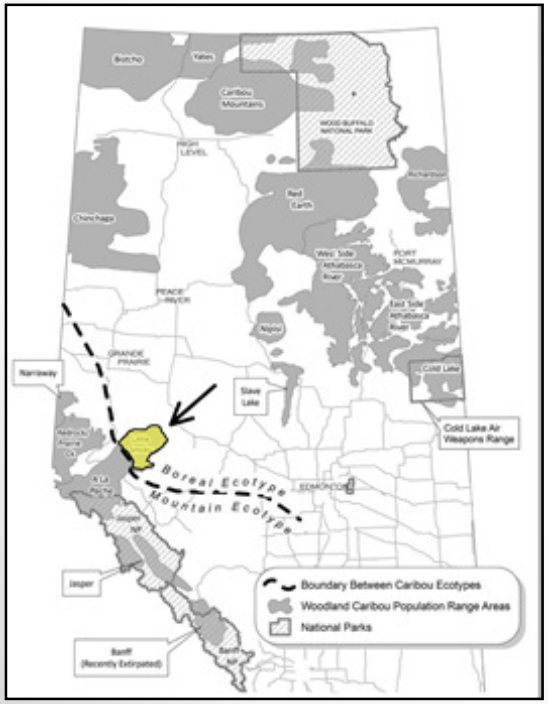
# Scenario modeling to support the protection of a threatened species (*Rangifer tarandus caribou*) in a highly industrialized landscape in Alberta, Canada

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Third International Conference on Biodiversity and Sustainable Energy Development
Valencia, Spain, June 24-26, 2014

# Context and study area (1)





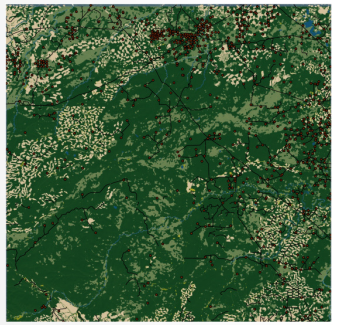

- Woodland caribou in Alberta are designated as threatened
  - Continued declines associated with human activities
- Little Smoky Caribou herd in west-central Alberta
  - Range covers about 3,100 $km^2$
  - Threatened herd includes 78 individuals
- The Alberta government recommends:
  - the assessment and management of cumulative effects on caribou
  - the provision of adequate habitat for their persistence

# Context and study area (2)

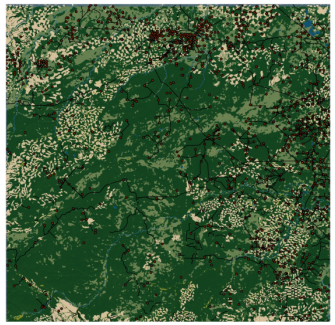
The range has the highest level of industrial development of any caribou herd in Canada

- Oil and gas industry (pipelines, seismic lines, wells)
- Forestry (cut blocks, roads)

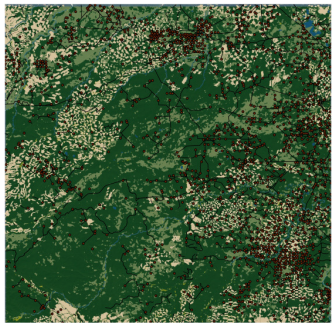
1998



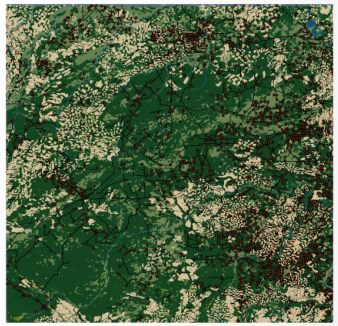
2001

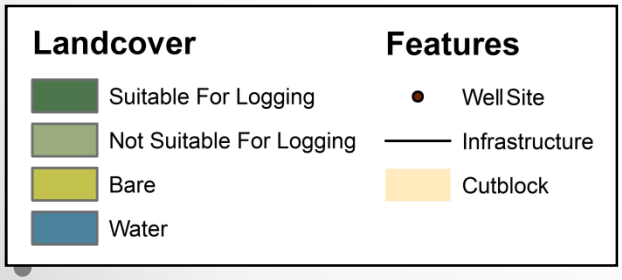


2004



2011






(Birkigt, 2011)

# Context and study area (3)





- These industrial activities affect caribou in several ways:
  - They destroy and fragment the caribou range composed of old growth conifer forests and muskegs
  - They remove large areas that contain lichens, their primary winter food source
  - They increase the risk of predation by facilitating the access to predators
  - They increase the stress on caribou that perceive anthropogenic activities and features as disturbance

# Objectives

To determine how the industrial activities influence woodland caribou habitat selection and use in the study area

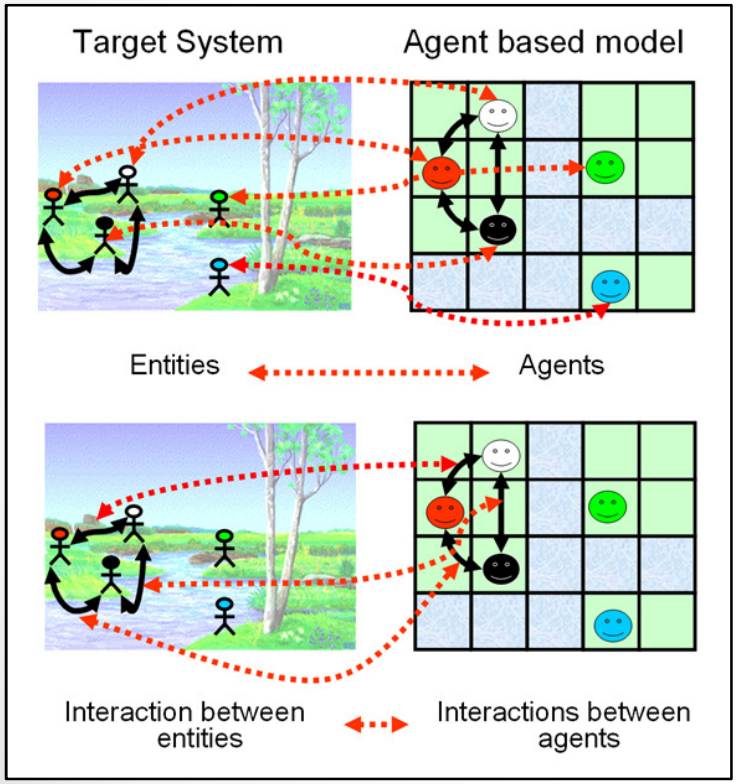




- An agent-based model was developed to:
  - Simulate and recreate the movement behaviors of caribou to explore how they select and use their winter habitat
  - Assess how caribou adapt to their changing environment
  - Determine the relative impact of different industrial features on caribou habitat selection strategies in winter

# Agent-based models (ABMs)

Agent-based models simulate a community of agents that interact within an environment that supports their activities




