HABITAT FUNCTIONALITY METRIC:

Quantifying the total impact of habitat loss & fragmentation on mobile species, in large continuous landscapes

Bram Van Moorter

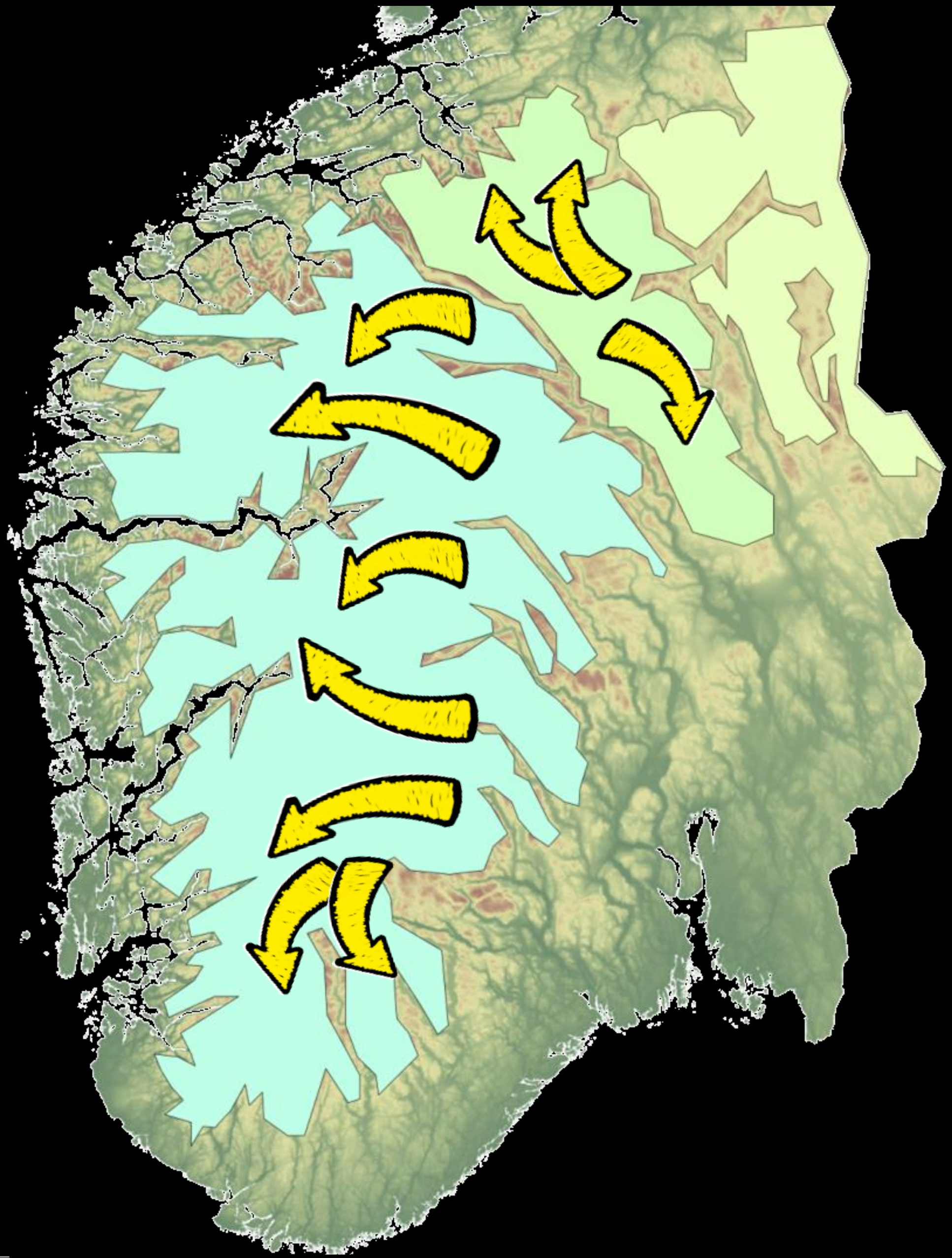
Ilkka Kivimaki, Robin Devooght, Manuela Panzacchi, Marco Saerens

