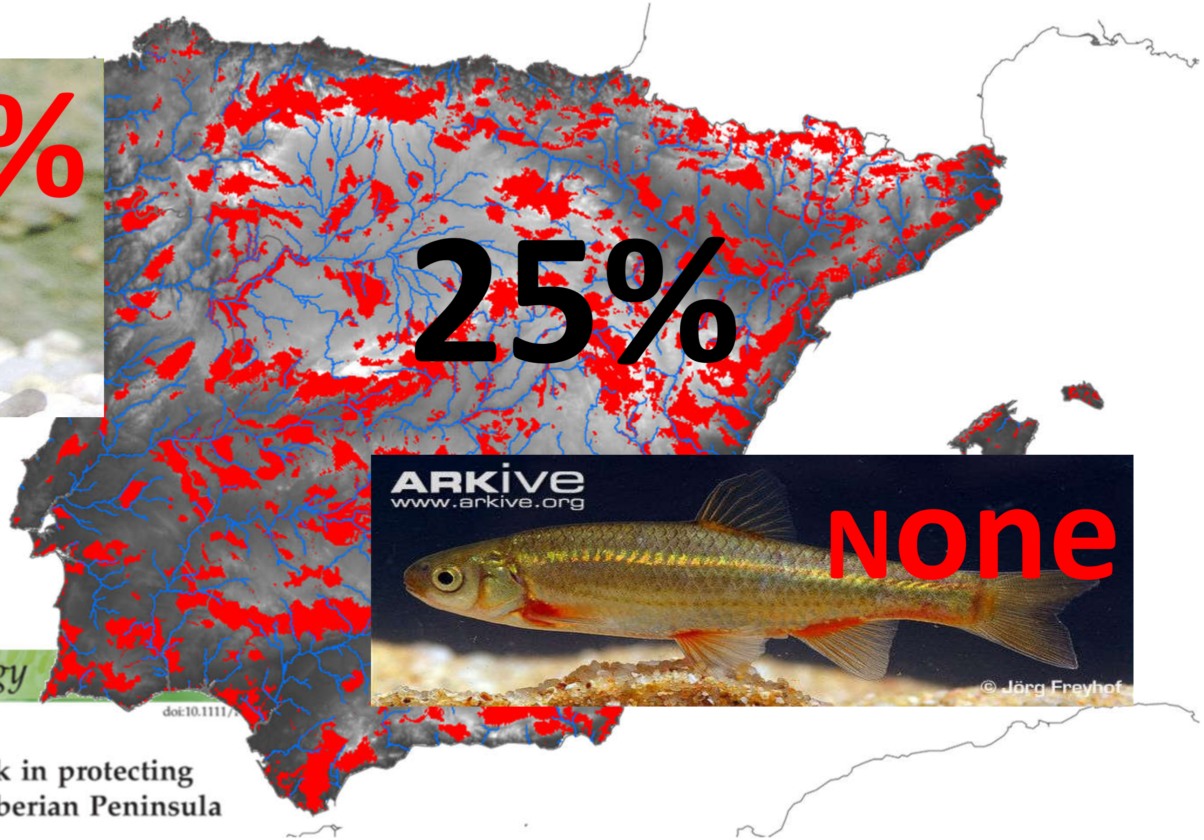
The main planning challenge is represented by:




**Challenge** We need to be capable of reaching a envirotmentally sustainable balance between economic development and biodiversity conservation.

# Introduction: Conservation Planning Relevance

But efforts must be properly planned:


Freshwater Biology

Freshwater Biology (2014) doi:10.1111/

**Effectiveness of a large reserve network in protecting freshwater biodiversity: a test for the Iberian Peninsula**

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# Introduction: Conservation Planning Tools

There are several modeling and algorithmic alternatives; see, e.g., the book of Millspaugh & Thompson 2008, and the review paper Billionnet 2013, EJOR.

In Beyer et al. 2016 (who developed a MIP model solving the same problema as in MARXAN it was shown that MIP-approach was capable of out-performing MAXAR; in terms of getting better solutions and much faster.

MARXAN is a (Simulated Annealing) heuristic-based solver that seeks for a subset of units that optimize the function:

Minimizing costs while achieving certaint conservation targets. units

In addition, MARXAN is also not efficient as it assumes that once one unit is selected then we act in all the threats for all species. .... Perhaps we may prefer not to act in all species and all theats of each unit (so basically marxan does not consider threats separately).

CFPF (Conservation Feature Penalty): penalty given for not adequately representing a conservation feature

Penalty: additional value associated with each underrepresented conservation feature

- Ecologically effective
- Reasonable quality/good trade-off

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# Introduction: Existing MIP Approaches

There are classical mixed integer programming approaches such as **Set Covering Problem** (Garey & Johnson, 1979), **Maximum Covering Problem** (Church & Revelle, 1974)

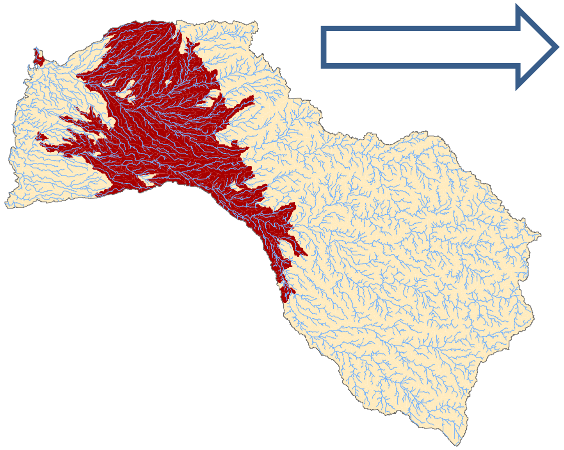
Current state-of-the-art MIP-based approaches allow to model spatial requirements; see, e.g., Williams et al. 2015, Billionet 2013, Beyer et al. 2016.