(Galan et al., 2009)

- Agents can be any entity of the real world
  - They are goal-driven and try to fulfill specific objectives
  - They are aware of and can respond to changes in their environment
  - They can communicate with other agents
  - They can cooperate, coordinate, and negotiate with each other
  - They have a memory
  - They can learn and adapt

# Modeling approach

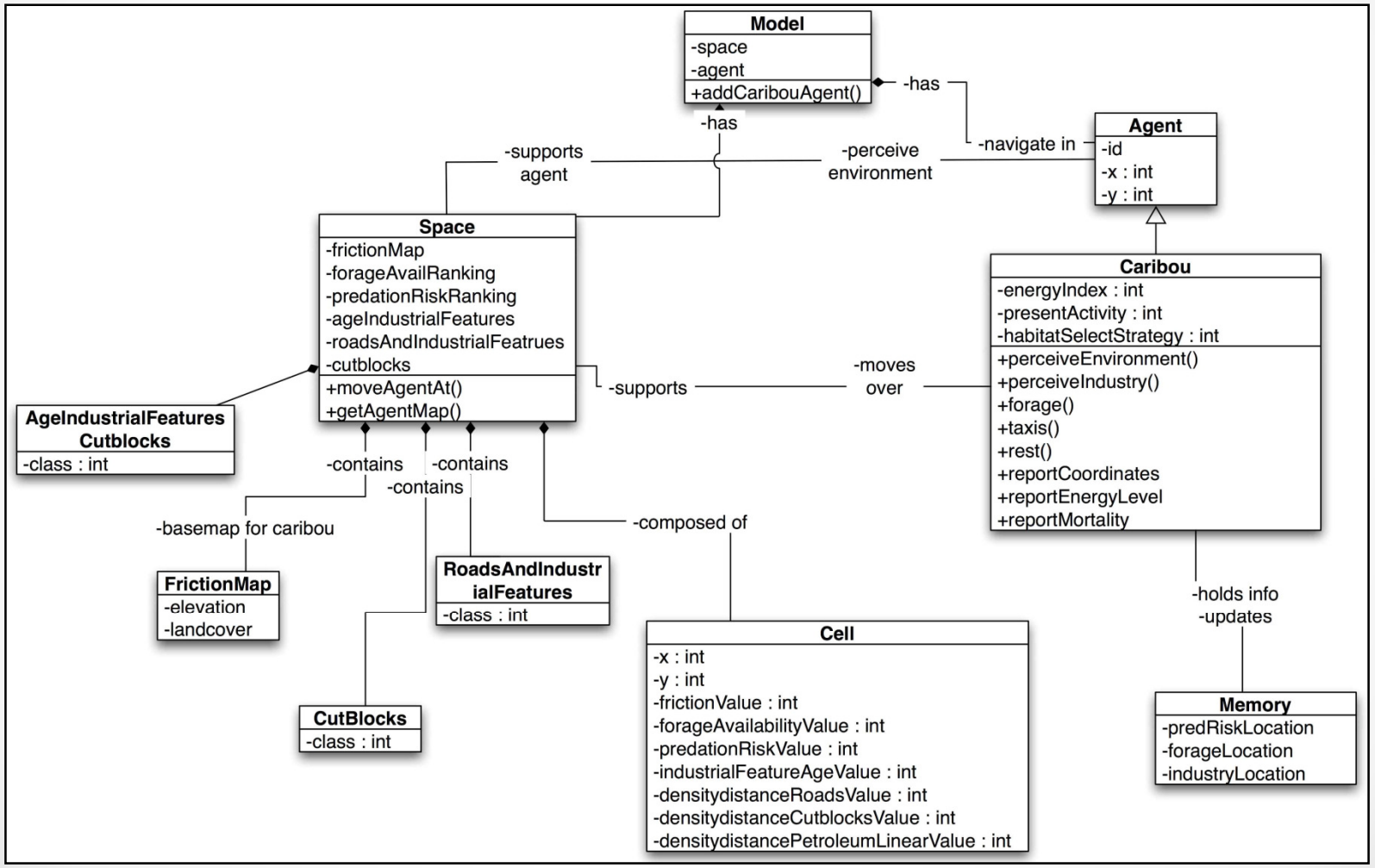
Our modeling approach combines movement ecology with behavioural ecology within an ABM framework





- The ABM simulates caribou as individual agents that:
  - Are capable of making trade-off decisions to maximize their survival and reproductive success
  - Are spatially aware of their surrounding environment
  - Have a memory
  - Can learn where to forage, while concurrently avoiding predators and habitat disturbance

# Model architecture




(Semeniuk et al., 2012)

# Caribou data collection

Caribou data were needed to parameterize and validate the ABM



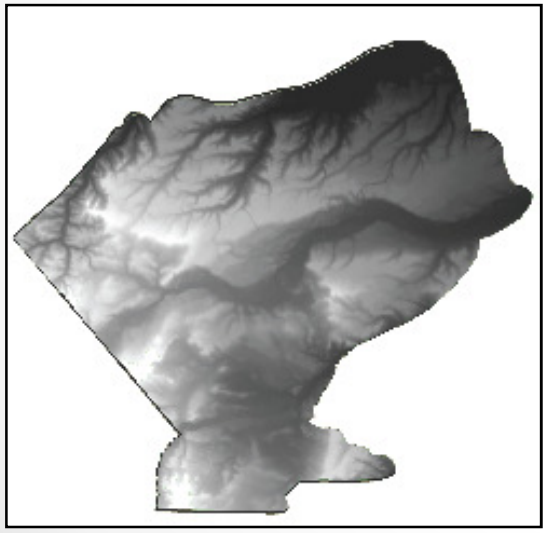
- These datasets include:
  - Radio-collared GPS location data from 13 female caribou in the winter 2004-2005
  - Preferred land-cover types and elevation
  - Bio-energetic functions
  - Movement (range, daily distance, speed)
  - Spatial memory

# Environmental data collection (1)

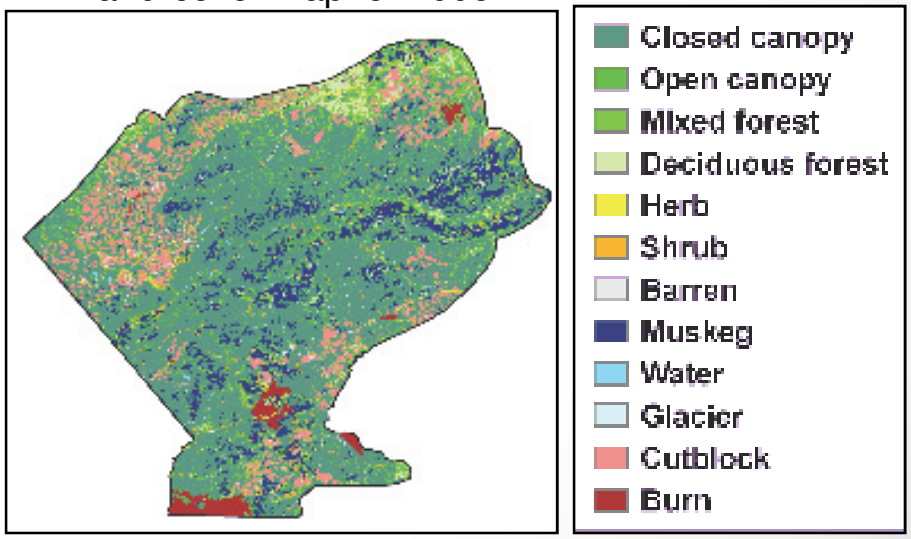
Several geographic datasets were incorporated into a GIS database as attribute layers of the study area