NINA Norwegian Institute for Nature Research

UCL Université catholique de Louvain

Aalto University

WILD REINDEER IN NORWAY: TRADITIONAL RANGE & MIGRATIONS

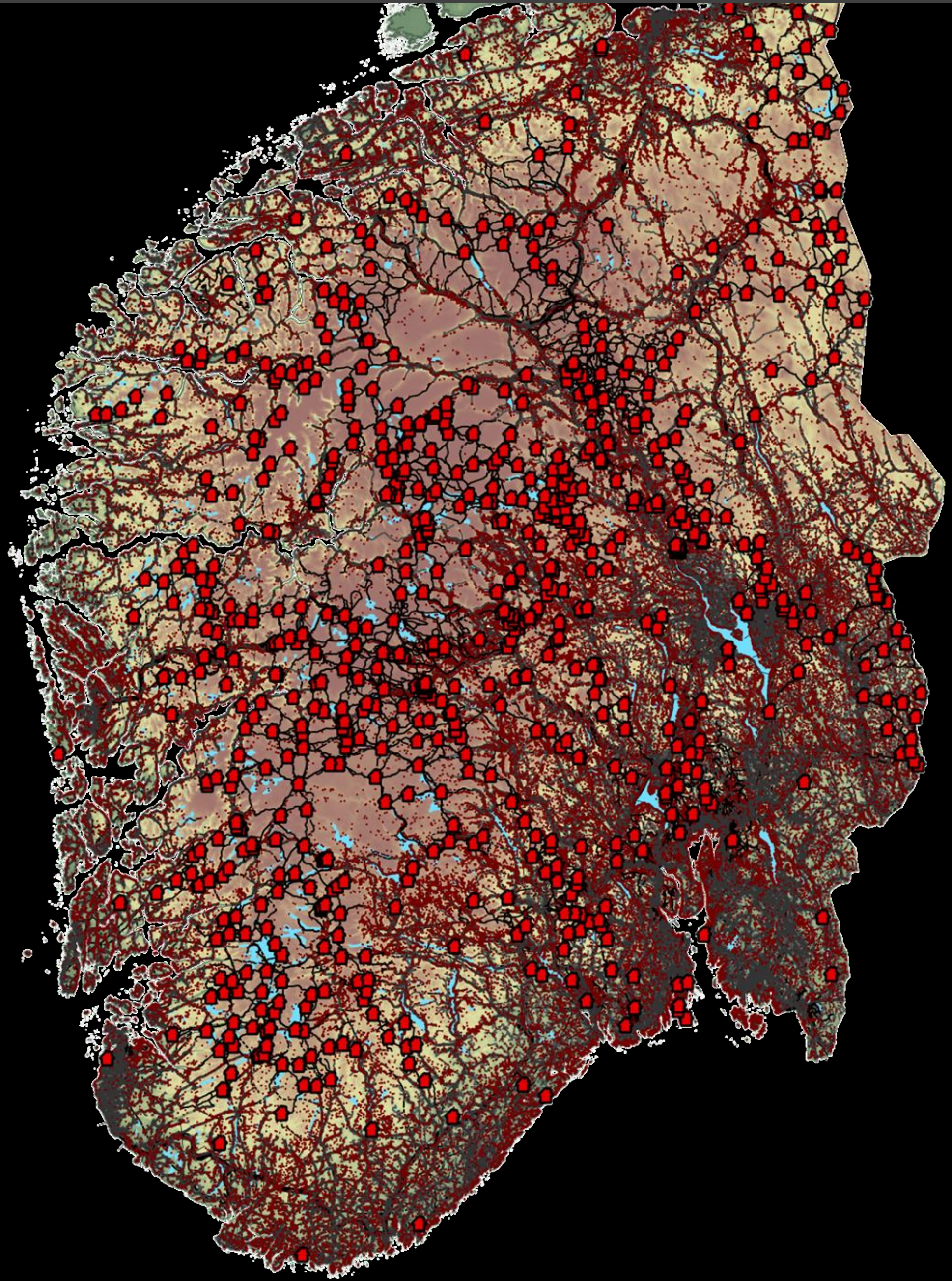


UNTIL ca. 1900-50

Few interbreeding,
migrating populations

based on large dataset of
archaeological data - pitfall traps

THE ANTHROPOCENE

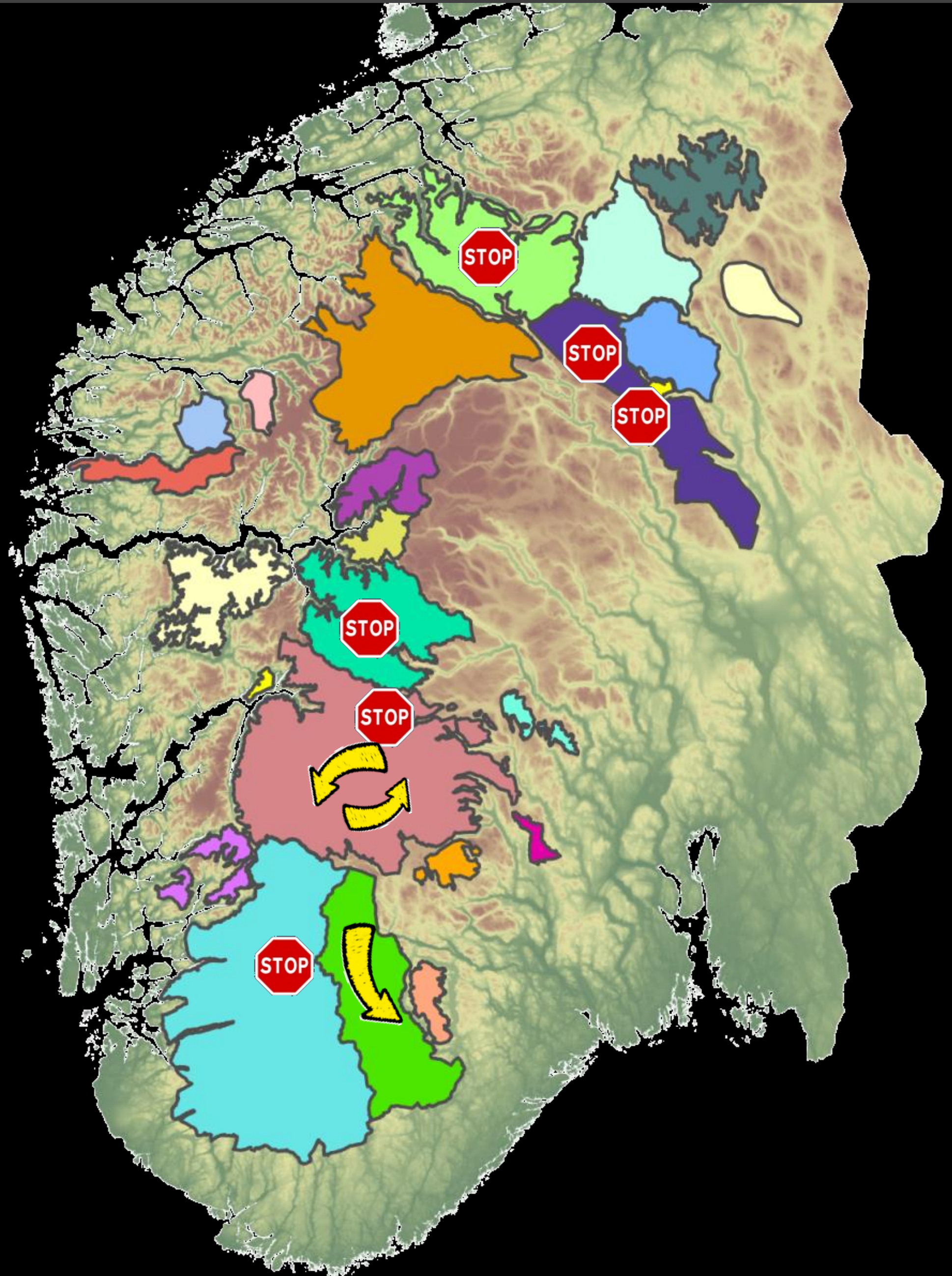


AFTER ca. 1900-50

- Major roads
- Railways
- Hydropower reservoirs
- Power lines
- Minor roads
- Tourist cabins
- Private cabins
- Marked trails
- … snow scooter, skiing, snowkiting, fishing…

***RAPIDLY* ONGOING HABITAT LOSS & FRAGMENTATION**

THE ANTHROPOCENE



NOW

- 23 isolated sub-pop.
- Fragmentation ongoing
- Few migrations left

Last populations in Europe

$\Rightarrow$ *international responsibility for conservation*

ANTHROPOGENIC LAND USE

main threat to
biodiversity worldwide

HABITAT LOSS

FRAGMENTATION

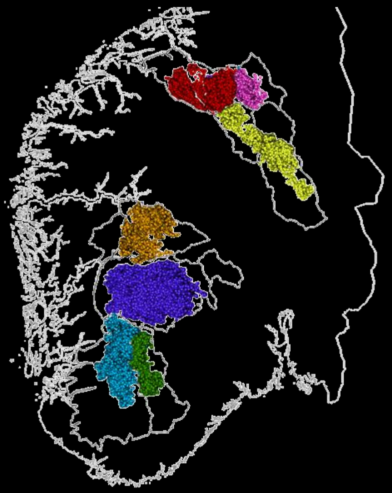
The total impact of land use is determined by the *magnitude, location & spatial configuration of* both habitat loss and fragmentation

good but non-accessible habitat is lost to the species

BACKGROUND WORK IN MOVEMENT ECOLOGY (IN A NUTSHELL)

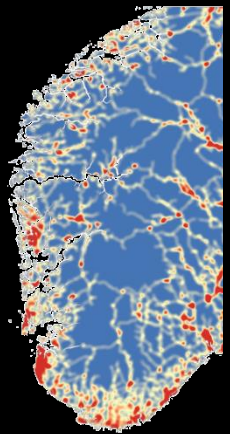
1 - QUANTIFYING SUITABLE HABITAT / HABITAT LOSS

GPS data

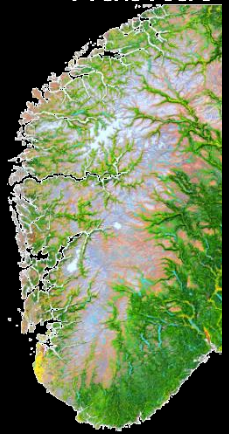


Compare used to available habitat
at each location using methods such as
Resource Selection Functions

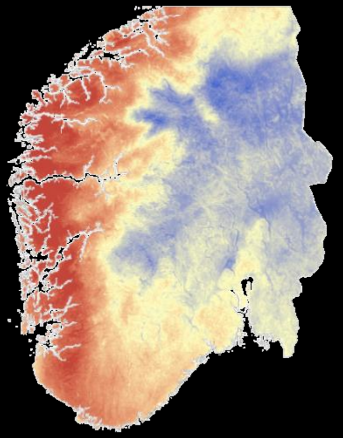
Disturbance

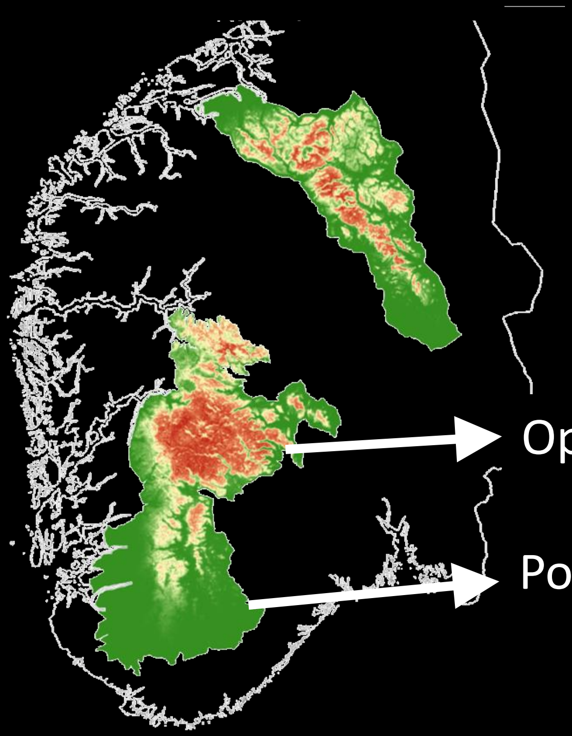


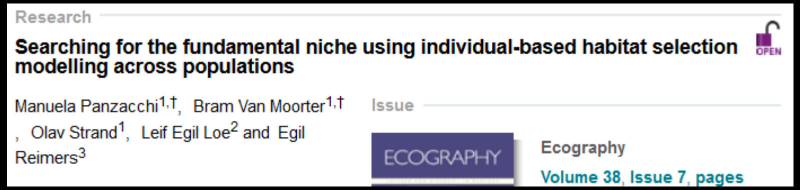
Habitat



Climate







Research

Searching for the fundamental niche using individual-based habitat selection modelling across populations

