Adaptive monitoring of Arctic ecosystems Why, What and How?

Nigel G. Yoccoz
Department of Arctic and Marine Biology
UiT -The Arctic University of Norway

Fram – High North Research Centre for Climate and the Environment

446 Review TRENDS in Ecology & Evolution Vol.16 No.8 August 2001

Monitoring of biological diversity in space and time

Nigel G. Yoccoz, James D. Nichols and Thierry Boulinier

Recent reviews of the existing programmes, with a focus on their design in particular, have highlighted the main weaknesses:

- **the lack of well articulated objectives and**
- **the neglect of different sources of error in the estimation of biological diversity**

Why monitor?

Scientific objectives focus entirely on learning and developing an *understanding of the behaviour and dynamics of the monitored system*.

Monitoring programmes designed to aid management provide information that is useful in *making informed management decisions*.

[predictions as such were not emphasized as an objective but as essential to compare models]

What to monitor

Decisions about which variables to monitor are *determined largely by the objectives* of the monitoring programmes; that is, by the answer to 'Why monitor?'

Monitoring programmes directed at scientific objectives should *focus on the state variables and associated rate parameters* that are important to the *a priori* hypotheses (and their associated *models*) of system behaviour.

Monitoring programmes designed to inform management should focus on the *state and other variables that are included in the objective function*, as well as on variables that are needed to *model the managed state variables* adequately

How to monitor

There are *two potential sources of error* that should be considered when estimating biological diversity

- Detection Error
- Spatial Variation and Survey Error

Ecological monitoring has emerged as a proper science

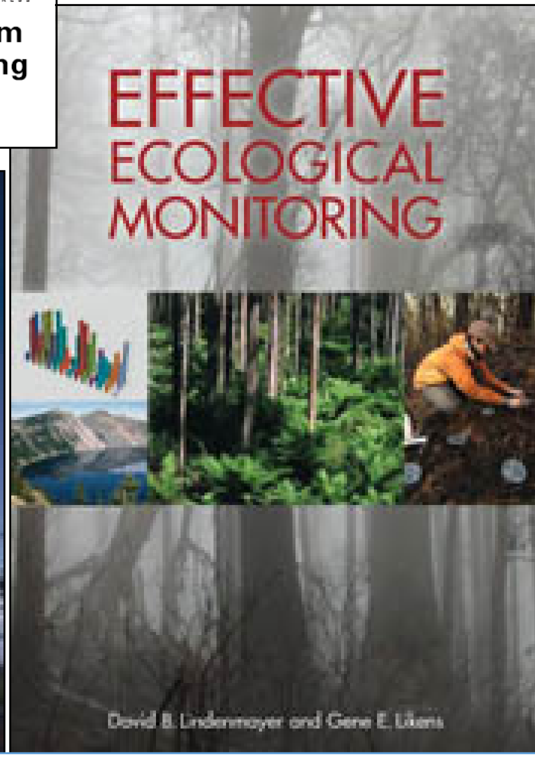
⇒ Theory, Approaches, Methods and a vivid scientific debate

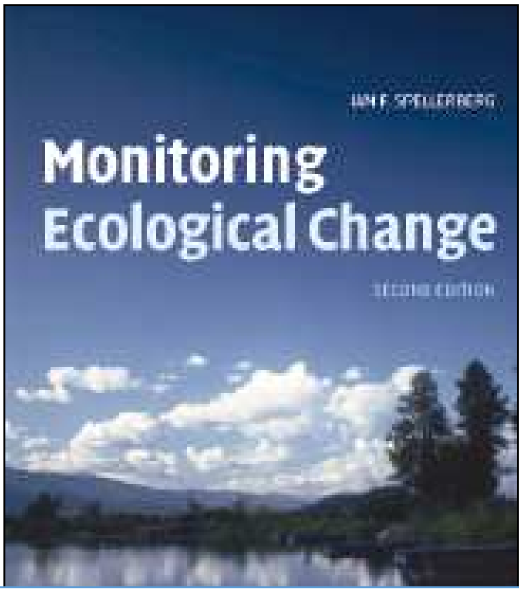
Opinion

Adaptive monitoring: a new paradigm for long-term research and monitoring

David B. Lindenmayer[1] and Gene E. Likens[1,2]