- Digital Elevation Model at 30 m resolution
- Land-cover map produced from Landsat TM imagery with 12 classes

Digital Elevation Model



Land-cover map for 2005



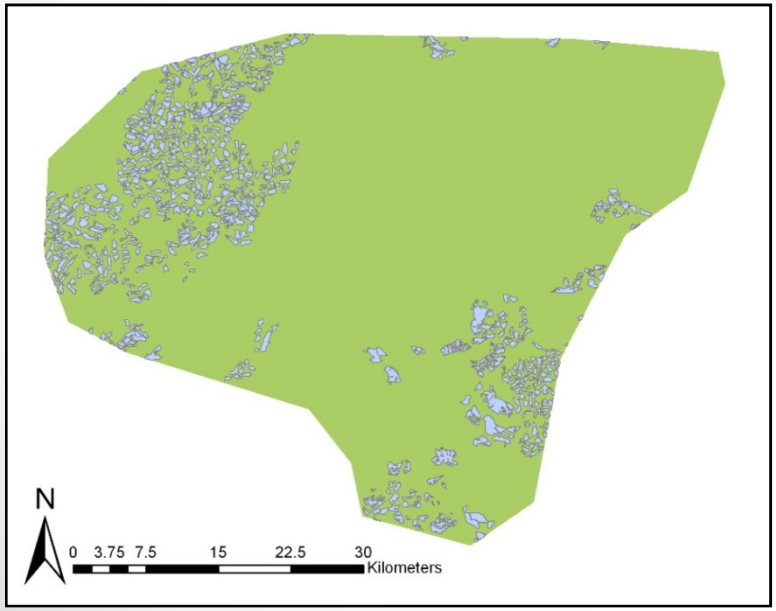

(Semeniuk et al., 2011)

# Environmental data collection (2)

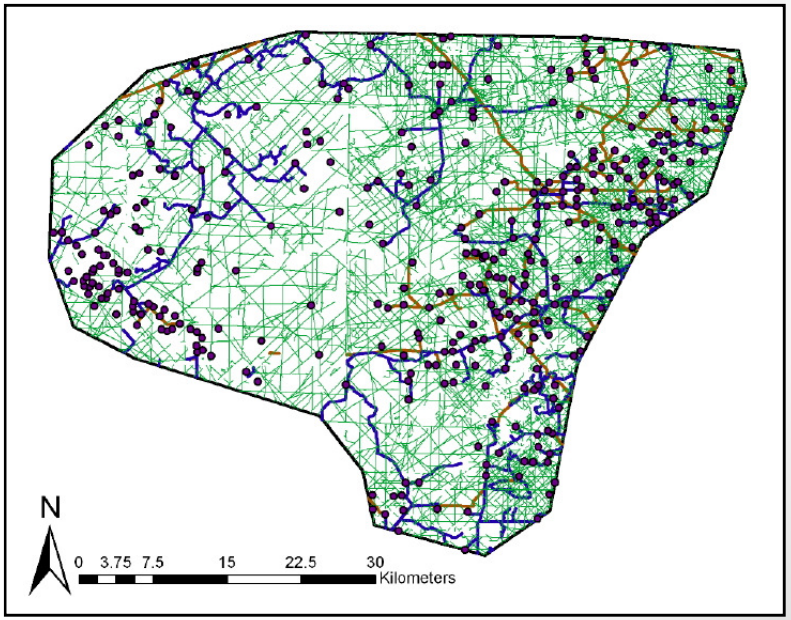
Other geographic datasets were incorporated into a GIS database as attribute layers of the study area

- Map of cut blocks for the year 2005
- Map of the industry features for the year 2005

Forestry cut blocks in 2005




Industry features in 2005

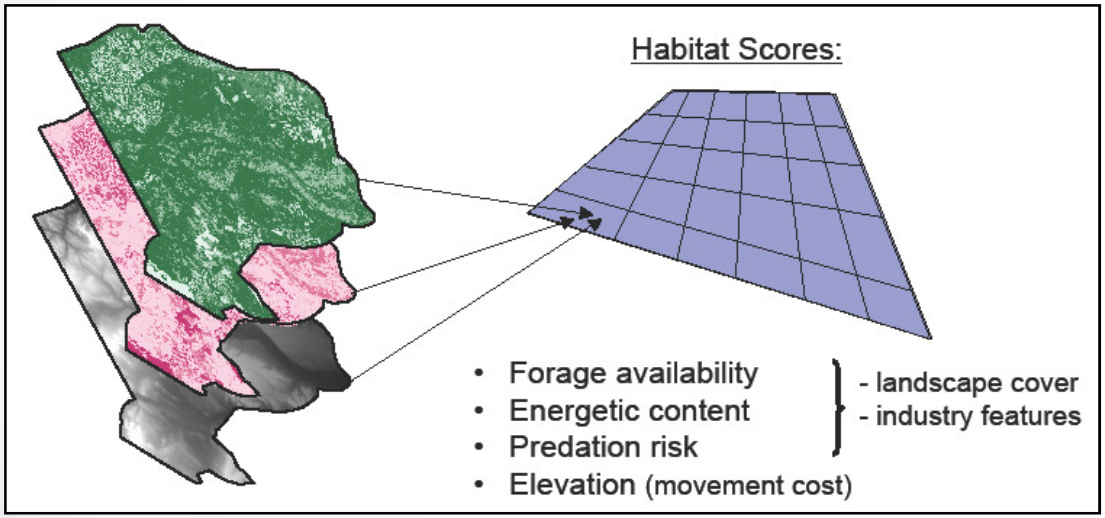



(Semeniuk et al., 2011)

# Representation of the environment

The environment was represented as a virtual grid (45 m resolution) where the caribou agents are located and perform their activities

Each cell of the environment was assigned four values:

