Artificial Intelligence Methods for Social Good

M1-2 [Optimization]:

Conservation Planning

08-537 (9-unit) and 08-737 (12-unit)

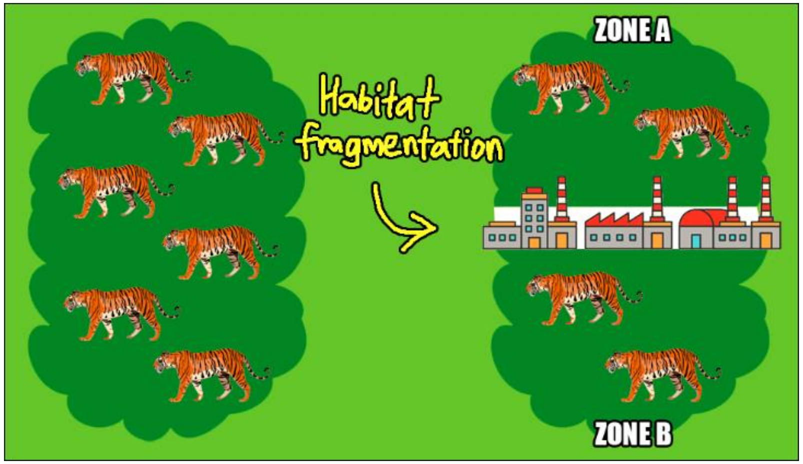
Instructor: Fei Fang

feifang@cmu.edu

Wean Hall 4126

Motivation

- Wildlife habitat diminished and fragmented



https://commons.wikimedia.org/wiki/File:Indiana_Dunes_Habitat_Fragmentation.jpg

https://cilisos.my/malaysia-is-building-a-love-tunnel-that-will-help-animals-find-their-soulmate/tiger-habitat-fragmentation/

Motivation

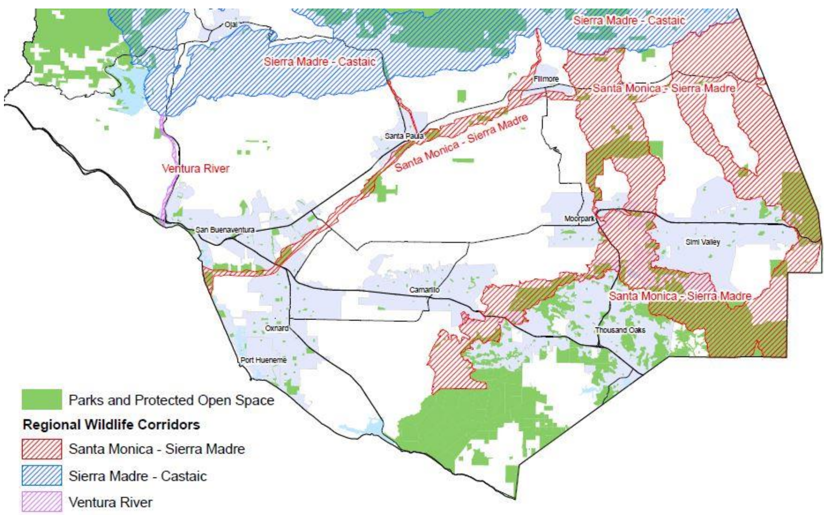
- Create (isolated) protected areas: not sufficient for long-term maintenance of biodiversity
- To create/enhance connectivity: build or protect wildlife corridors