In Beyer et al. 2016 it is shown that a MIP-approach was capable of **outperforming** MARXAN: better solutions and much faster.

While MARXAN solves only one type of problem, a MIP-based approach is capable of incorporating additional side constraints.

# Multi-Action Planning for Threat Management: Preliminaries

The problem we are aiming to solve can be characterized as follows:



**In each unit:** There is a set of species
There is a set of threads

Besides, we must consider:

- Penalty associated to units fragmentation ($\beta_1$)
- Distances among units ($cv_{ii'}$)
- Cost for *buying* each unit ($cf_i$)
- Cost for treating each threat in each unit ($c_{ik}$)

For formulating the problem:

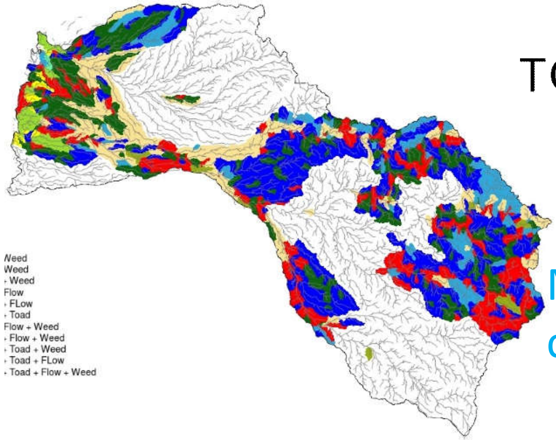
$I$ is the set of all units → $J_i \subseteq J$ the set of species in unit $i$; $K_i \subseteq K$ the set of threats in unit $i$

$J$ is the set of all species → $K_j \subseteq K$ the set of threats menacing species $j$

$K$ is the set of all threats

## **Multi-Action Planning for Threat Management:** Heuristic approach

In Cattarino et al. 2015, the authors seek for a set $S$ of units along with a set of actions against threats so that the function:




$$\text{TC} = \mathbf{c}(S) + \mathbf{p}(S) + \mathbf{f}(S)$$ must be **minimized**

- $\mathbf{c}(S)$: Monitoring cost
- $\mathbf{p}(S)$: penalty for insufficient conservation
- $\mathbf{f}(S)$: penalty for units fragmentation

... so that a conservation target $t_j$ is (almost) fulfilled for each species $j$

In Cattarino et al. 2015 the authors implemented an ad-hoc Simulated Annealing algorithm for solving the problem.

The authors also compared their approach with the solutions obtained using Marxan on a properly modified set of instances.

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# Multi-Action Planning for Threat Management: A MIP Model

The decisión variables to cosinder are:

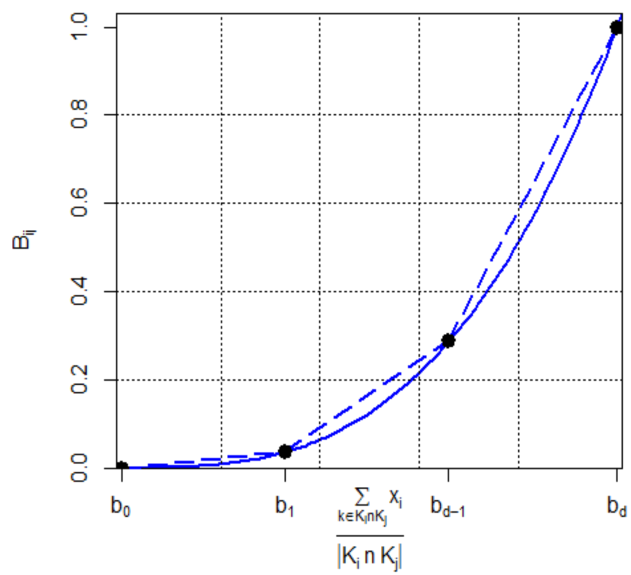
If the unit i is selected as part of the reserve ($w_i$)

If an action is taken against threat k in unit i ($x_{ik}$)

The contribution of selecting unit $i$ and applying actions in it, to the conservation of species $j$ is given by:

$$B_{ij} = \left[\frac{\text{\# of treated threats in } i \text{ that affect } j}{\text{Total \# of threats in } i \text{ that affect } j}\right]^3$$

$$= \left(\frac{\sum_{k \in K_i \cap K_j} x_{ij}}{|K_i \cap K_j|}\right)^3$$



# Multi-Action Planning for Threat Management: A MIP Model

Hence, the MIP model for Multi-action planning for threat management is given by

action costs Monitoring cost fragmentation costs

$$\min \sum_{i\in I}\sum_{k\in K_i} c_{ik}x_{ik} + \sum_{i\in I} cf_i w_i + \beta_1 \sum_{i_1\in I}\sum_{i_2\in I: i_1\neq i_2} cv_{i_1 i_2} w_{i_1}(1-w_{i_2})$$

$\beta_1$ Weight to conectivity

subject to

$$\sum_{i\in I:|K_i\cap K_j|\neq 0} B_{ij} + \sum_{i\in I:|K_i\cap K_j|=0} z_{ij} \geq t_j,\ \forall j\in J$$

ensures conservation **targets**

$$\sum_{k\in K_i} x_{ik} \leq |K_i|\, w_i,\ \forall i\in I$$

$$\sum_{j\in J_i} z_{ij} \leq |J_i|\, w_i,\ \forall i\in I$$

$$x_{ik}, z_{ij}, w_i \in \{0,1\},\ \forall k\in K, i\in I, j\in J$$

We want to achieve connectivity: The idea is that if two units that are connected are selected then penalti is 0…

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## Multi-Action Planning for Threat Management: An extension