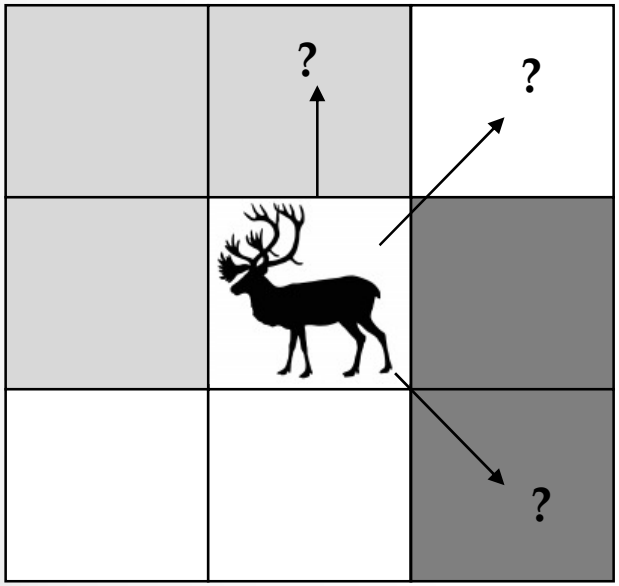



(Semeniuk et al., 2011)

- A forage availability score
- An energetic content
- A predation risk score
- An elevation value

# Agent's behavior (1)

The ABM is based on the premise that the individual animal's internal state influences how it perceives its environment, which drives its decision-making process



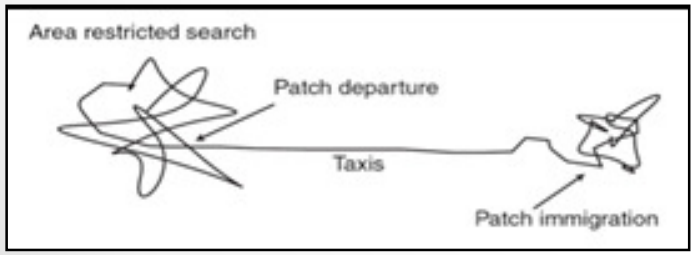

(Semeniuk et al., 2011)

- Based on caribou bio-energetics, the model considers:
  - The internal state of the animal (why to move)
  - The motion (how to move)
  - The navigation (when and where to move)

# Agent's behavior (2)

Caribou engage in different types of movement, reflecting different scales of habitat selection

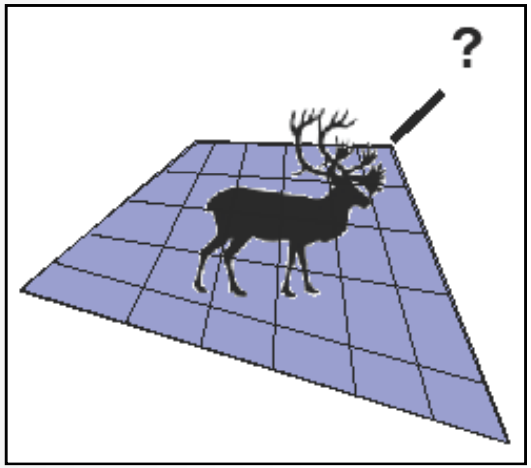





- The model simulates four types of movement:
  - Local, intra-patch foraging where caribou move one cell at a time
  - Inter-patch foraging, up to two cells at a time
  - Random taxiing to an unknown location
  - Revisiting a previously-visited patch drawn from memory

# Agent's memory

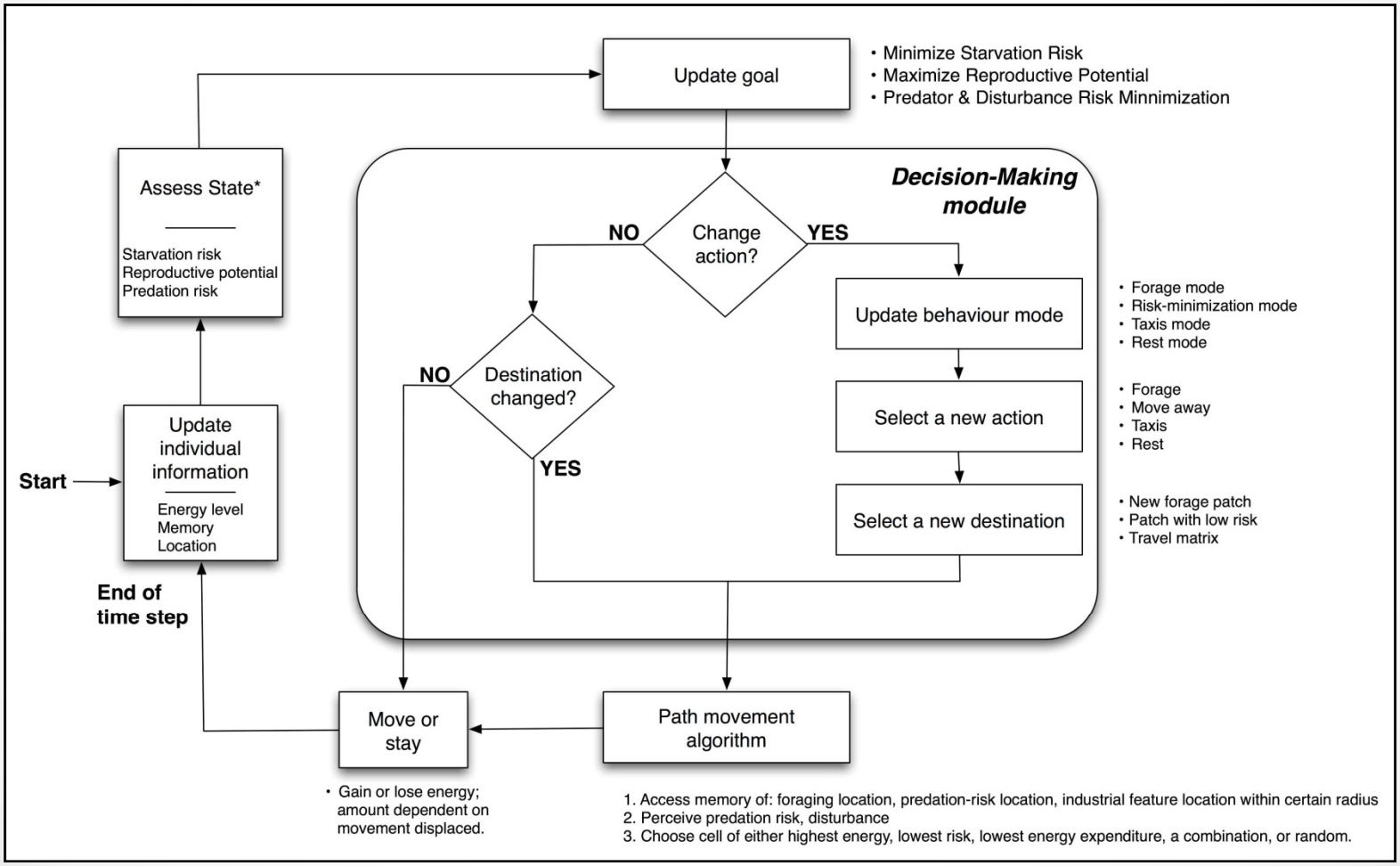
The model considers two types of memory: reference and working




(Semeniuk et al., 2011)