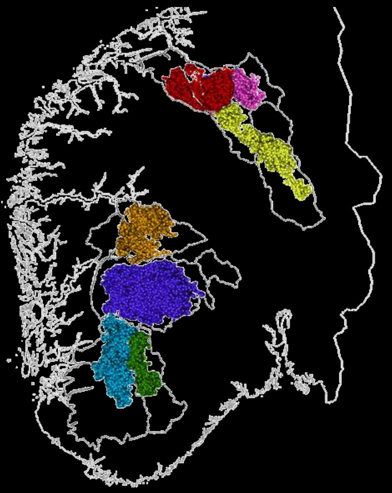
Manuela Panzacchi[1,†], Bram Van Moorter[1,†], Olav Strand[1], Leif Egil Loe[2] and Egil Reimers[3]

Issue
ECOGRAPHY
Ecography
Volume 38, Issue 7, pages

Link between resource selection and population carrying capacity (*in prep)*

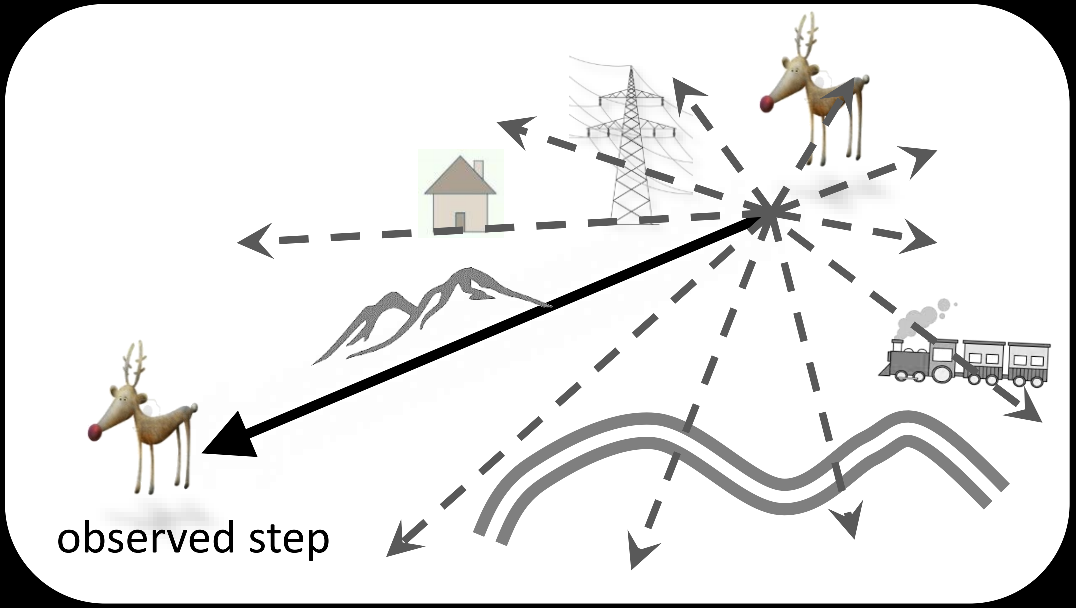
2 - QUANTIFYING LANDSCAPE PERMEABILITY TO "STEPS"

GPS data



Calculate the probability of traversing each landscape feature with a "step"

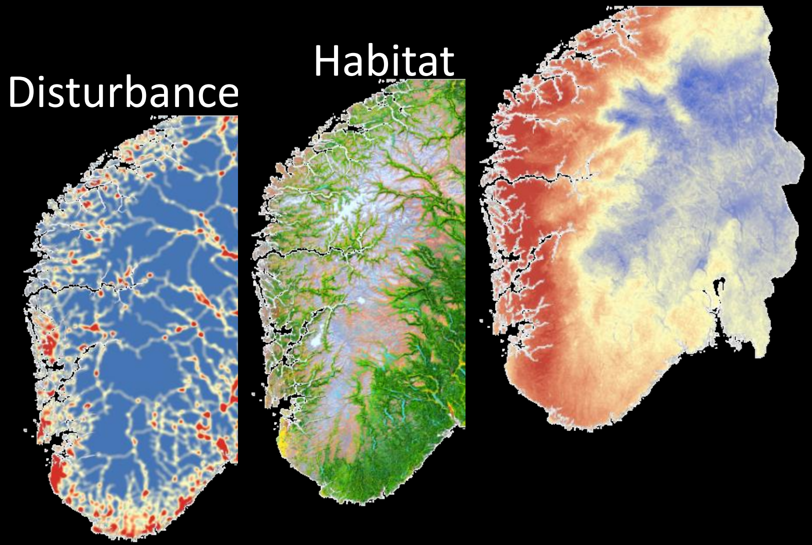
Step Selection Functions



Disturbance

Habitat

Climate



Variables	coef	se(coef)	z	p
Step length (corrected)	-1.142e-03	1.171e-05	-97.500	***
(Max slope)^2	-1.165e-03	3.559e-05	-32.732	***
Max trail density	-1.538e-01	2.338e-02	-6.581	***
Max road density	-5.324e-01	1.006e-01	-5.295	***
Solar radiation	3.978e-01	1.051e-02	37.832	***
LC: bog	-5.510e-01	1.570e-01	-3.509	***
LC: mountain not edible veg.	1.516e-01	6.908e-02	2.195	*
LC: mountain edible veg.	5.996e-01	6.096e-02	9.835	***
LC: non dammed lakes	-1.431e+00	1.268e-01	-11.288	***
LC: dammed lakes	-3.936e+00	4.645e-01	-8.473	***
Road crossing	-3.099e-01	1.264e-01	-2.451	*

2 - QUANTIFYING LANDSCAPE PERMEABILITY TO "STEPS"

Predicting the probability of traversing each landscape feature with a "step"