In order to improve the functional and ecological performance of the reserve, we are also interested in reducing the fragmentation of the units sharing actions against commont threats:

$$\text{Actions fragmentation cost} = \beta_2 \sum_{k \in K} \sum_{i_1 \in I} \sum_{i_2 \in I : i_1 \neq i_2} cv_{i_1 i_2} x_{i_1 k} (1 - x_{i_2 k})$$

The idea is that if two units that are connected are selected then penalti is 0…

So the objective function becomes:

$$\min \sum_{i \in I} \sum_{k \in K_i} c_{ik} x_{ik} + \sum_{i \in I} cf_i w_i + \boxed{\beta_2 \sum_{k \in K} \sum_{i_1 \in I} \sum_{i_2 \in I : i_1 \neq i_2} cv_{i_1 i_2} x_{i_1 k} (1 - x_{i_2 k})} + \beta_1 \sum_{i_1 \in I} \sum_{i_2 \in I : i_1 \neq i_2} cv_{i_1 i_2} w_{i_1} (1 - w_{i_2})$$

Although this is a small change in the problem definition, the algorithmic strategy developed in Cattarino et al. 2015 **cannot easily address it**, while in our **MIP strategy** this can be done **straighforwardly**.

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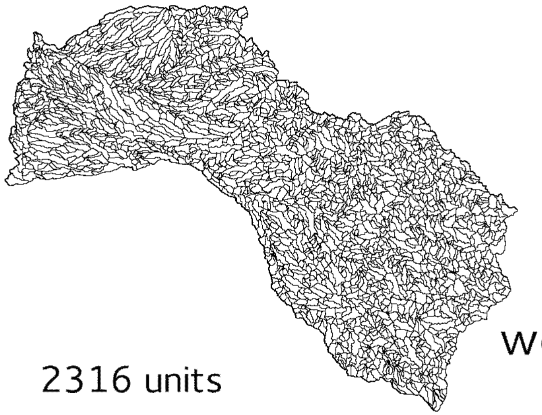
# Mitchell River Catchment : General Information

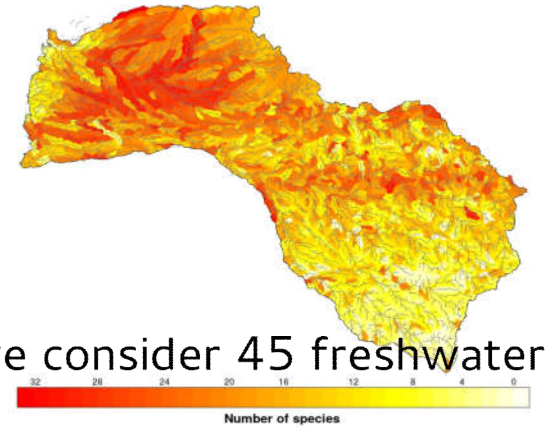
The Mitchell River catchment is located in northen region of Australia