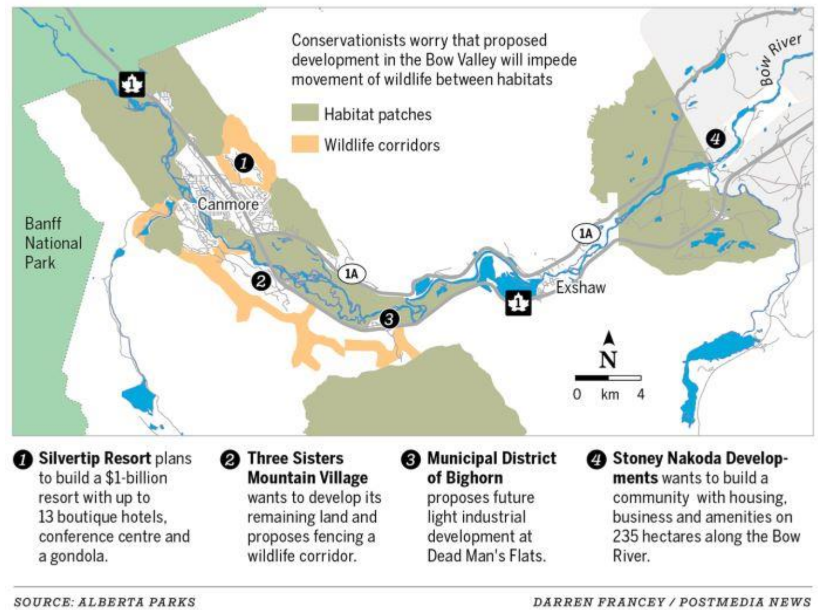
https://envirothink.wordpress.com/2015/06/09/new-wildlife-corridor-to-be-built-in-washington-state/

https://www.lifegate.com/people/lifestyle/5-important-wildlife-corridors

Motivation

- Question: Where to build wildlife corridor?





https://twitter.com/Y2Y_Initiative/status/841314661039460352

http://colabvc.org/wildlife-corridors-already-wild/

Learning Objectives

- Briefly describe
  - Challenges in wildlife corridor design
  - Graph model
  - MILP-based solution
  - Methodology of applying it to a specific case
  - Evaluation criteria
- Write down general constraints for network flow problems

Outline

- Motivation
- Problem Statement
- Model
- Solution Approach
- Case Study
- Discussion

Problem Statement

- Wildlife distribution: High density in core areas
  - Core areas of different species may overlap
- Wildlife movement:
  - May move in any direction, heterogeneous difficulty
  - Each pixel associated with a resistance cost
  - Path of higher total resistance cost is more difficult to walk through
- Build a corridor: purchase parcels of land to connect protected areas
  - Parcels purchased + existing protected area = conservation network

Problem Statement

- Single-minded goal: build corridors to connect core areas of a species and minimize total resistance cost
  - Connect core areas: exist a path that falls entirely within the conservation network
- Limitations
  - Economic cost is not considered
  - Multiple species is not considered
- Ideally:
  - Connect core areas for all species
  - Low total resistance cost (cumulative resistance)
  - Low expenditure on purchasing the parcels (expenditure)

Problem Statement

- Budget constrained corridor design for multiple species
  - Set limit on expenditure
  - Minimize cumulative resistance
  - Ensure connectivity between each pair of core areas of each species

Outline

- Motivation
- Problem Statement
- Model
- Solution Approach
- Case Study
- Discussion

Model

- A raster of grid cells
- A core area: a set of contiguous raster cells

- Def 1: Graph Model for Corridor Design Problem
  - Nodes: a cell being considered
  - Edges: connecting neighboring cells
  - Additional nodes: virtual nodes for core areas
  - Additional edges: core areas and neighboring cells
  - Node has acquisition cost and resistance cost (for each species)
  - Corridor design: select a subset of nodes on the graph to ensure connectivity between core areas

Solution Approach

- Optimization Problem for Single Species
  - MILP 1
  - Flow constraints to ensure connectivity

Quiz 1

- Given directed graph $G = (V, E)$, each node representing a city. A company needs to send K cellphones from city s to city d. It may send the cellphones through multiple paths. Let y_e be the number of cellphones sent through edge $e \in E$. Let $\delta^-(v)$ and $\delta^+(v)$ denote the set of incoming and outgoing edges for $v \in V$. Which of the following constraints are necessary constraints for y_e?
  - A: $\sum_{e \in \delta^+(s)} y_e = K$
  - B: $\sum_{e \in \delta^-(d)} y_e = K$
  - C: $\sum_{e \in \delta^+(v)} y_e = K, \forall v \in V$
  - D: $\sum_{e \in \delta^+(v)} y_e = \sum_{e \in \delta^-(v)} y_e, \forall v \in V$
  - E: $\sum_{e \in \delta^+(v)} y_e = \sum_{e \in \delta^-(v)} y_e, \forall v \in V \backslash \{s, d\}$