Step Selection Functions

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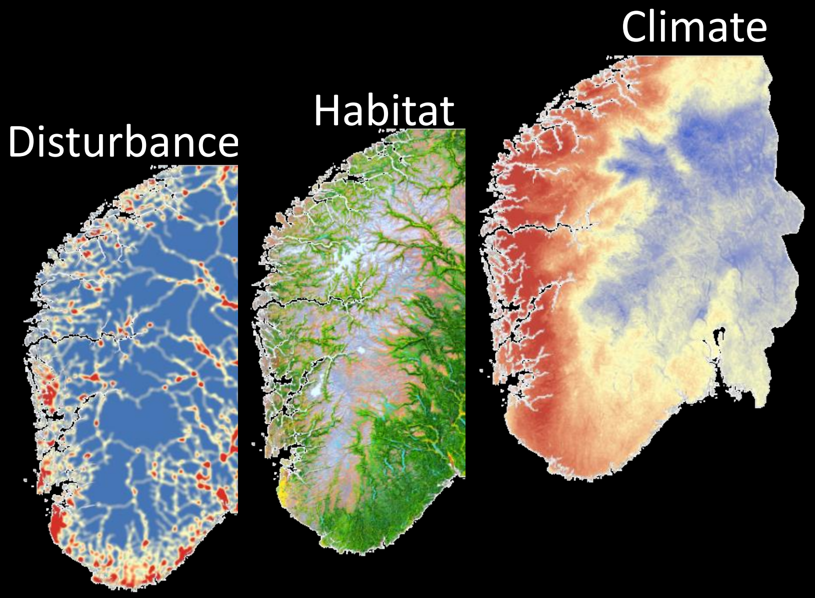
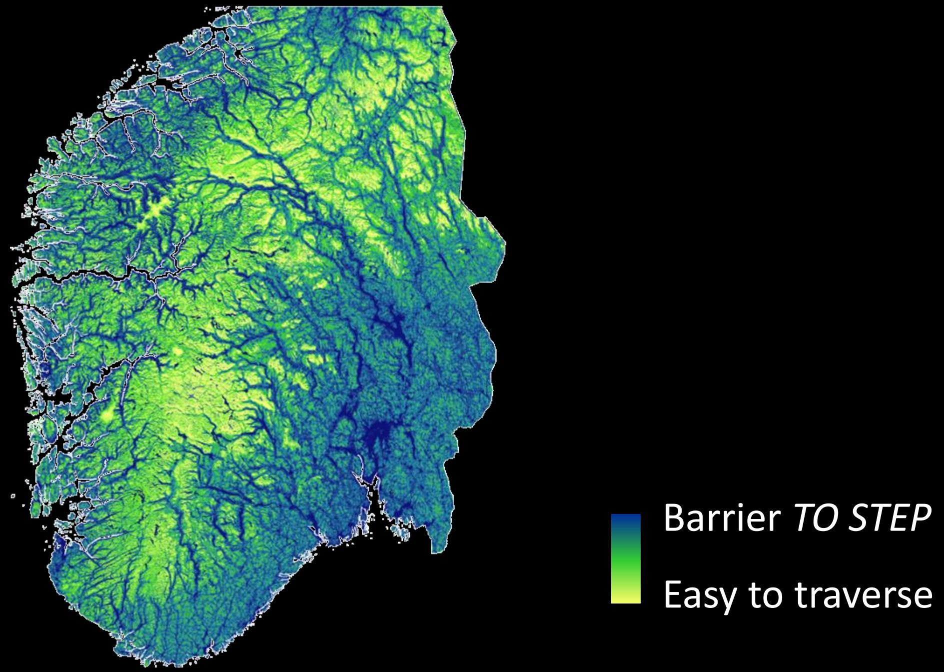
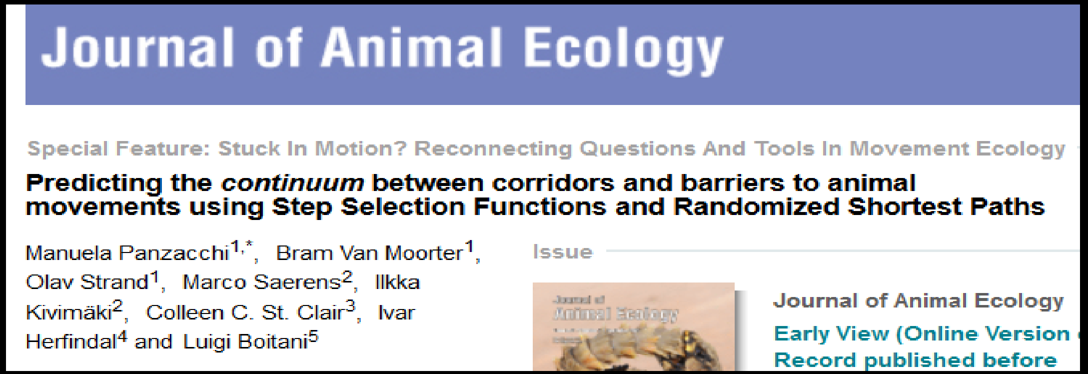





Journal of Animal Ecology

Special Feature: Stuck In Motion? Reconnecting Questions And Tools In Movement Ecology

Predicting the *continuum* between corridors and barriers to animal movements using Step Selection Functions and Randomized Shortest Paths

Manuela Panzacchi[1,*], Bram Van Moorter[1], Olav Strand[1], Marco Saerens[2], Ilkka Kivimäki[2], Colleen C. St. Clair[3], Ivar Herfindal[4] and Luigi Boitani[5]

Issue

Journal of Animal Ecology

Early View (Online Version

Record published before

3 - IDENTIFYING ENTIRE MIGRATION CORRIDORS

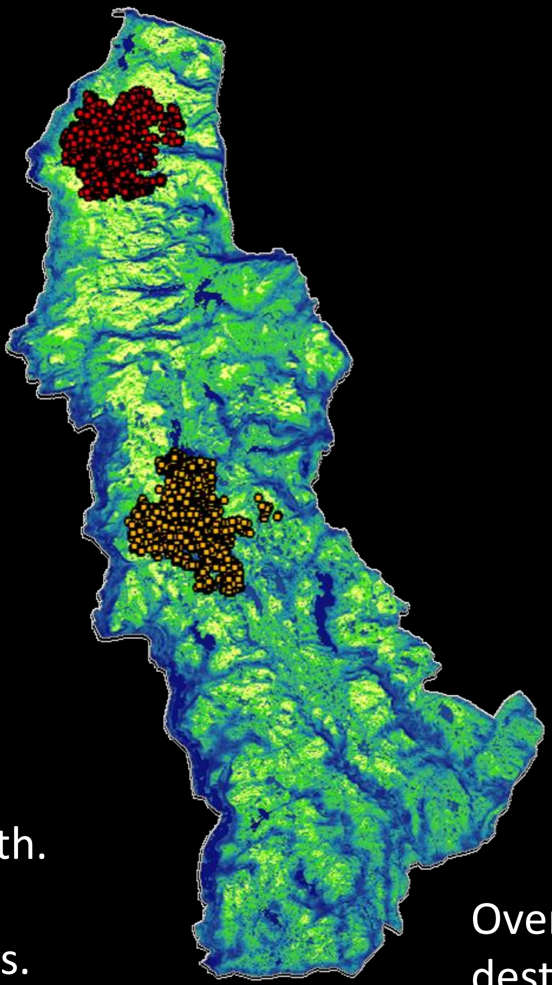
We know where does migration start and end & how permeable is the landscape in between

… but which way do reindeer walk?

OPTIMAL MOVEMENTS

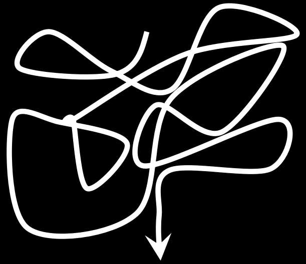
«as the fox runs»

e.g. Least Cost Path



RANDOM WALK

«the drunkard's walk»



e.g. Current Models, Diffusion Models

Assumption: perfect knowledge of the entire landscape; optimal movement along one single path.

High sensitivity to pixel size and classification errors.
The resulting corridor is only one-pixel wide

Assumption: no knowledge of the landscape, no memory, random movements.

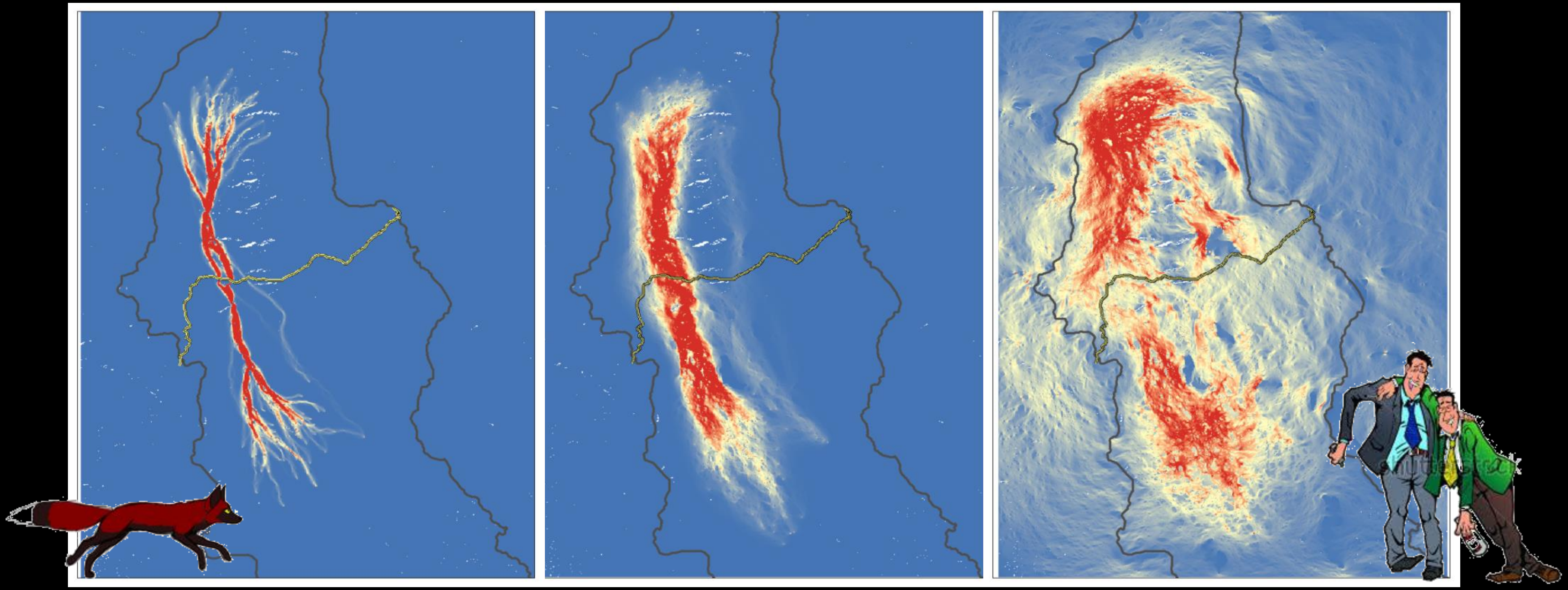
Overemphasizes areas surrounding the source-destination pairs; underemphasize single travel routes and wide swaths of highly suitable areas