- Reference memory:
  - Stores locations for profitable feeding and low risk areas
- Working memory:
  - Used to avoid backtracking on recently depleted food patches

# Caribou agent's decision making




(Semeniuk et al., 2012)

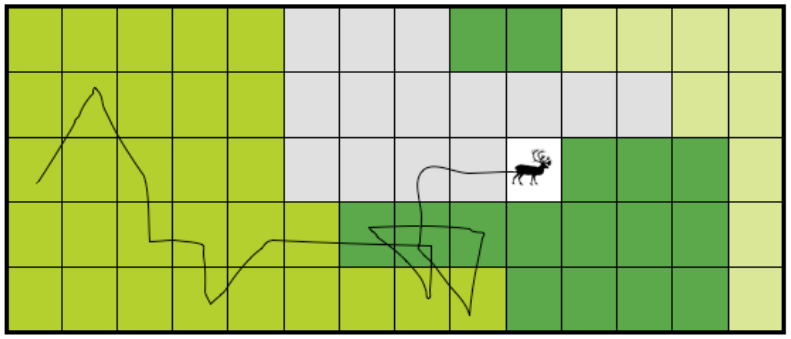
# Simulation framework (1)

The simulation framework is as follow:

- The model is run with one agent per simulation
- The spatial resolution is 45 m
- The time step is 30 min
- The model is run for 180 days (winter season)
- An agent represents a pregnant female at 132 kg
- Initial starting coordinates match the location of actual caribou
- Each simulation is replicated 65 times; results are averaged
- The model was developed in NetLogo

# Simulation framework (2)

The model keeps a record of the caribou agent's internal state and movement during the simulation



(Semeniuk et al., 2011)

- The following information is recorded:
  - Location, the cell occupied by the caribou agent
  - Current energetic uptake
  - Cumulative amount of energy accumulated and lost
  - Net cumulative energy
  - Previous locations of high energy return and low predation risk

# Simulation framework (3)

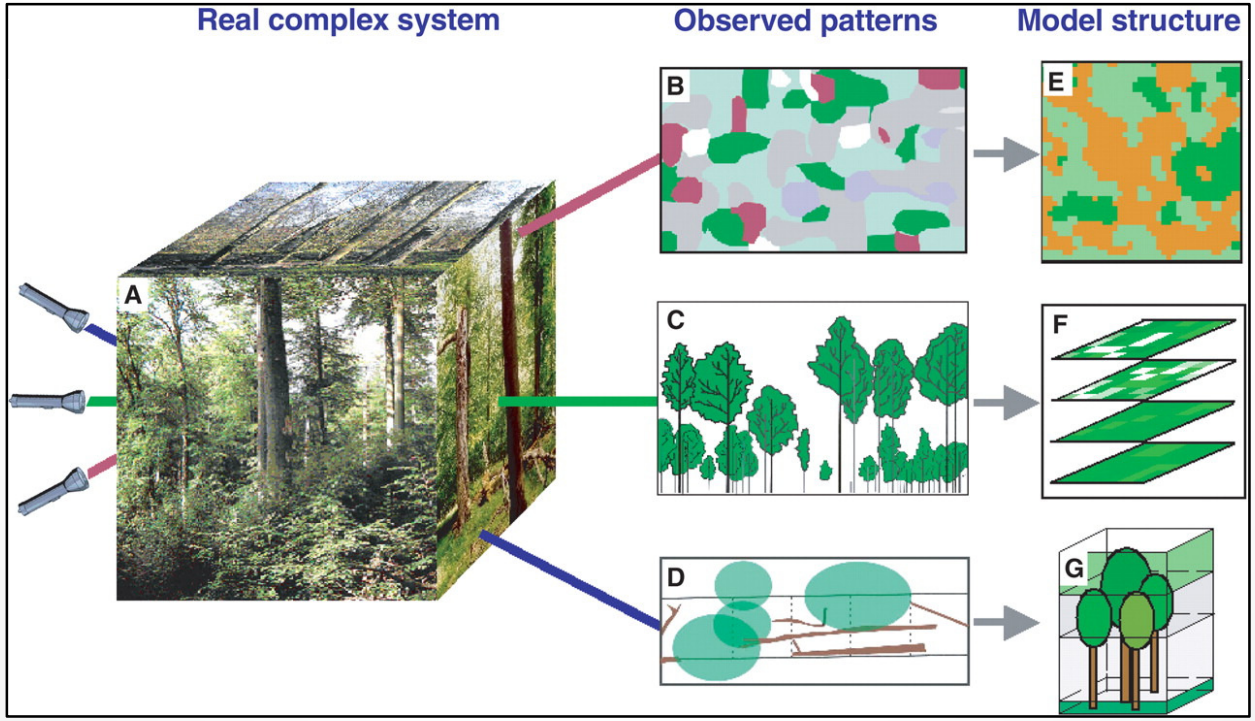
Five behavioral strategy scenarios were simulated:

- **DRP**: balance between energy requirements, long-term reproduction and avoidance of predation
- **DP**: reproductive requirements are neglected
- **RP**: reproductive requirements take precedence
- **DR**: predation insensitive
- **P**: predation hyper-sensitive

# Model validation (1)

The quality of the simulation results was measured using the pattern-oriented modeling approach (Grimm et al., 2005)

Consists in comparing simulated patterns with observed ones



# Model validation (2)

Different metrics were used to compare the patterns generated through the simulation with observed patterns from the scientific literature and field observations



- Bio-energetic patterns:
  - Daily energy gain/expenditure
  - Cumulative energy loss over winter
  - Energy budget
- Spatio-temporal patterns:
  - Daily distance traveled
  - Daily step length pattern
  - Use of low/high elevations
  - Land-cover usage
  - Range: minimum convex polygon

# Results: bio-energetic patterns (1)

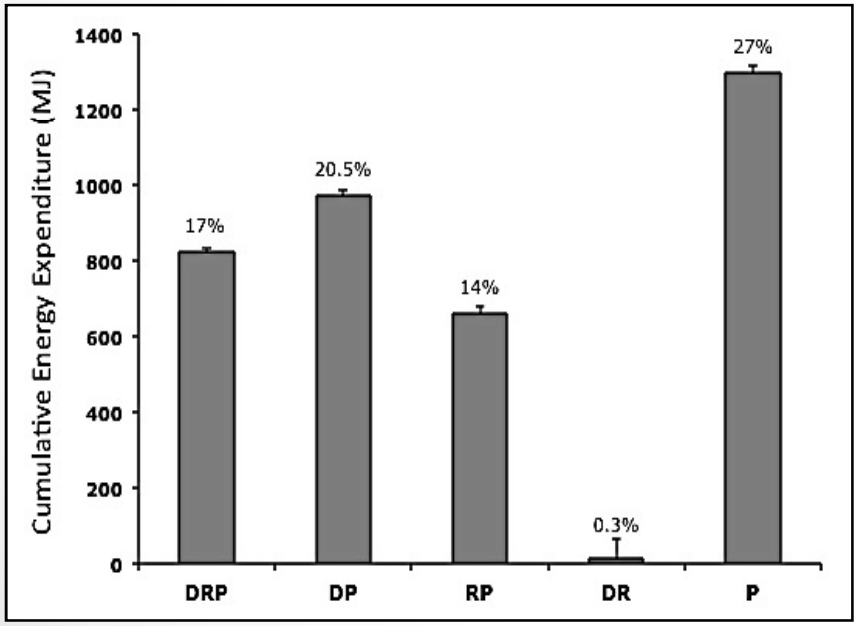
The values obtained with the model fall within the range of values reported in the literature