UNITS DISTRIBUTION



2316 units

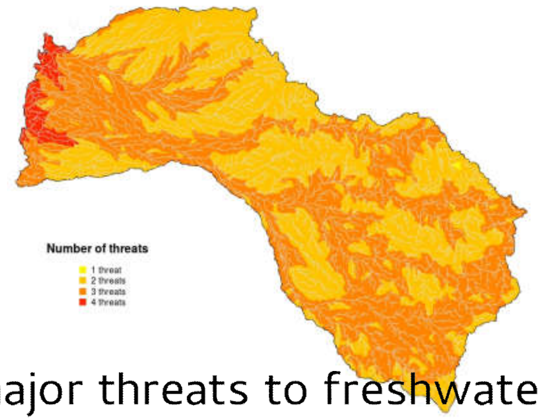
SPECIES DISTRIBUTION

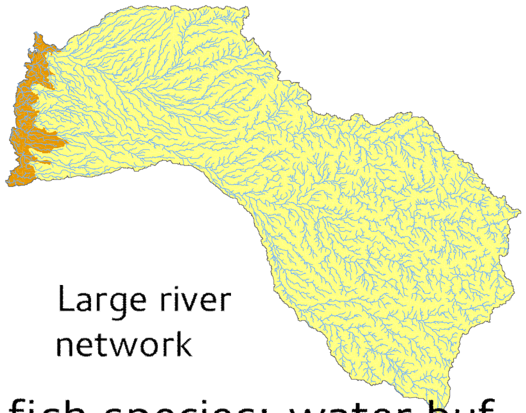



we consider 45 freshwater fish species

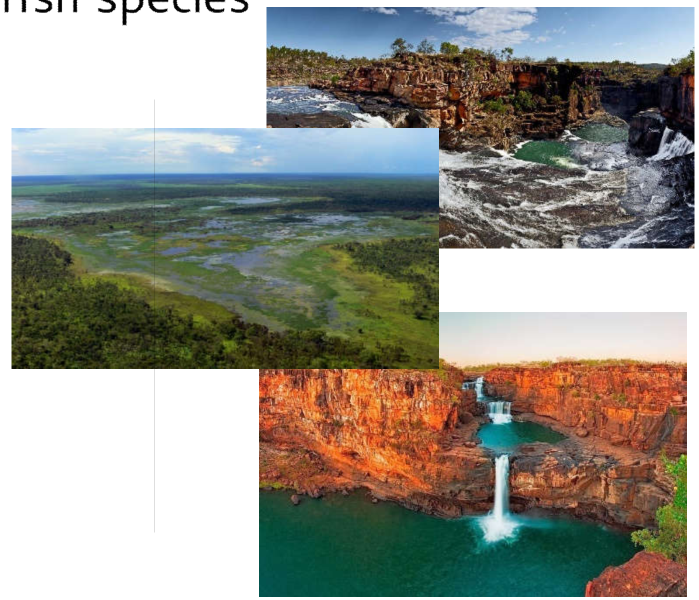
Total area: 71,630 km$^2$

THREATS DISTRIBUTION



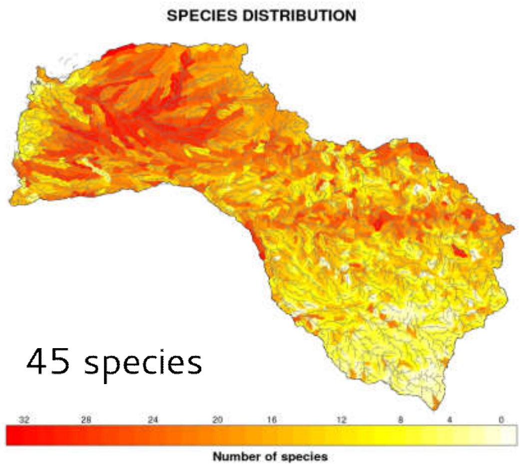



Large river network



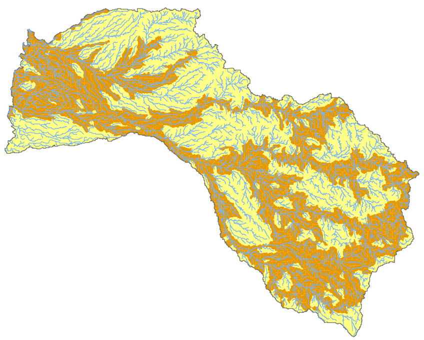
4 major threats to freshwater fish species: water buffalo, cane toad, river flow alteration, and grazing land use.

# Mitchell River Catchment : Species and threats distribution



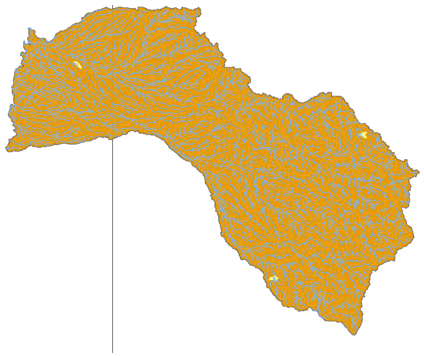

In total we consider 45 freshwater fish species which are unevenly distributed accross the whole catchment

4 major threats to freshwater fish species: water buffalo, cane toad, river flow alteration, and grazing land use.

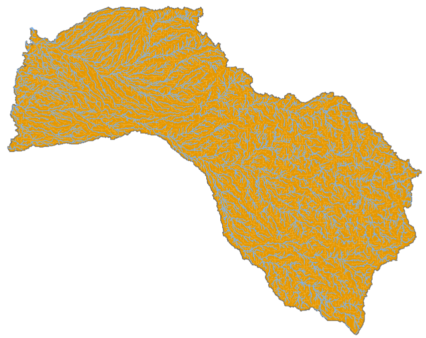


River flow alteration.

Water buffalo.



Grazing land use



Cane toad

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## Computational Results: Comparison with state-of-the-art considering Cost efficiency and Connectivity

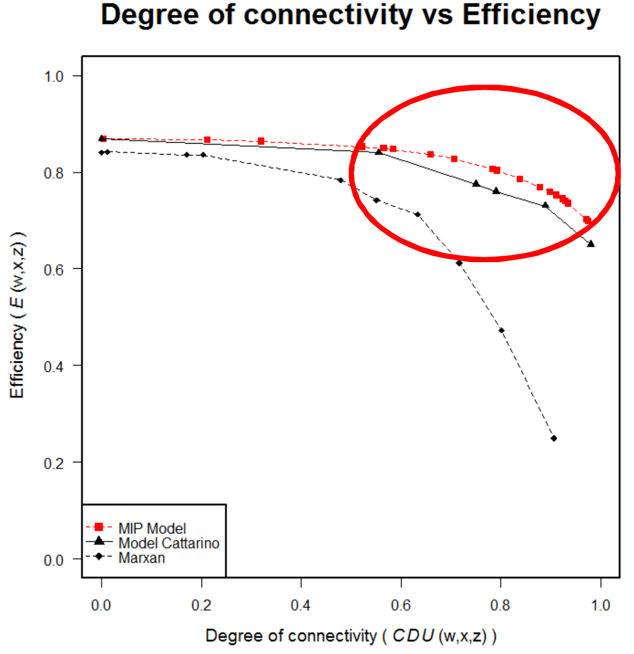
Following Cattarino et al. 2015, we computed solutions for different penalties

$$\beta_1 \in \{0, 0.2, 0.4, 0.6, 0.8, 1, 2, 3, \ldots, 9, 10\},$$

Compared the efficiency for different levels of connectivity
Efficiency is measured as the cost of the plan divided by the cost of protecting the whole area

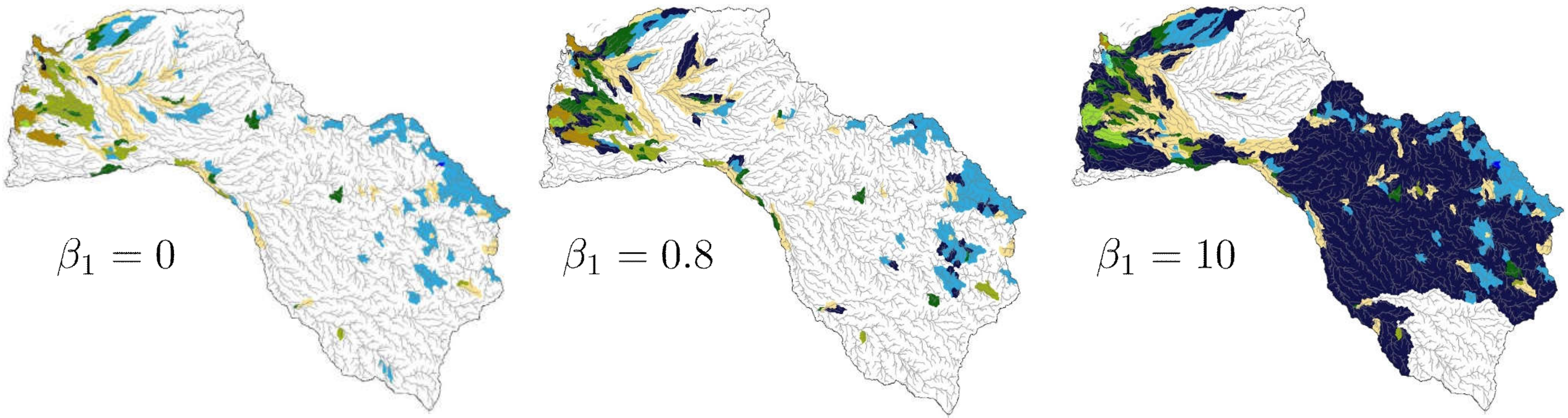
As can be seen in the plot, our approach provides a good efficiency/connectivity trade-off