Solution Approach

- Optimization Problem for Two Species
  - Updated objective function of MILP 1
  - α controls the balance between the two species

- Boundary Solutions
  - Minimum budget to ensure connectivity
    - Slight modifications to MILP 1
  - Minimum cumulative resistance if no budget constraint
  - Minimum budget solution among the ones with minimum cumulative resistance
    - First find minimum cumulative resistance
    - Then make slight modifications to MILP 1

Outline

- Motivation
- Problem Statement
- Model
- Solution Approach
- Case Study
- Discussion

Case Study

- Wolverines and Grizzly Bears in Western Montana
  - Low population, concentrated
    - Yellowstone National Park, Bob Marshall Wilderness Complex
    - 12.8 wolverines across 3 mountain ranges
    - 48 grizzly bears in 9900-km^2 zone

https://www.pinterest.com/pin/488429522063700417/

https://en.wikipedia.org/wiki/Grizzly_bear#/media/File:Grizzlybear55.jpg

Case Study

- Wolverines and Grizzly Bears in Western Montana
  - Different habitat requirements
  - Habitats partially overlap
  - Different capability of movement

Case Study

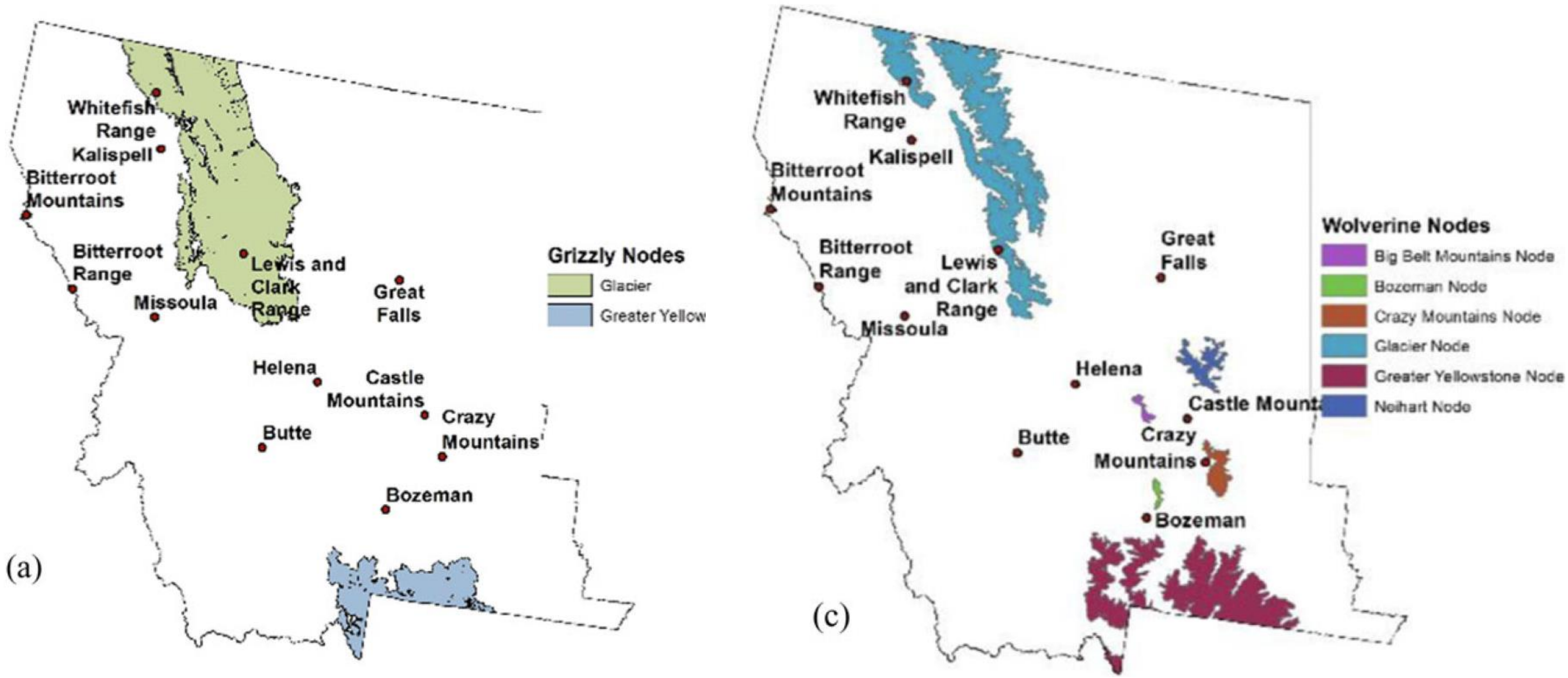
- Lands being considered
  - Public area (held by National Parks, U.S. Forest Service etc)
  - Tribal lands
  - Private lands (held by NGOs, timber companies, individuals etc)