| | Actual Values | Energetics & Predation (DRP) | Energy Acquisition (DP) | Energy Conservation (RP) | Predation-Insensitive (DR) | Predation – hypersensitive (P) |
|---|---|---|---|---|---|---|
| **Median daily energy gain (MJ)** | 22 - 33 | 25.4 | 24.6 | 24.6 | 28.2 | 21.7 |
| **Mean daily energy loss (MJ)** | -28.7 | -28.1 | -28.1 | -26.4 | -25.9 | -27.8 |
| **Percent time spent foraging (%)** | 50 – 88 | 76.9 | 69.6 | 71.2 | 74.6 | 64.9 |

(Semeniuk et al., 2012)

# Results: bio-energetic patterns (2)

As expected, in each simulated scenario, the caribou agents experienced a cumulative energetic deficit by the end of the season

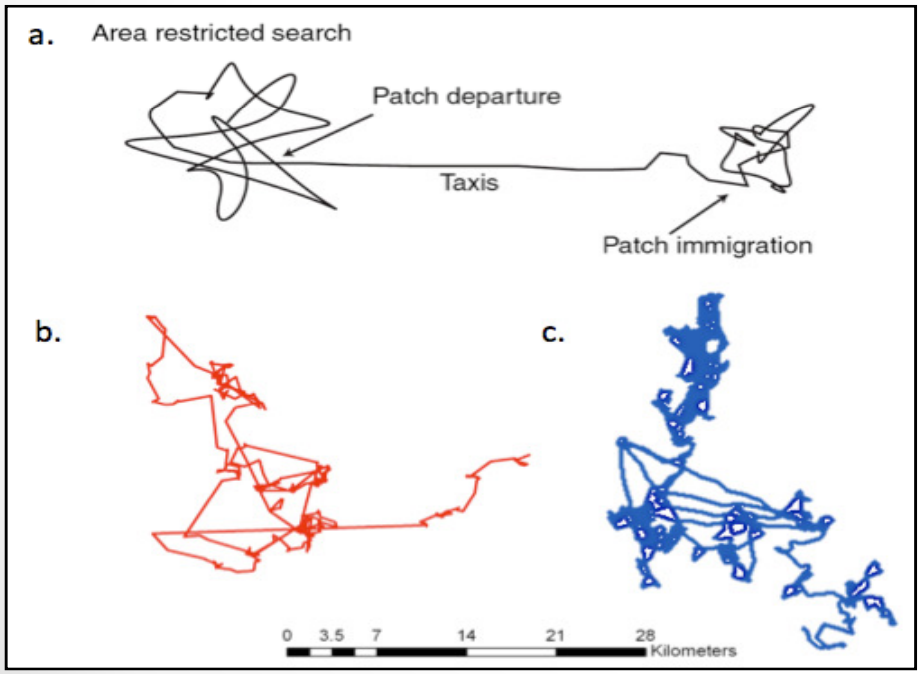



(Semeniuk et al., 2012)

- The deficit is the largest for the scenario P in which the agents are hypersensitive to predation
- It is the smallest for the scenario DR in which the agents are not sensitive to predation

# Results: movement patterns (1)

The trajectories of the agents exhibit the typical movement path displayed by real caribou: high tortuosity in the small-scale movements separated by straighter tracks in the large-scale ones

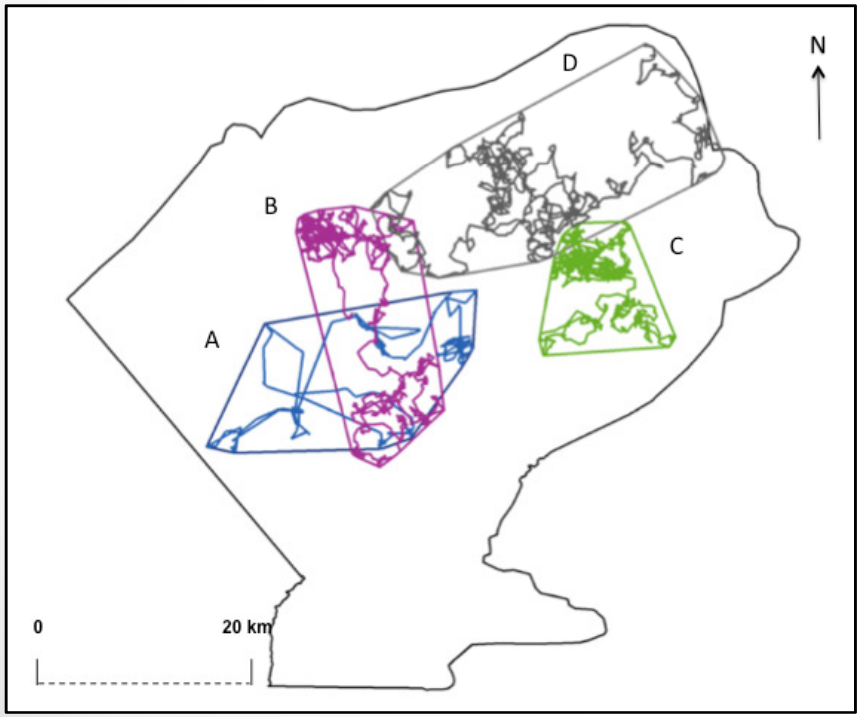



(Semeniuk et al., 2012)

- a: typical movement behavior
- b: movement displayed by a real female caribou
- c: movement of a simulated caribou agent

# Results: movement patterns (2)

The trajectories of three simulated agents (B, C, and D) closely match the individual minimum convex polygon of a real caribou