The MIP approach **outperforms** MARXAN and the approach proposed by Cattarino et al. 2015



# Computational Results: Results for different penalties

Spatial impact of having different fragmentation penalty:




**Very reasonable solution from an ecological point of view.**

**Impractical solution**

- Bufalo + Flow + Weed
- Bufalo + Toad + Weed
- Bufalo + Toad + FLow
- Bufalo + Toad + Flow + Weed
- Toad + Weed
- Bufalo + Weed
- Toad + Flow
- Bufalo + FLow
- Bufalo + Toad
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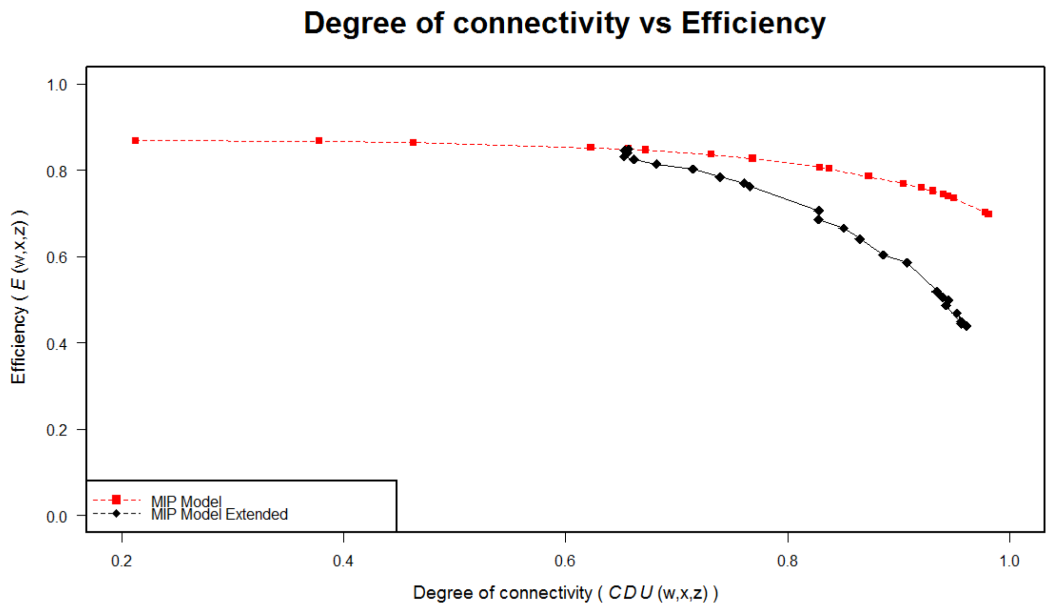
# Computational Results: Results of the extended model

For the extended model (penalty to actions fragmentation), we considered penalties

$$\beta_2 \in \{0, 0.2, 0.4, 0.6, 0.8, 1, 2, 3, \ldots, 9, 10\},$$

and computed the Efficiency v/s Connectivity plot (fixing $\beta_1 = 0.8$)

Penalizing the fragmentation of spatial distribution of actions yields less efficient solutions



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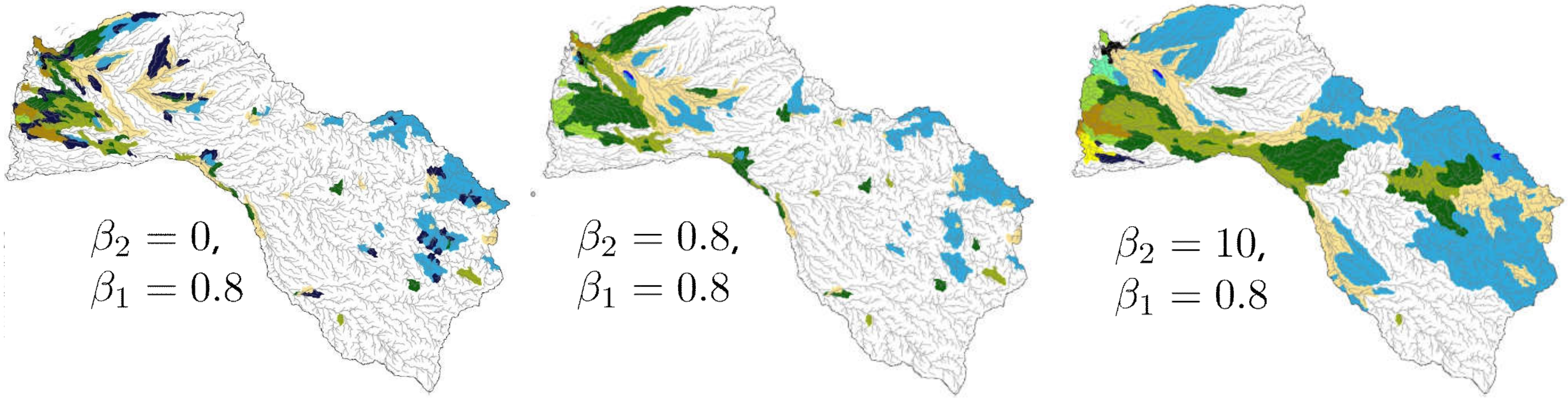