RANDOMIZED SHORTEST PATH ALGORITHM

RSP bridges the gap between LCP and random-walk approaches

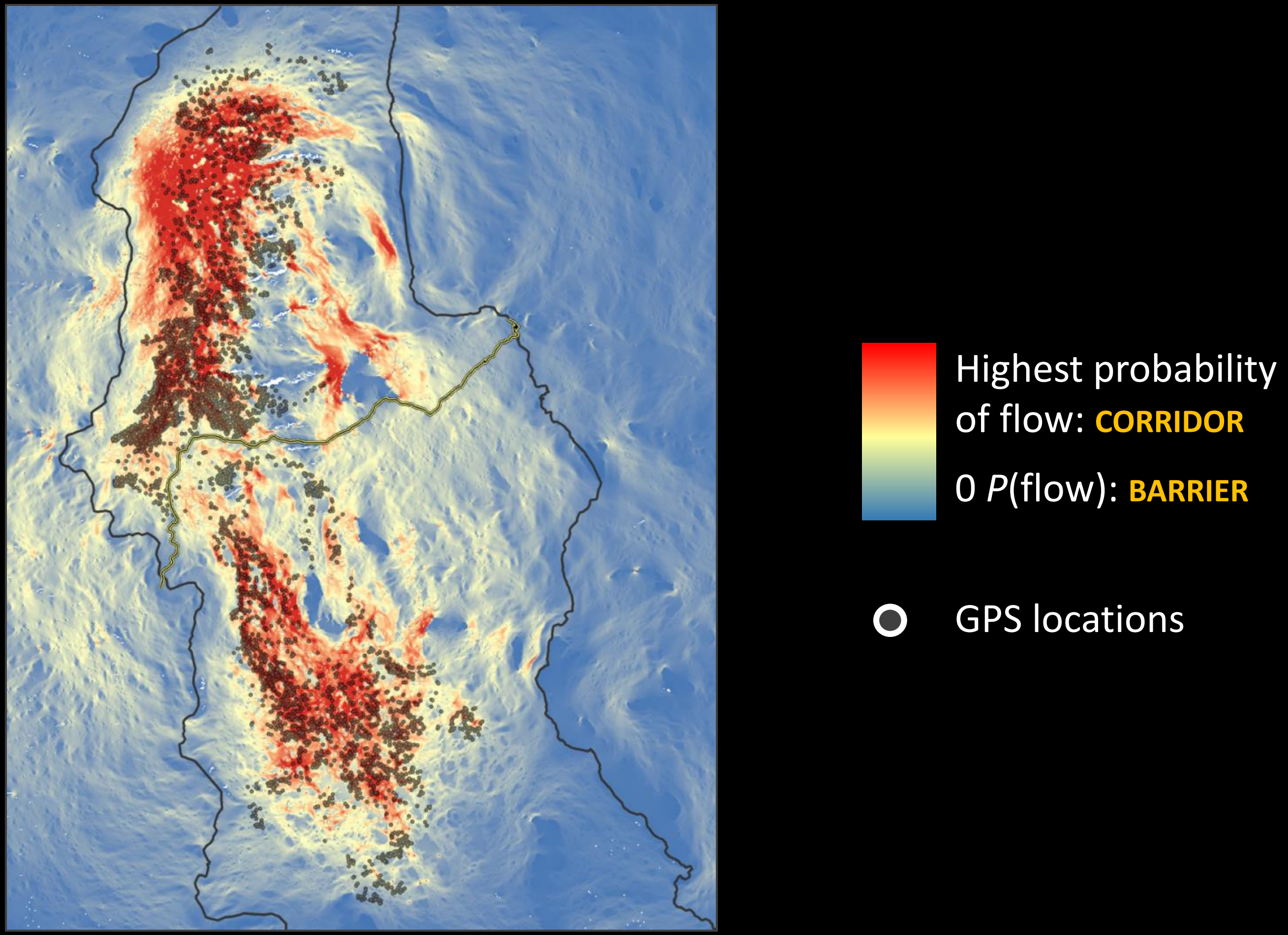
It allows modelling the entire *continuum* between optimal and random movements by identifying the paths based on a *given degree of randomness* in animal movements (controlled by parameter Θ):

Θ = 20 (Least Cost Path) «Something in between» Θ = 0 (Random Walk)



Panzacchi et al, J. Anim. Ecol. 2016

PREDICTED VS. OBSERVED MIGRATION CORRIDORS



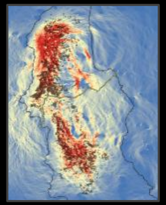
Sensitivity analyses shows that reindeer movement patterns neither fully random nor fully optimal, and this patterns is likely to be widespread among animals

Panzacchi et al, J. Anim. Ecol. 2016

NEED FOR FORMAL INTEGRATION OF DIFFERENT APPROACHES

Habitat quality

Friction to steps



Migration barriers/corridors

These information, separately, are valuable but insufficient to estimate the total impact of anthropogenic land use.

Management actions require a synthetic and spatially explicit representation of the total impact of habitat loss and fragmentation

Crucial to identify habitat that is *at the same time* good & accessible – «*Functional habitat*»

good but non-accessible habitat is lost to the species

HABITAT FUNCTIONALITY METRIC

Probability of Connectivity

= Amount of Reachable Habitat

$$= \sum_{s} \sum_{t} a_s a_t p^{*}_{s,t}$$

p*: highest probability path (Least Cost Path)

a: patch attribute (e.g. size, quality)

Available online at www.sciencedirect.com

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Landscape and Urban Planning 83 (2007) 91–103

LANDSCAPE AND URBAN PLANNING

www.elsevier.com/locate/landurbplan

A new habitat availability index to integrate connectivity in landscape conservation planning: Comparison with existing indices and application to a case study

Santiago Saura*, Lucía Pascual-Hortal

PROBABILITY OF CONNECTIVITY & HABITAT FUNCTIONALITY METRICS

Probability of Connectivity

$$= \sum_{s} \sum_{t} a_s a_t p^*_{s,t}$$

p*: highest probability path (Least Cost Path)

a: patch attribute (e.g. size, quality)

Habitat Functionality

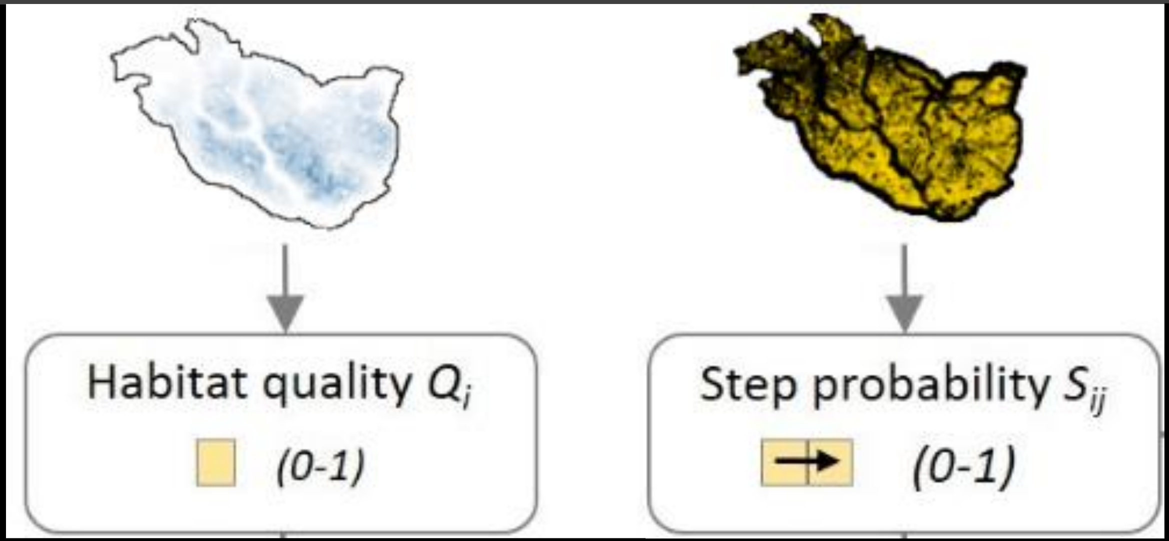
$$= \sum_{s} \sum_{t} Q_s Q_t Prox_{s,t}$$