[1] Fenner School of Environment and Society, The Australian National University, Canberra, ACT 0200, Australia
[2] Cary Institute of Ecosystem Studies, Millbrook, NY 12545, USA





Contents lists available at ScienceDirect
Biological Conservation
journal homepage: www.elsevier.com/locate/biocon

Review

The science and application of ecological monitoring

David B. Lindenmayer [a,*], Gene E. Likens [a,b]

Global Change Biology

Global Change Biology (2009) 15, 2770–2778, doi: 10.1111/j.1365-2486.2009.01971.x

Long-term ecological sites: musings on the future, as seen (dimly) from the past

H. H. JANZEN
Agriculture and Agri-Food Canada, Lethbridge, AB, Canada T1J 4B1

Review

Special Issue: Long-term ecological research

Accessible ecology: synthesis of the long, deep, and broad

Debra P.C. Peters
Jornada Basin Long Term Ecological Research Program and USDA ARS, Jornada Experimental Range, Las Cruces, NM 88003, USA

Special Issue: Long-term ecological research

Monitoring does not always count

Eve McDonald-Madden[1,2], Peter W.J. Baxter[1,3] ...
Edward T. Game[4], Jensen Montambault[5] and ...

Monitoring for conservation

James D. Nichols[a] and Byron K. Williams[b]

ECOSYSTEMS

Direct Measurement Versus Surrogate Indicator Species for Evaluating Environmental Change and Biodiversity Loss

David B. Lindenmayer[1*] and Gene E. Likens[1,2]

Contents lists available at ScienceDirect
Forest Ecology and Management
journal homepage: www.elsevier.com/locate/foreco

A new approach to forest biodiversity monitoring in Canada

Stan Boutin[a,*], Diane L. Haughland[a], Jim Schieck[a,b,c], Jim Herbers[b,c], Erin Bayne[a]

We share this view of monitoring:

Ecological monitoring most effective when based on hypotheses/models that :

- Outline the known or assumed functioning of the ecological systems
- Define adequate monitoring targets and their inter-relations
- Predict the state of monitoring targets when subjected to drivers of change
- Models/hypotheses *direct* monitoring designs = model-based sampling design
  - ✓ Sampling intensity
  - ✓ Spatial resolutions and extents
  - ✓ Temporal resolution