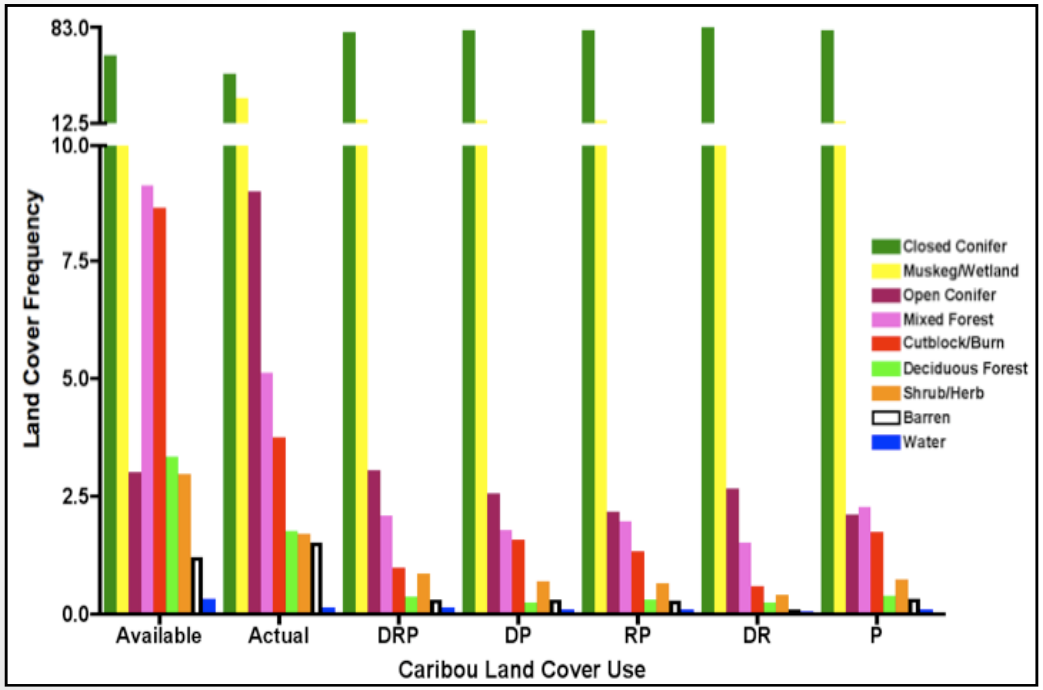



(Semeniuk et al., 2012)

- Scenarios:
  - A: real caribou
  - B: energetics and predation
  - C: predation-insensitive
  - D: predation hypersensitive
- The caribou agents use the landscape differently depending on the scenario being simulated

# Results: land-cover use

Simulated caribou used land-cover classes similarly to actual caribou with respect to the overall order




(Semeniuk et al., 2012)

- Closed conifers and muskeg/wetlands are used the most in all scenarios
- Open conifers is not used as much by the agents as the actual caribou do; this is due to the allocation of forage value and energetic content during the calibration of the model

# Results: summary

The ranking of scenarios based on how closely they match the patterns of real caribou reveals the following:

- The Energetics and Predation scenario (DRP) in which the caribou agent must trade-off its daily energy requirement, minimize its reproductive energy loss and minimize the predation risk is the best-fit scenario
- Not recognizing industrial features as predation risk (Predation insensitive scenario, DR) causes simulated caribou to unrealistically reduce their daily and landscape movements
- The Hyper-sensitive scenario (P) results in unrealistic energetic deficits and large-scale movement patterns, unlike those observed in real caribou

The simulated patterns are the result of trade-off decisions made by the caribou agents; they *emerge* from these decisions

# Conclusion

Our model demonstrates that caribou (LSM) are sensitive to industrial features on the landscape that evoque anti-predator responses and bioenergetic costs in the absence of any explicit predators modelled



- Management efforts should ensure that caribou:
  - are not increasingly energetically stressed
  - have enough high-quality forage and available habitat to meet their needs required for reproduction
- Management efforts should limit new industrial development and restore some areas

# Acknowledgements

Semeniuk, C., M. Musiani, M. Hebblewhite, S. Grindal, and D. J. Marceau, 2012. Incorporating behavioral-ecological strategies in pattern-oriented modelling of caribou habitat use in a highly industrialized landscape. *Ecological Modelling* 243: 18-32.



- Funding was provided by:
  - GEOIDE
  - MITACS/NSERC
  - ConocoPhillips Canada
  - Tecterra

# Work in progress: dynamic landscape (1)

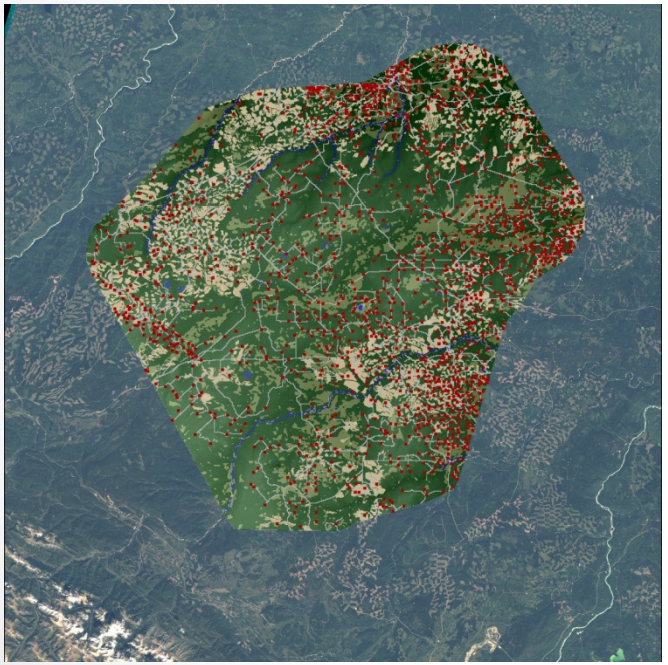
In its actual version, the ABM simulates the behavior of caribou agents on a static environment corresponding to know conditions for a specific season (winter 2004-2005)

- Work is in progress to simulate a changing landscape using a CA model
  - Scenarios of future land development plans (oil and gas and forestry) are being simulated

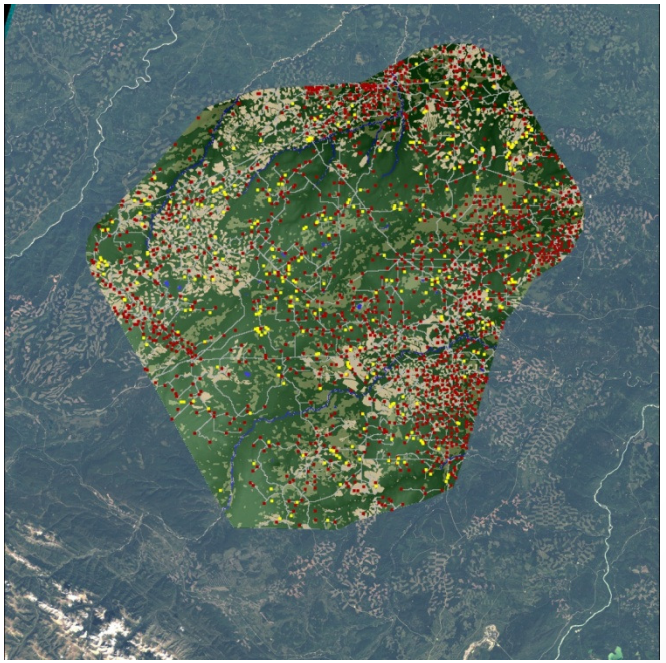
- Transition rules implemented for well development:
  - Wells are located preferably on low slope
  - They are located in areas having a high resource potential
  - They are preferably found within 2 km of existing infrastructure
  - They are preferably located within 1.8 km of another well