**Very reasonable solution from an ecological point of view.**


In average, all solutions verified an optimality gap of less than 3%

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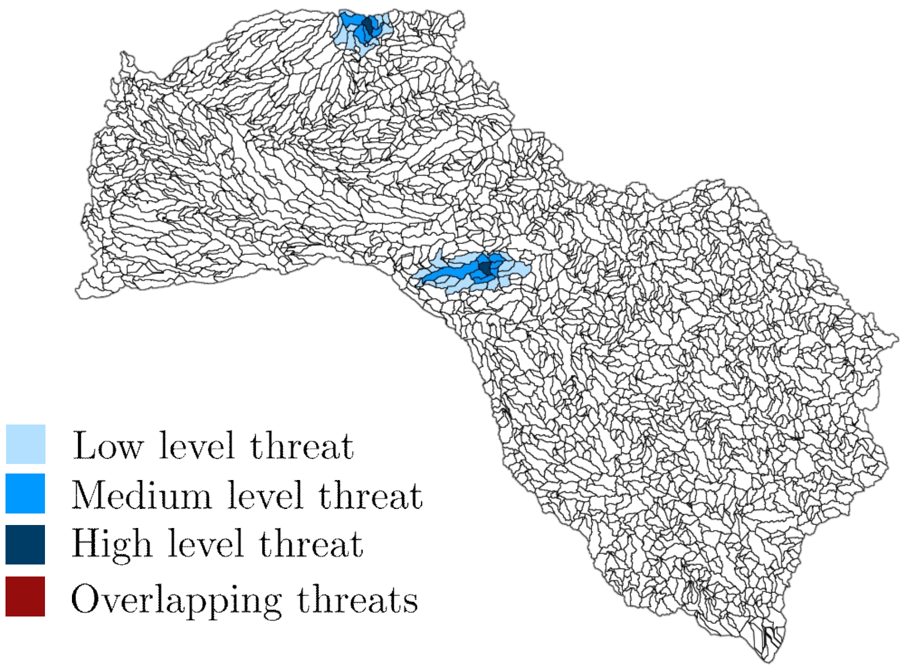
- **Extension of the work**

# A second Extension

What happends if we consider a temporary priorization taking into account dynamic threats? How do decisions change?




Subject to:

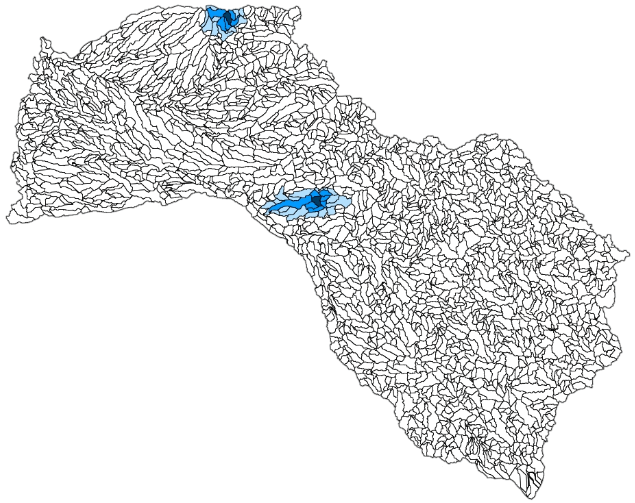
- Levels of threats
- Types of propagation
- Propagation speeds
- Sources of propagation
- Planning periods

# Following challenge

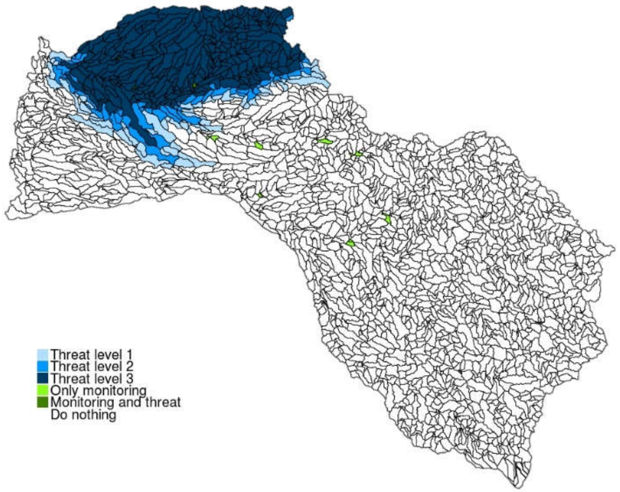
How do the solutions behave?

**Instance 1**

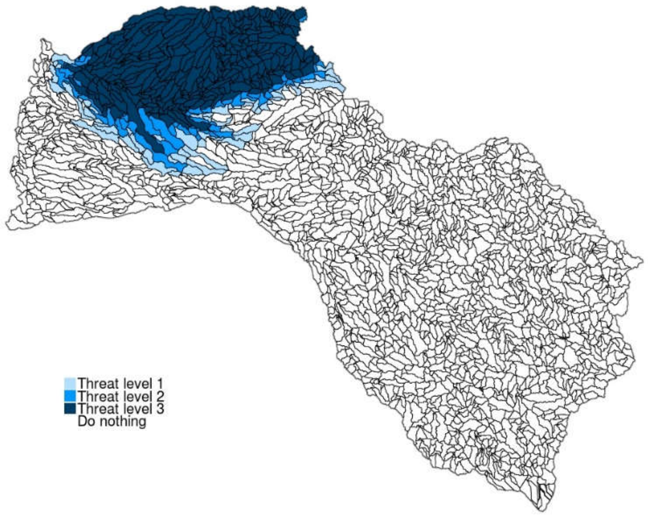
- Type of propagation: both radial propagations
- Propagation speeds: Adjacency only
- Planning periods: 10