Opinion

Adaptive monitoring: a new paradigm for long-term research and monitoring

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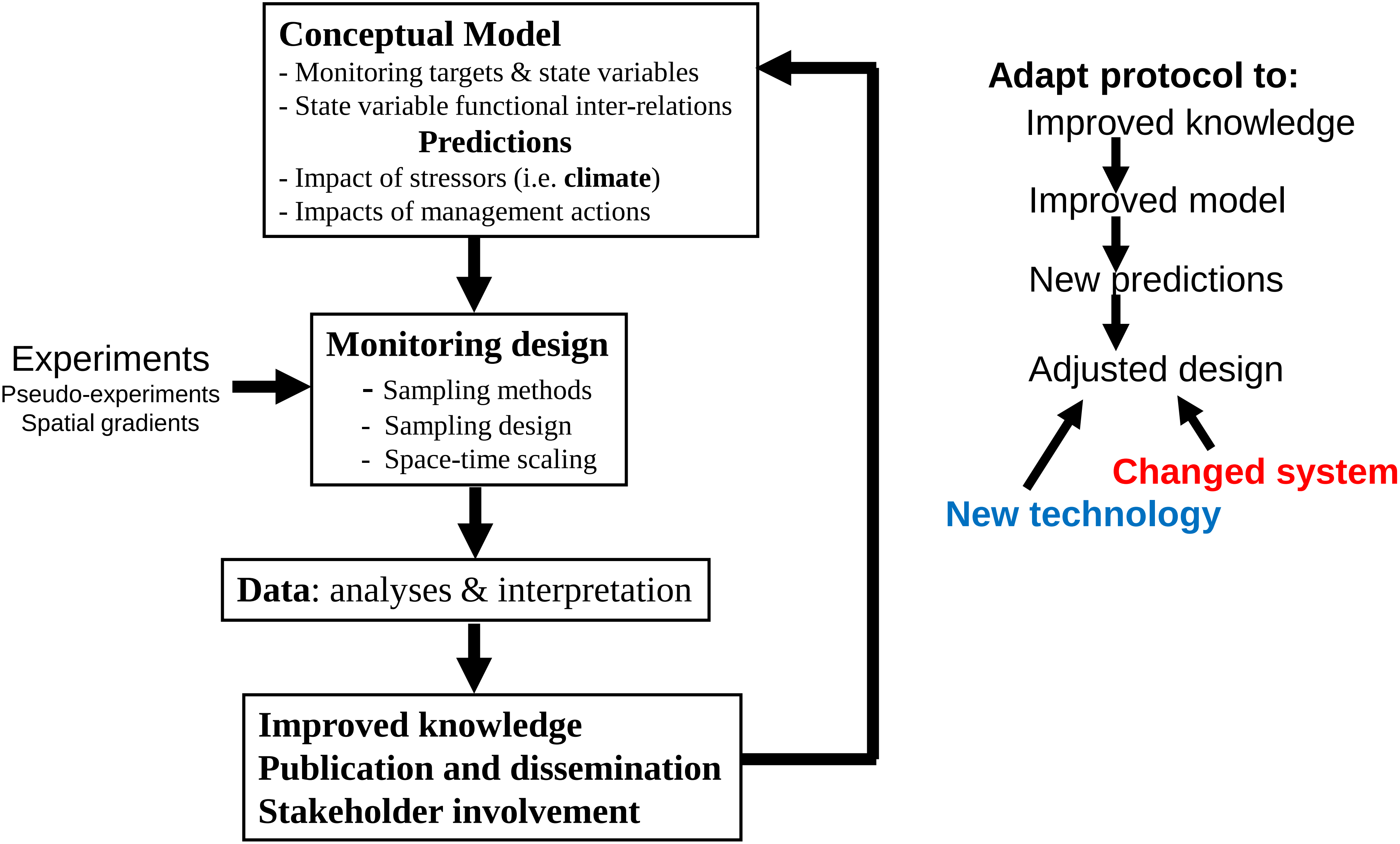
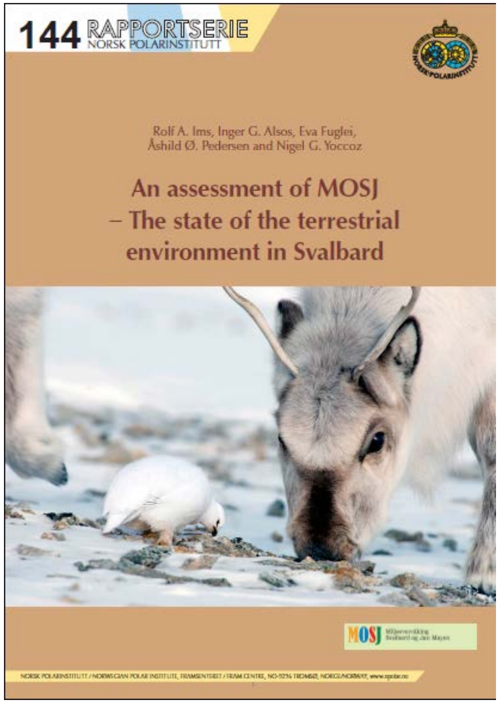
Austral Ecology (2015) 40, 213–224