Prox: opposite of distance (exp. cost) from *Randomized Shortest Path*

Q: pixel quality

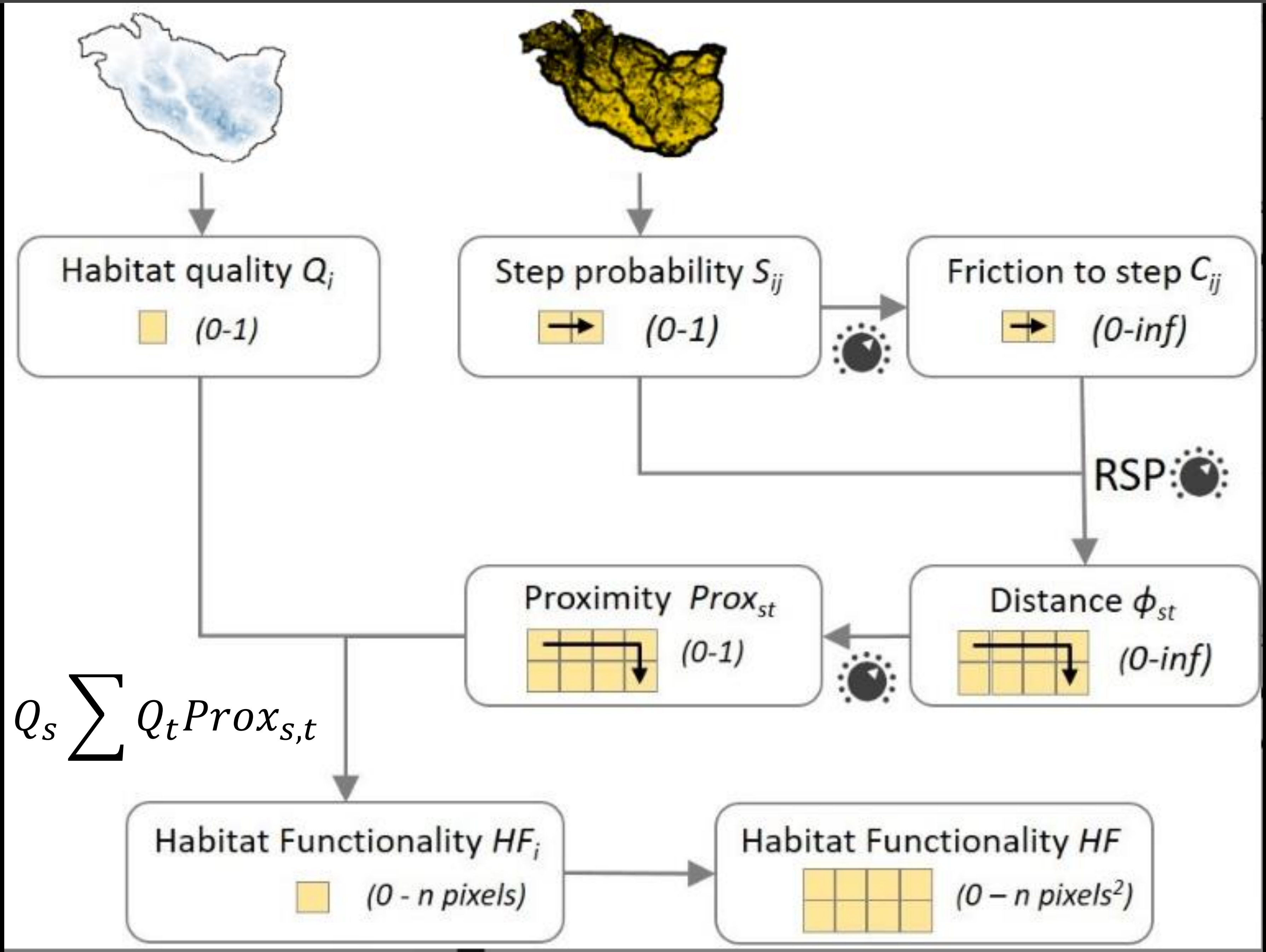
HABITAT FUNCTIONALITY - WORKFLOW

inputs



HABITAT FUNCTIONALITY - WORKFLOW

inputs



outputs

HABITAT FUNCTIONALITY - TUNED TO THE SPECIES' MOVEMENT PATTERNS

Step cost is the opposite of the step probability:

- Inverse: $c_{i,j} = {}^{1}/_{s_{i,j}}$
- Inverse, corrected: $c_{i,j} = {}^{1}/_{s_{i,j}} - 1$
- Logarithmic: $c_{i,j} = -\log(S_{i,j})$

Randomized Shortest Path:

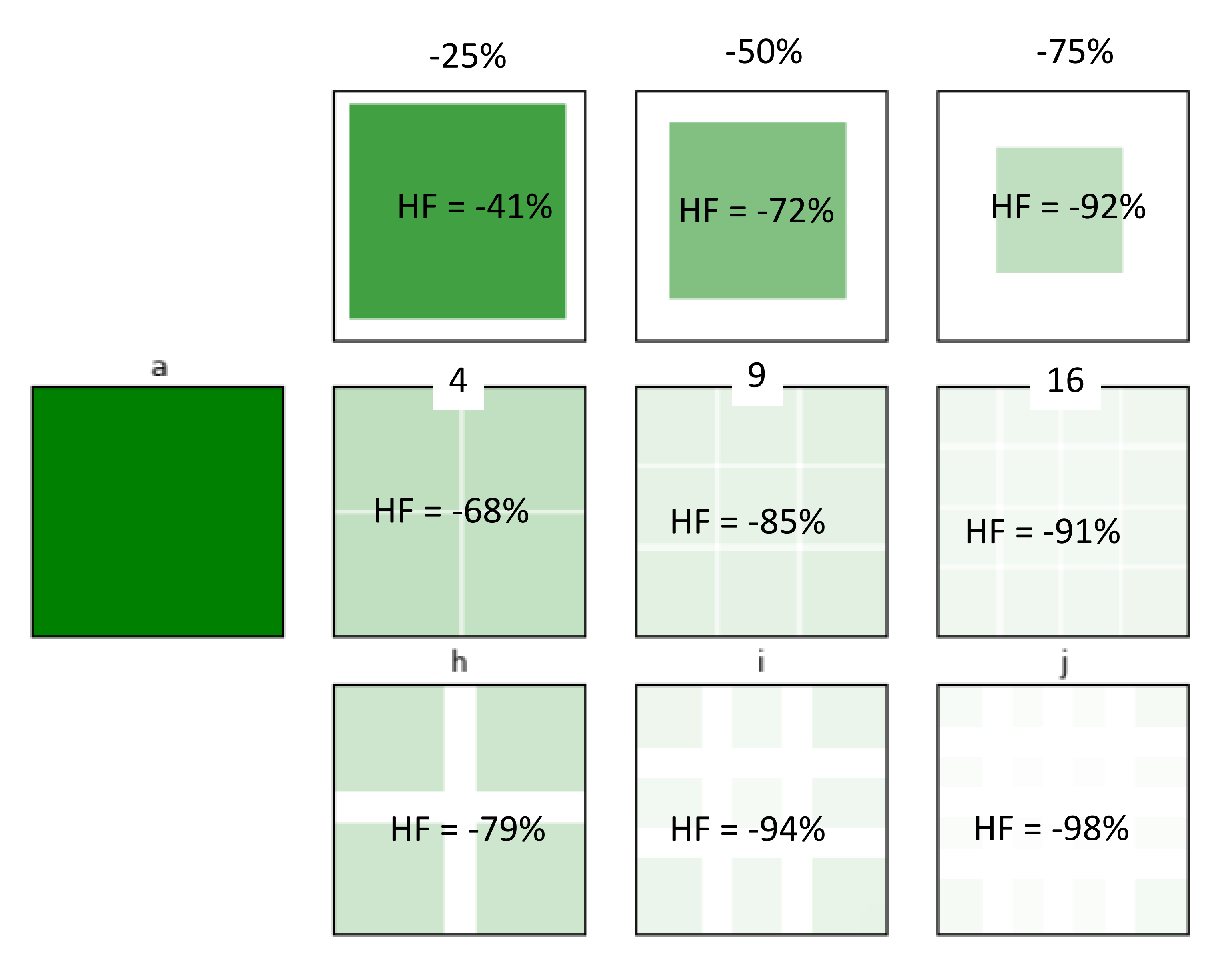
- $\theta \rightarrow 0$ = Random walk, "Circuitscape"
- $\theta \rightarrow \infty$ = Least-Cost Path