**Small** budget:

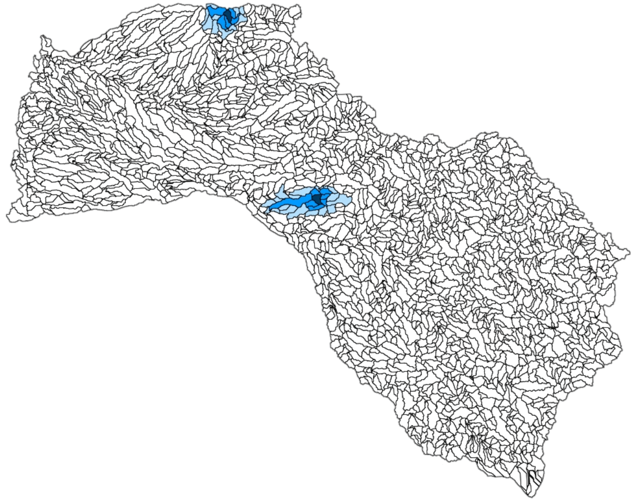



Do nothing:




Threat 1 (period 10)

# Following challenge



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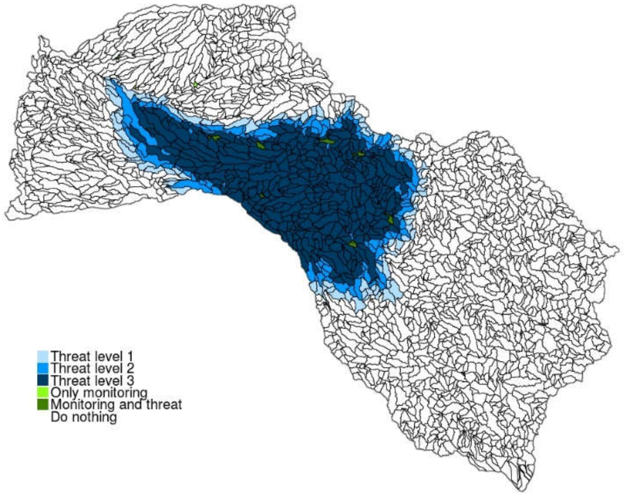
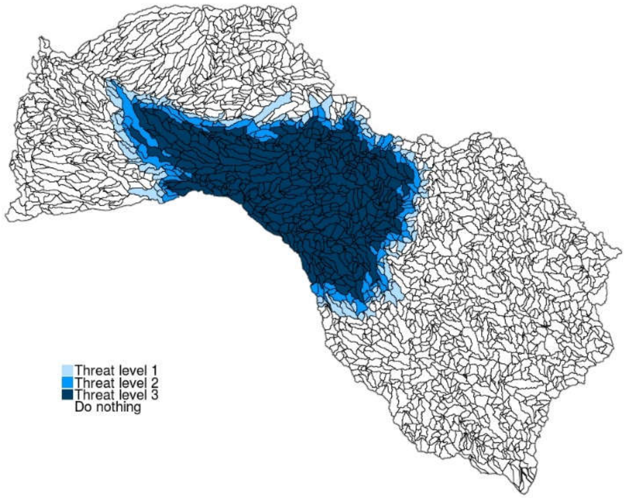



Do nothing:



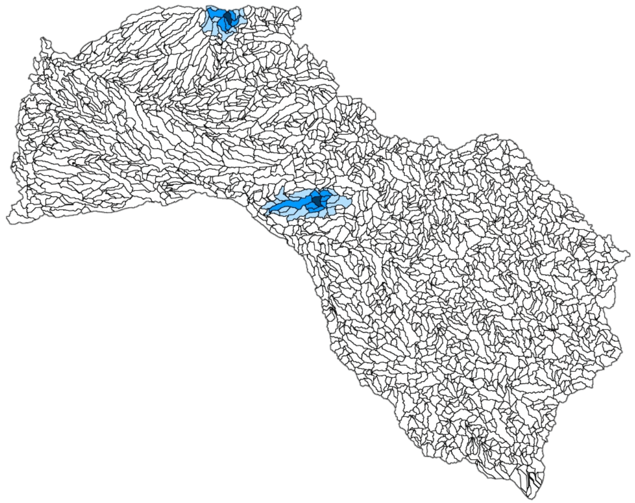

Threat 2 (period 10)

# Following challenge

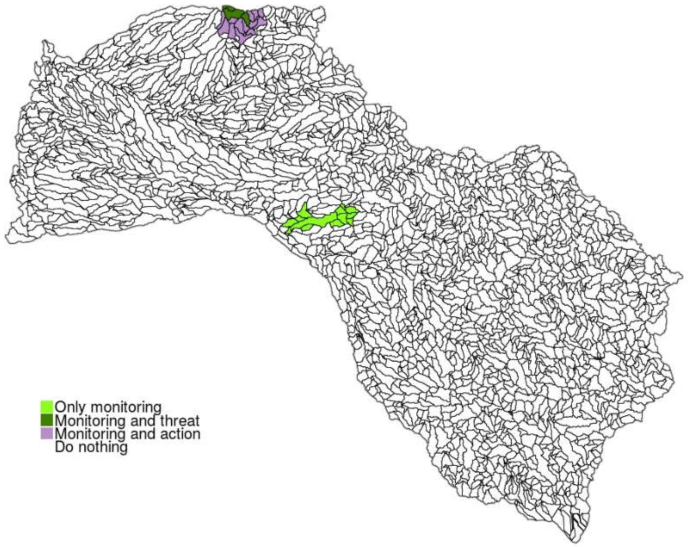
How does the solution change when we increase the budget?