Case Study

- Input for the Model / Data source
  - Western Montana, 1000m grid
  - Acquisition cost
    - Tax records
    - Information on conserved lands
    - Other information: water body, urban parcel, etc
    - Gap between model and practice: a parcel is not a set of cells
    - Estimated acquisition cost: area-weighted sum of all the parcel values in the cell (using ArcGIS)
  - Resistance
    - Geographical information and other landscape features
      - Grizzly bears: vegetation, human development, road density
      - Wolverines: snow cover, housing development, forest edge
    - Estimate resistance: Follow established method in conservation

Case Study

- Core areas
  - Grizzly bears: Northern Continental Divide Ecosystem and Greater Yellowstone Ecosystem
  - Wolverines: use habitat rule to identify core areas



Case Study

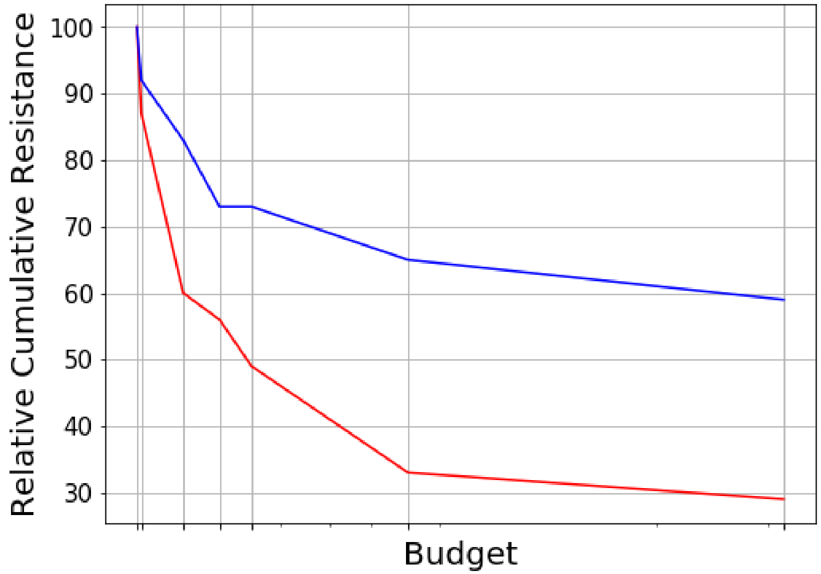
- Computation
  - Pruning (could be lossy), i.e., exclude cells that
    - Could not be made passable
    - Very far from any reasonable pathway
    - If included in the path, will lead to a high cumulative resistance
  - 42065 cells
  - Solve MILP using CPLEX, run on cluster
    - 5-40 hours of computer time

Case Study

- Results
  - Provide insights, suggestions, visualizations to assist decision makers
    - Boundary Solutions
      - Minimum budget to ensure connectivity: $2.9M (high cumulative resistance)
      - Least-resistance paths: $31.8M expenditure (cumulative resistance is 29% and 59% of the min-budget design for grizzly bear and wolverine separately)

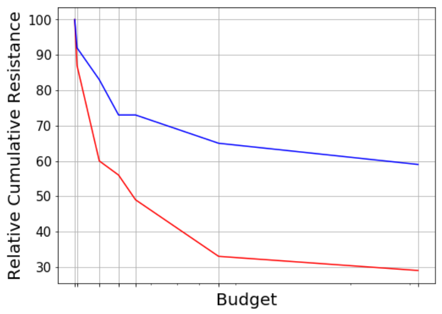
Case Study

- Results
  - Provide insights, suggestions, visualizations to assist decision makers
    - Fix $\alpha = 0.5$, examine tradeoff between budget and cumulative resistance
      - Find "Elbow" point