Proximity is the opposite of the ecological distance (exp. cost):

- Inverse: $Prox_{s,t} = {}^{1}/_{1+d_{s,t}}$
- Exponential: $Prox_{s,t} = \exp(-d_{s,t})$

$$HF = \sum_{s}\sum_{t} Q_s Q_t Prox_{s,t} \quad = \sum_{s}\sum_{t} a_s a_t p^{*}_{s,t} = \text{Probability of Connectivity}$$

PERFORMANCE OF HABITAT FUNCTIONALITY ON SIMULATED LANDSCAPES



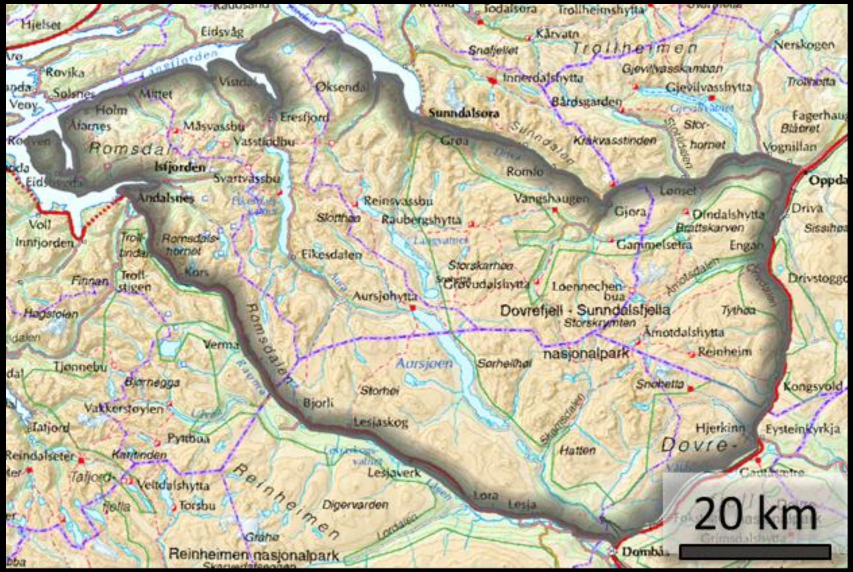
Habitat loss

Fragmentation

Hab loss + Fragmentation

HABITAT FUNCTIONALITY - DEMO

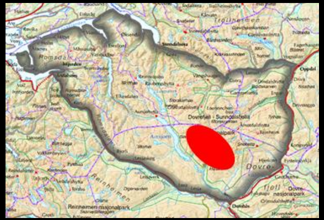
- Calculate HF for a reindeer management area



- Scenario approach: Estimate total impact of two *hypothetical* land development plans on HF

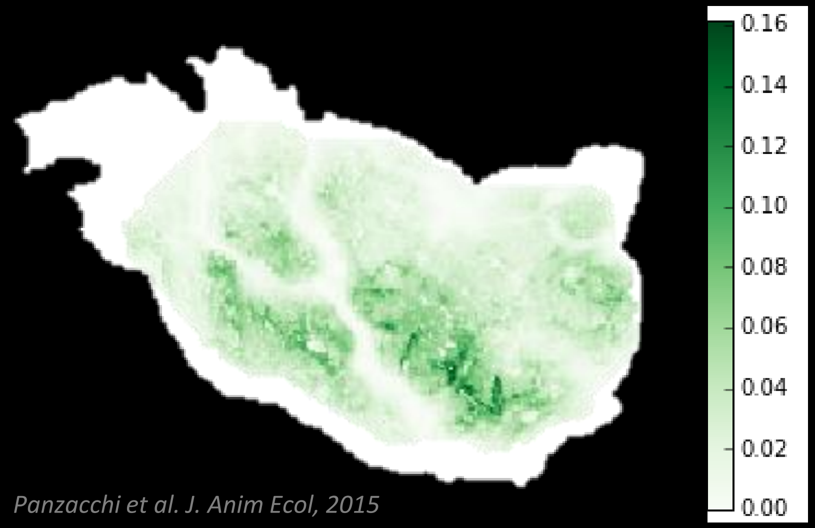
- *Scenario 1*: increased road traffic (increase fragmentation)

- *Scenario 2*: construction of cottage field (decrease habitat quality)