**Instance 1**

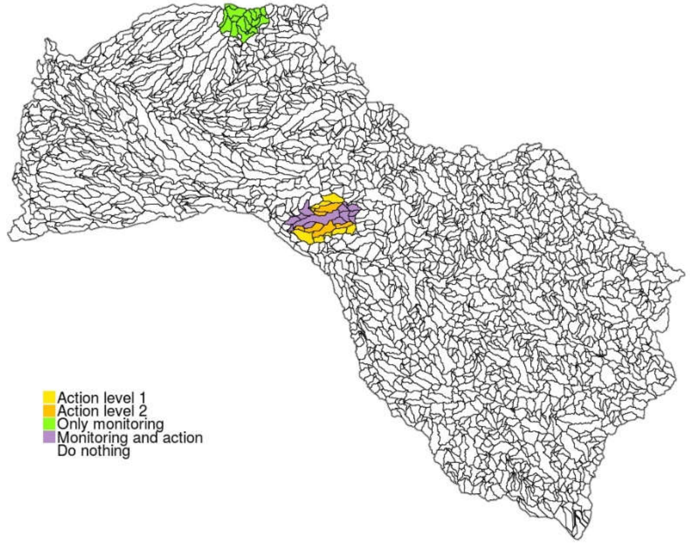
- Type of propagation: both radial propagations
- Propagation speeds: Adjacency only
- Planning periods: 10



**High** budget:

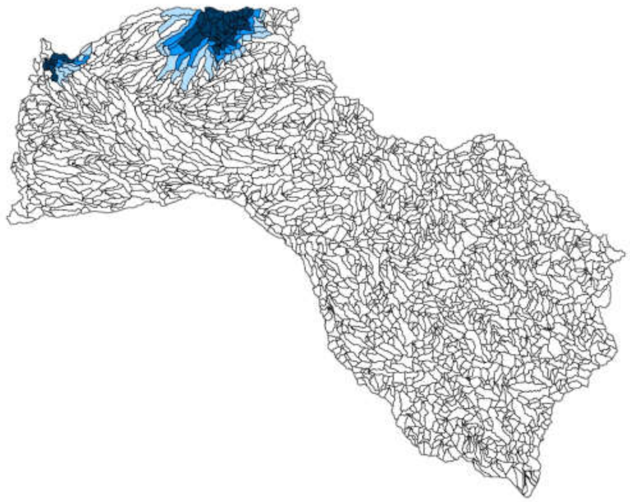



Threat 1 (period 6)




Threat 2 (period 6)

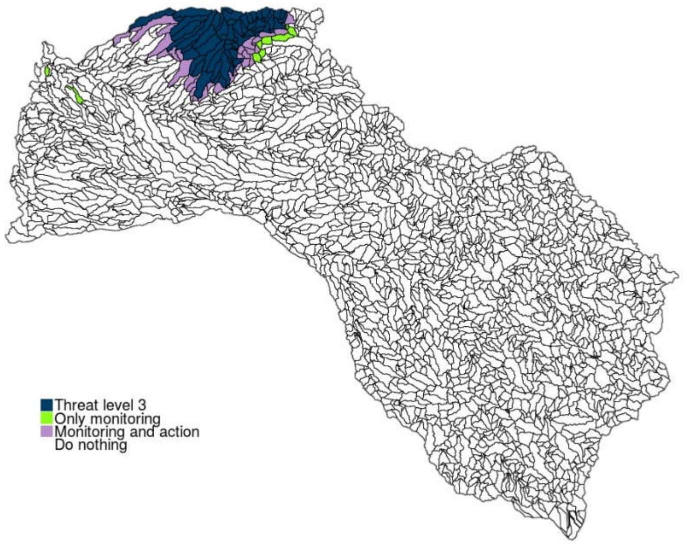
# Following challenge



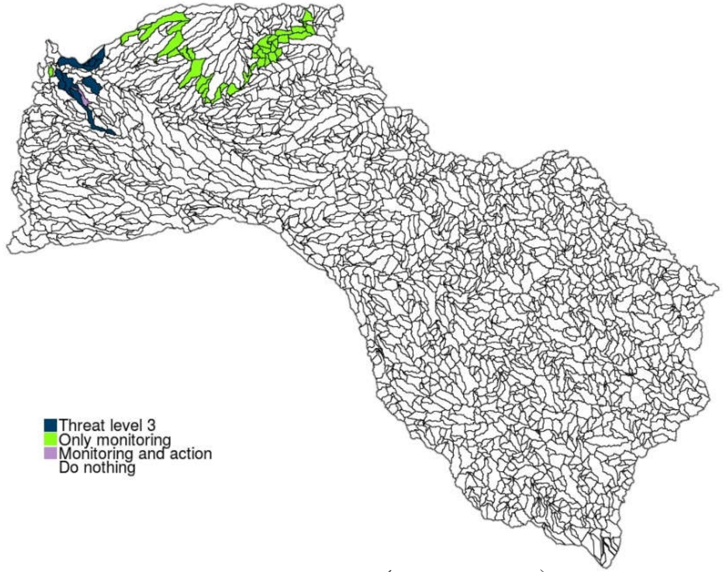
**Instance 2**

- Type of propagation: radial propagation and upstream propagation
- Propagation speeds: Adjacency only
- Planning periods: 10

**Moderate** budget:




Threat 1 (period 8)




Threat 2 (period 8)

# Conclusions

A relevant conservation planning problem was addressed.

A Mixed Integer Programming formulation was used to model the corresponding conservation problem.

The obtained solutions outperform those obtained by Cattarino et al. 2016

From computational point of view, the proposed approach seems to be more effective than heuristic strategies.

The dynamic model is much closer to reality, so we are able to make better plans (never done before at least that authors know).

Future Challenge is to incorporate uncertainty in;

i) presence of the species in the area
ii) sensitivity of the species to the threat
iii) response of the threat to the interventions
iv) uncertainty in propagation rate etc..

Thank you!!!

Questions??