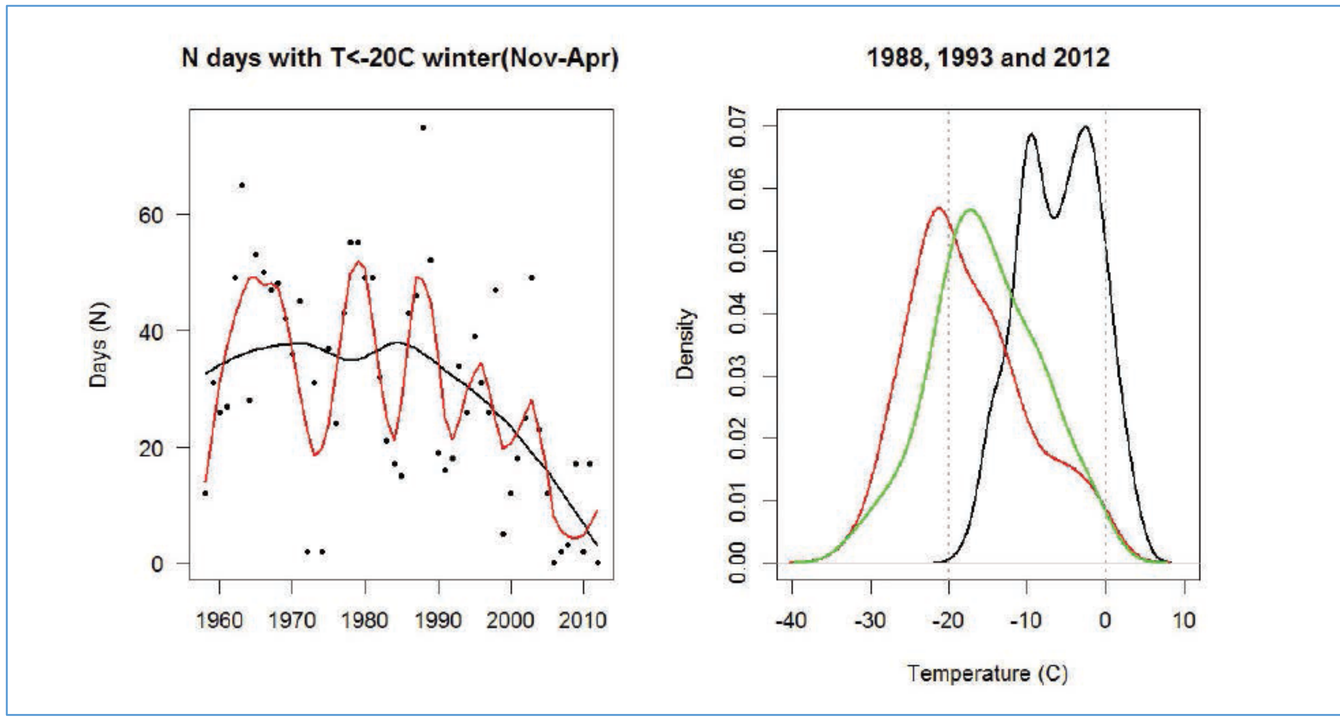
Contemplating the future: Acting now on long-term monitoring to answer 2050's questions

DAVID B. LINDENMAYER,[1,2]* EMMA L. BURNS,[1,2] PHILIP TENNANT,[1,2]

Protocol for adaptive and model-based monitoring (Lindenmayer, Likens *et al.*)




144 RAPPORTSERIE
NORSK POLARINSTITUTT
Rolf A. Ims, Inger G. Alsos, Eva Fuglei,
Åshild Ø. Pedersen and Nigel G. Yoccoz
An assessment of MOSJ
– The state of the terrestrial
environment in Svalbard
MOSJ


N days with T<-20C winter(Nov-Apr)
Days (N)
60
40
20
0
1960
1970
1980
1990
2000
2010
1988, 1993 and 2012
Density
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
-40
-30
-20
-10
0
10
Temperature (C)