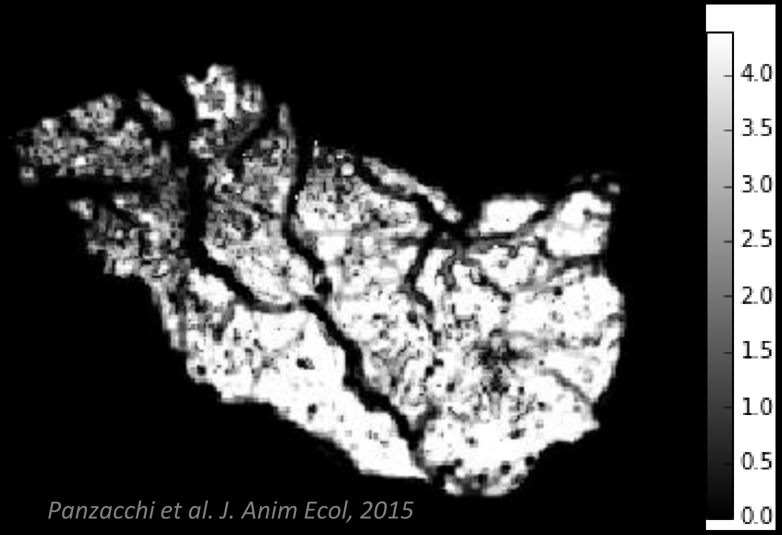
HABITAT FUNCTIONALITY - DEMO

Habitat quality

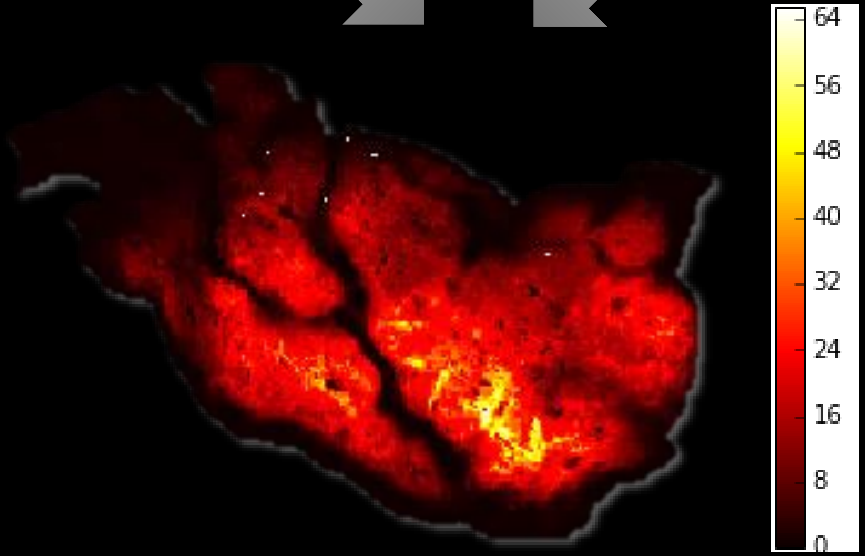


Panzacchi et al. J. Anim Ecol, 2015

Permeability to movement



Panzacchi et al. J. Anim Ecol, 2015

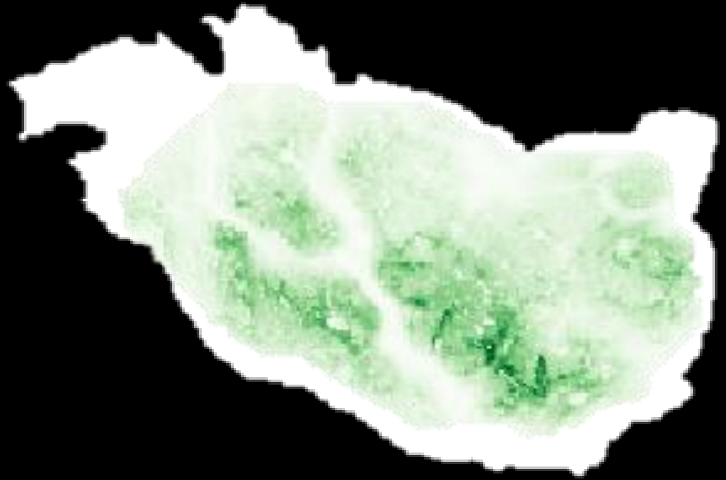


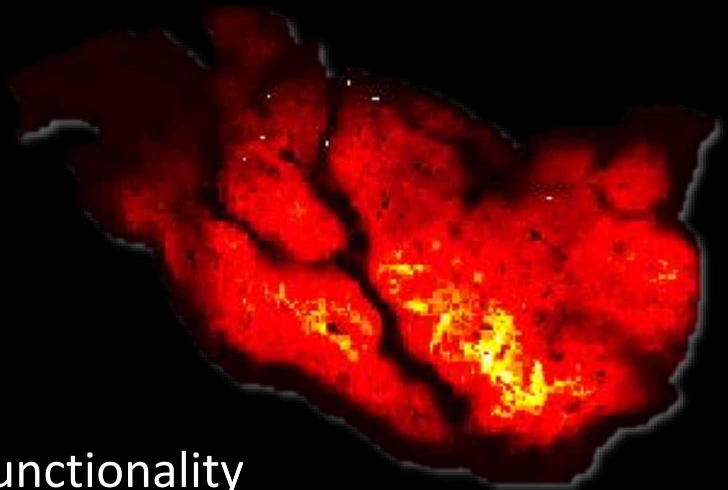
Habitat Functionality

Habitat that is simultaneously of high quality **&** well-connected

HABITAT FUNCTIONALITY - DEMO

Habitat quality





Habitat Functionality

DIFFERENCE

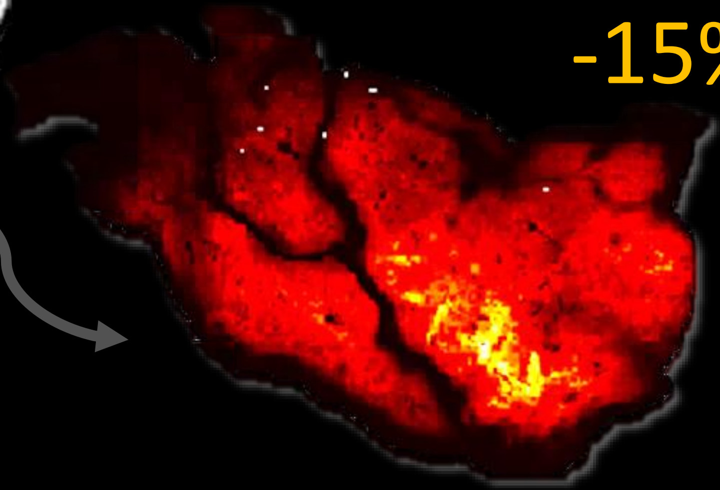
Relatively high quality,
but poorly connected habitat

SCENARIO 1: INCREASE ROAD TRAFFIC

No changes in hab. quality
reduction in permeability

Habitat Permeability

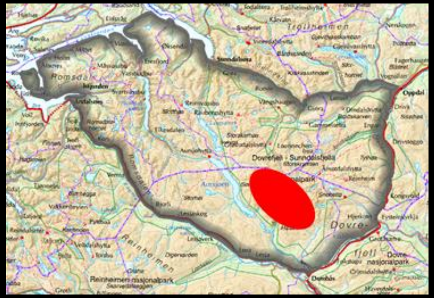
Habitat Functionality
-15%



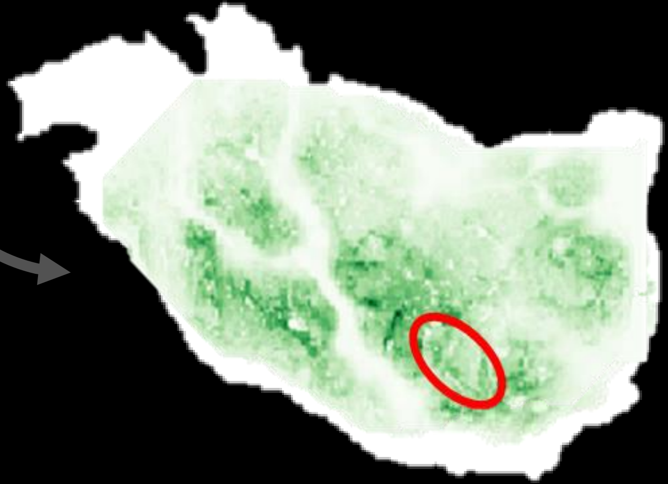
HABITAT FUNCTIONALITY - DEMO

SCENARIO 2: BUILD A COTTAGE FIELD

Local reduction in habitat quality

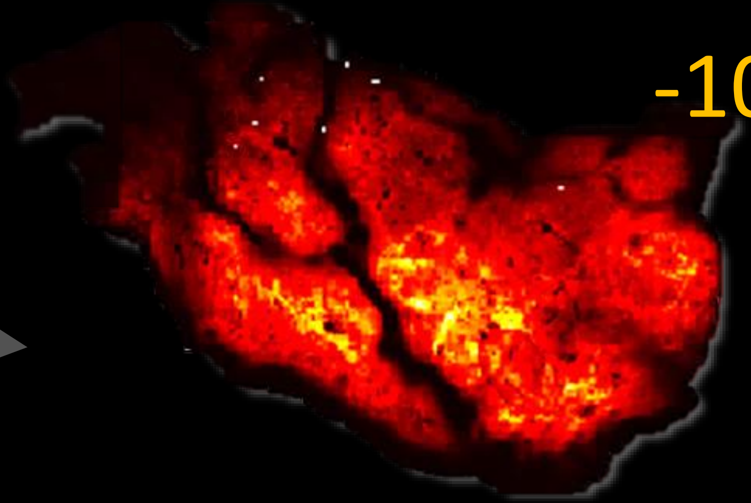


Habitat Quality



Habitat Functionality:

-10%



TAKE HOME MESSAGES

HF formally integrates advances from:

Landscape Ecology

1. HF is a generalization of the Probability of Connectivity (Saura & Pascual 2007)

Movement Ecology

2. Computed on continuous landscapes: each pixel provides both habitat and connectivity
3. Pixel quality & transition probability can be estimated directly from data
   However, expert based classifications of habitat types or indicators (e.g. human footprint) can also be used

Computer Science

4. Randomized Shortest Path algorithm: integrates Circuit Theory & Least-Cost Path
   Realistic movement corridors => Realistic ecological distances
4. Closed-form computation (Python) of expected cost between all pairs of pixels =>
   fast computation over large landscapes (< 10 min, standard laptop, 20.000 pixel landscape)

TAKE HOME MESSAGES

HF quantifies jointly, efficiently and realistically the total impact of two major drivers of biodiversity loss – i.e. habitat loss and fragmentation – on mobile species:

- high-quality, continuous landscapes are always classified as the most functional
- both habitat loss and fragmentation lead to reduction in HF; their combined effect is larger than each one independently
- space does matter: the impact of habitat / connectivity loss is highly dependent on their geographic locations
- isolated, good habitat locations have low HF, and contribute little to the HF of other locations
- poor quality locations have little HF, *but may contribute greatly to the functionality of other areas* by providing connectivity. This is an important difference with respect to previous studies, as movement corridors are not necessarily characterized by optimal habitat (e.g. road overpasses)

APPLICATIONS: assess or forecast the total impact of existing or planned anthropogenic development / mitigation options

Given these properties, HF may represent an appropriate alternative to traditional metrics in studies aiming at identifying with great accuracy areas to be prioritized for conservation of mobile species, or sustainable land development options

Thank you!

http://www.nina.no/english/Research/Projects/Renewable-Reindeer

The Research Council of Norway

NINA Norwegian Institute for Nature Research

MILJØ-DIREKTORATET

Norges vassdrags- og energidirektorat NVE

Sira-Kvina KRAFTSELSKAP

UCL Université catholique de Louvain

Villreinrådet i Norge

Norsk VILLREINSENTER

UNIVERSITY of GUELPH

UNIVERSITY OF ALBERTA

bc3 BASQUE CENTRE FOR CLIMATE CHANGE Klima Aldaketa Ikergai

Aalto University School of Science and Technology

Siri Bøthun Naturforvaltning