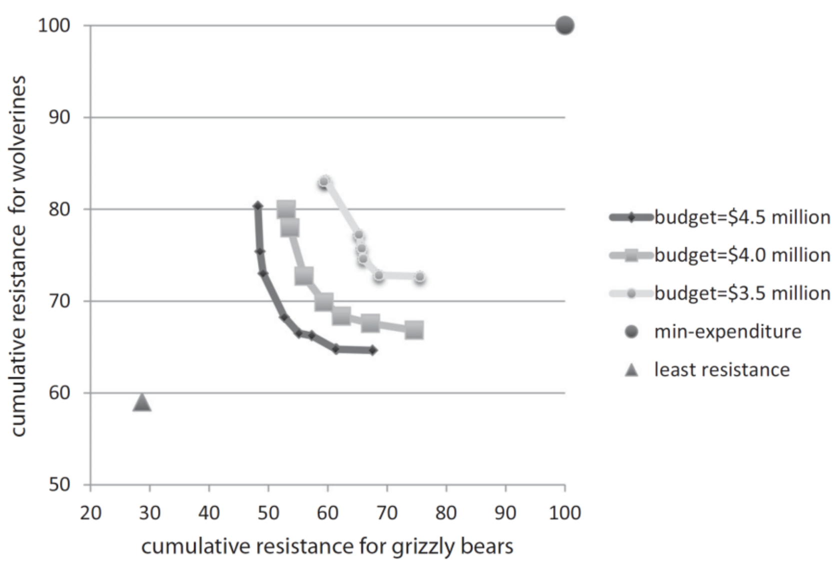
Quiz 2

- Which ones of the following are true about the "elbow" point in the tradeoff plot of budget and cumulative resistance?
  - A: When budget is above this point, increase in budget does not lead to a significant reduction in cumulative resistance (compared to when budget is below this point)
  - B: Can be found by linking the first and last point to get a line, and check which point is farthest from this line
  - C: Is the ideal solution for wildlife corridor design problem
  - D: Can be a suggested point to policy makers



Case Study

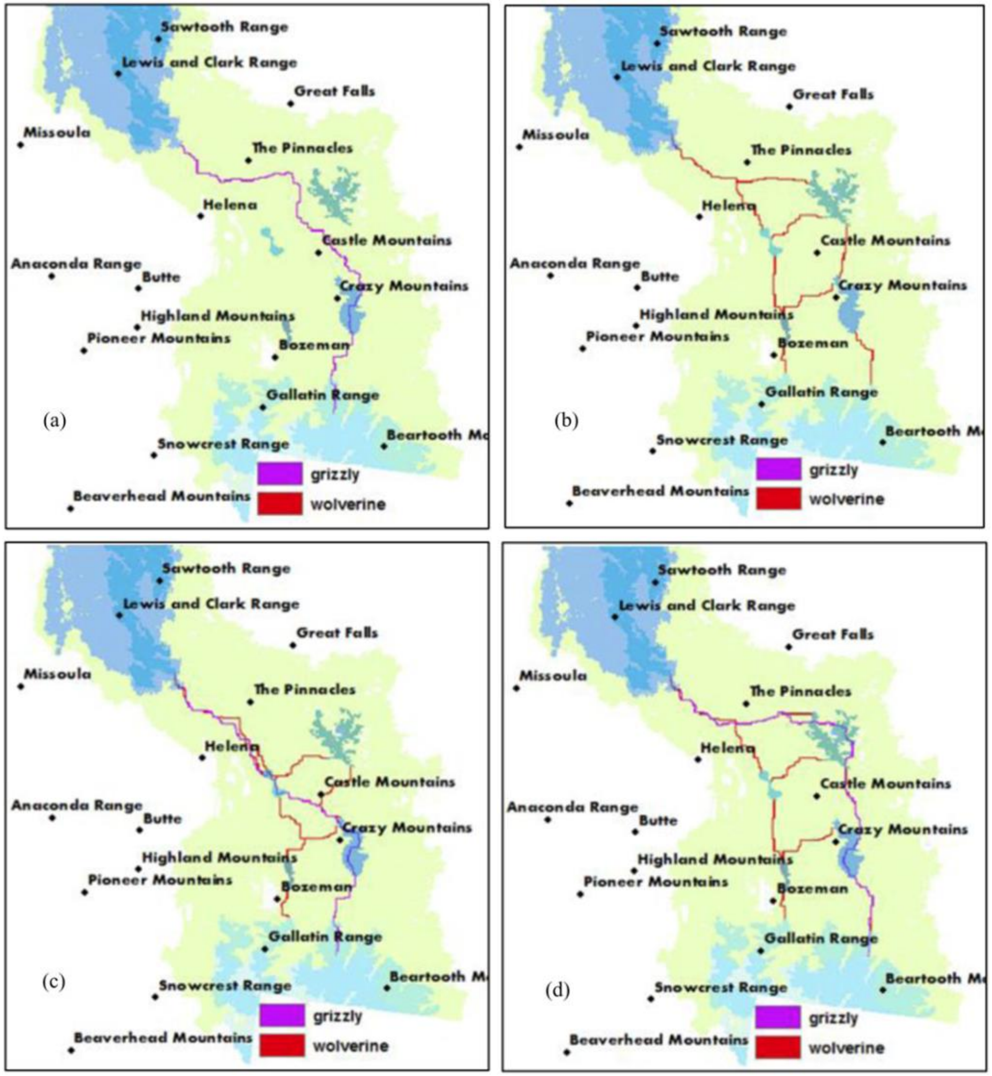
- Results
  - Provide insights, suggestions, visualizations to assist decision makers
    - Fix budget, plot cumulative resistance of two species with varying α
      - Find "Elbow" point
      - Difference across species: societal concerns and need for connectivity