# Work in progress: dynamic landscape (2)

Land use map 2011



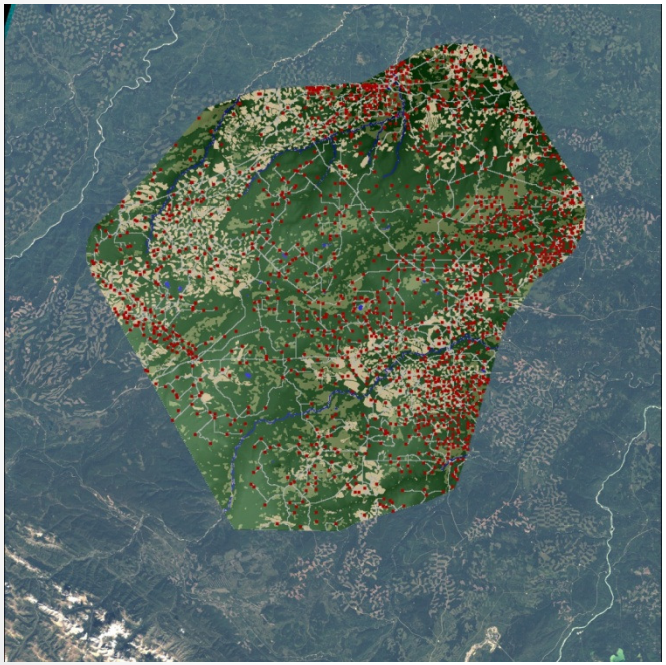
Simulated well development in 2015



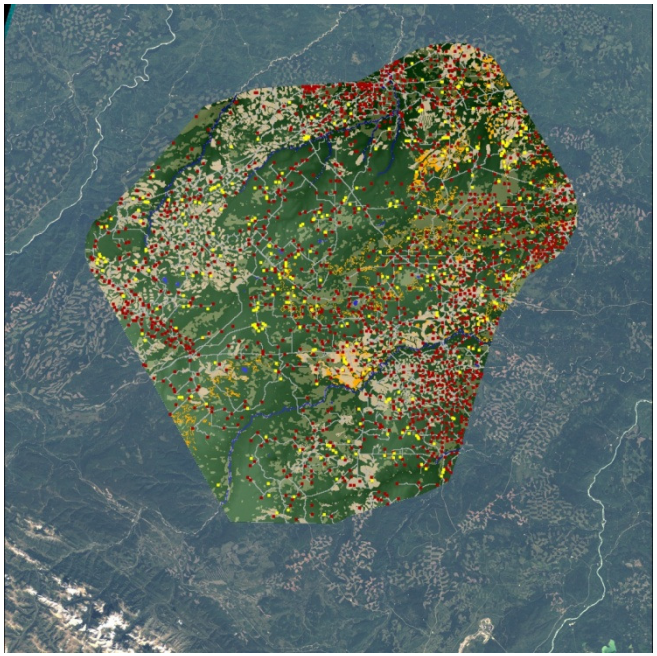

(Birkigt, 2012)

# Work in progress: dynamic landscape (3)

Land use map 2011



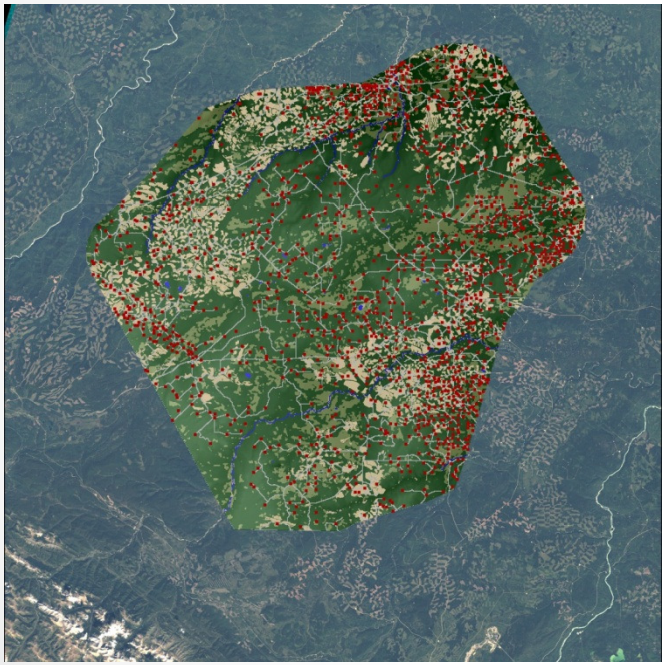
Simulated well development and one harvesting plan in 2015



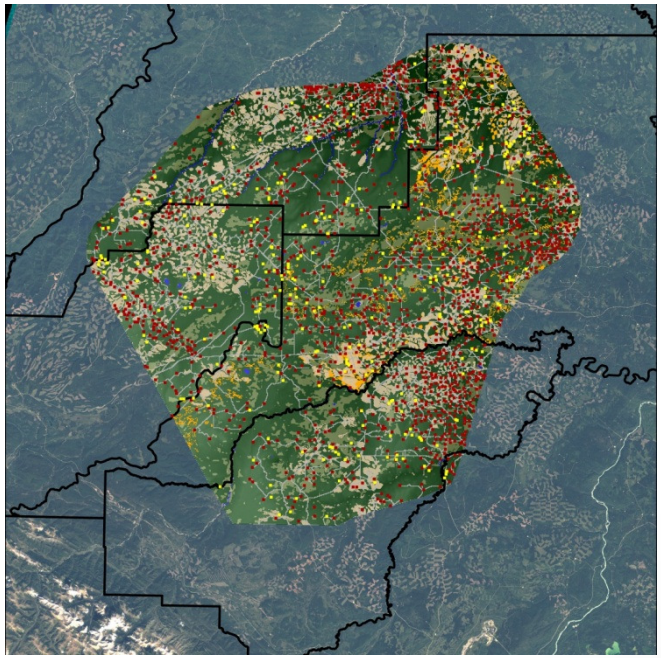

(Birkigt, 2012)

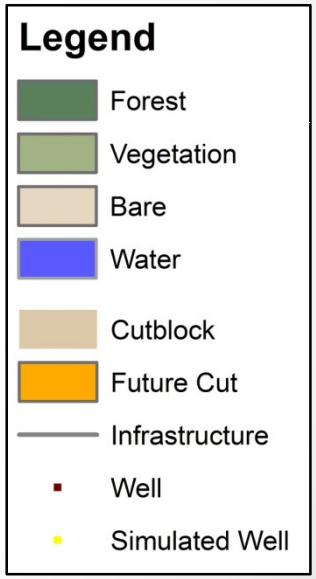
# Work in progress: dynamic landscape (4)

Land use map 2011



Management forestry units






(Birkigt, 2012)