Case Study

- Evaluation
  - Evaluate the advantage of optimizing jointly
  - Compare against separate single-species corridor design
  - Same total budget, compare cumulative resistance for both species
    - $4M for single-species corridor design for each species, get 67% and 40% of relative cumulative resistance for grizzly bear and wolverine
    - $8M for two-species corridor design with α= 0.5, get 65% and 33%
    - What's missing here?

Quiz 3



- Compare the two results in the lower half. They correspond to different value of α (importance of grizzly bears). Which one corresponds to a higher value of α?
  - Lower Left
  - Lower Right

Outline

- Motivation
- Problem Statement
- Model
- Solution Approach
- Case Study
- Discussion

Discussion

- Heterogeneity: What if different core area pairs have different important?
- Uncertainty in input: what if estimated resistance is not accurate?
- Uncertainty in acquisition: what if the purchase of a patch may fail?
- What if estimated resistance is not additive?
- How to reduce the runtime?

Learning Objectives

- Briefly describe
  - Challenges in wildlife corridor design
  - Graph model
  - MILP-based solution
  - Methodology of applying it to a specific case
  - Evaluation criteria
- Write down general constraints for network flow problems

Paper Discussion

- Wildlife corridor design with one species (Dilkina and Gomes, 2010)
- Summary
  - Societal challenge
  - AI method
  - Contributions
- Questions
- Brainstorming Ideas
  - Improvement / future direction / other valid discussions
  - Societal challenge and AI method that can potentially be used to tackle it (not necessarily relevant to the paper)

Reference and Related Work

- *Trade-offs and efficiencies in optimal budget-constrained multispecies corridor networks*
  - Bistra Dilkina, Rachel Houtman, Carla P. Gomes, Claire A. Montgomery, Kevin S. McKelvey, Katherine Kendall, Tabitha A. Graves, Richard Bernstein, Michael K. Schwartz
- (PRA1) *Solving Connected Subgraph Problems in Wildlife Conservation*
  - Bistra Dilkina & Carla P. Gomes
- *Robust Network Design for Multispecies Conservation*
  - Ronan Le Bras, Bistra Dilkina, Yexiang Xue, Carla P. Gomes, Kevin S. McKelvey, Michael K. Schwartz, Claire A. Montgomery

- Reserve design which accounts for tradeoff between economic costs and ecological benefits (Moilanen et al. 2009)