FEC	ATTRIBUTE	PRIORITY	PARAMETER	SCALE	METHOD/ REFERENCE	PROTOCOL COMPLEXITY	TEMPORAL RECURRENCE (Minimum)	COMMENTS
LARGE HERBIVORES (caribou/reindeer, muskox, moose)	Abundance	Essential	Number, density	Local/ regional	*Aerial/land-based surveys*, cue counts	Basic	3 years	
	Demographics	Essential	Age structure, mortality, fecundity	Local/ regional	*Aerial/land-based surveys*, telemetry, cue counts	Basic	3 years	
	Spatial structure	Essential	Distribution of migratory herds	Local/ regional	*Telemetry; aerial/ land-based surveys*, harvest records, tissue samples	Basic/ advanced	3 to 5 years	Monitoring of seasonal changes in spatial structure may be needed for e.g. migratory species
	Health	Essential	Pathogen prevalence and intensity, body condition, contaminants	Local/ regional	*Harvest records, tissue samples*, fecal analysis; bone length; some animal collections	Basic/ advanced	Annually	Monitoring parasites (e.g., botflies or other groups can be considered where capacity exists)
	Diversity: genetic	Recommended	Heterozygosity, population genetics and connectivity, breeding	Local	*DNA analysis*	Advanced	3 to 5 years	
	Phenology	Essential	Parturition; breeding	Local/ regional	*Telemetry; surveys*	Basic	Annually	
Medium sized herbivores (hares)	Abundance	Essential	Number, density	Local/ regional	*Land based surveys*, cue counts	Basic	Annually	
	Demographics	Essential	Age structure, mortality, fecundity	Local/ regonal	Land based surveys, harvest records, tissue samples	Basic	3 to 5 years	
	Spatial structure	Recommended	Temporal distribution	Local/ regional	Land based surveys, telementary, cue counts	Basic	3 to 5 years	
	Health	Essential	Prevalence	Local/ regional	*Harvest records, tissue samples*, fecal analysis	Basic/ advanced	3 to 5 years	
	Diversity: genetics	Recommended	Heterozygosity, population genetics and connectivity, breeding	Local	*DNA analysis*	Advanced	3 to 5 years	
	Phenology	Essential	Parturition; breeding	Local/ regional	*Telemetry; surveys*	Basic	Annually	
Small herbivores (lemmings, voles)	Abundance	Essential	Number, density	Local	Land-based surveys, cue counts	Basic	Annually	
	Demographics	Recommended	Age structure, mortality, fecundity	Local	Land-based surveys, telemetry, cue counts	Basic	Annually	
	Spatial structure	Recommended	Temporal distribution	Local	Live/ snap trapping	Basic	3 to 5 years	
	Health	Essential	Prevalence	Local	Tissue samples	Advanced	3 to 5 years	
	Diversity: genetics	Recommended	Heterozygosity, population genetics and connectivity, breeding	Local	DNA analysis	Advanced	3 to 5 years	
	Phenology	Essential	Parturition; breeding	Local/ regional	Telemetry; surveys	Basic	Annually	
Large predators (brown bear, grey wolf)	Abundance	Essential	Number density	Regional	*Cue count*, aerial/land-based surveys	Basic	3 years	
	Demographics	Essential	Age structure, mortality, fecunity	Regional	*DNA analysis*, den surveilance	Advanced	3 years	

COAT = **C**limate-ecological **O**bservatory of **A**rctic **T**undra

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The aims of COAT:

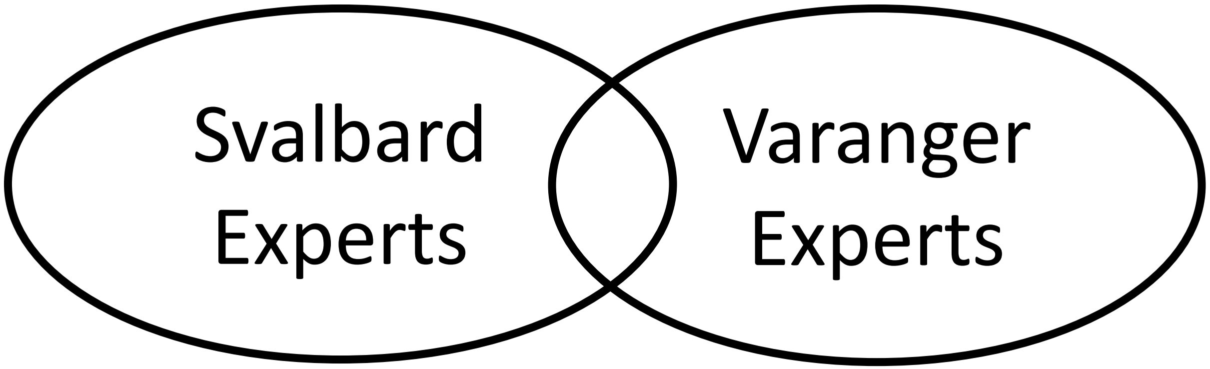
to implement an ***adaptive monitoring system***
that documents how focal components (=monitoring targets)
of Norwegian tundra ecosystems respond to climate change

to establish knowledge/options for implementing ***management actions***

COAT monitoring targets:
State variables that are predicted to change (sensitive to climate change)
Ecosystem functions, ecosystem service, and *conservation targets*
Variables that can be managed locally

2011-2012: Developing the COAT plan

COAT planning task force (23 ecologists & climatologists)



Rolf A. Ims, UiT

Challenge: To develop of common framework

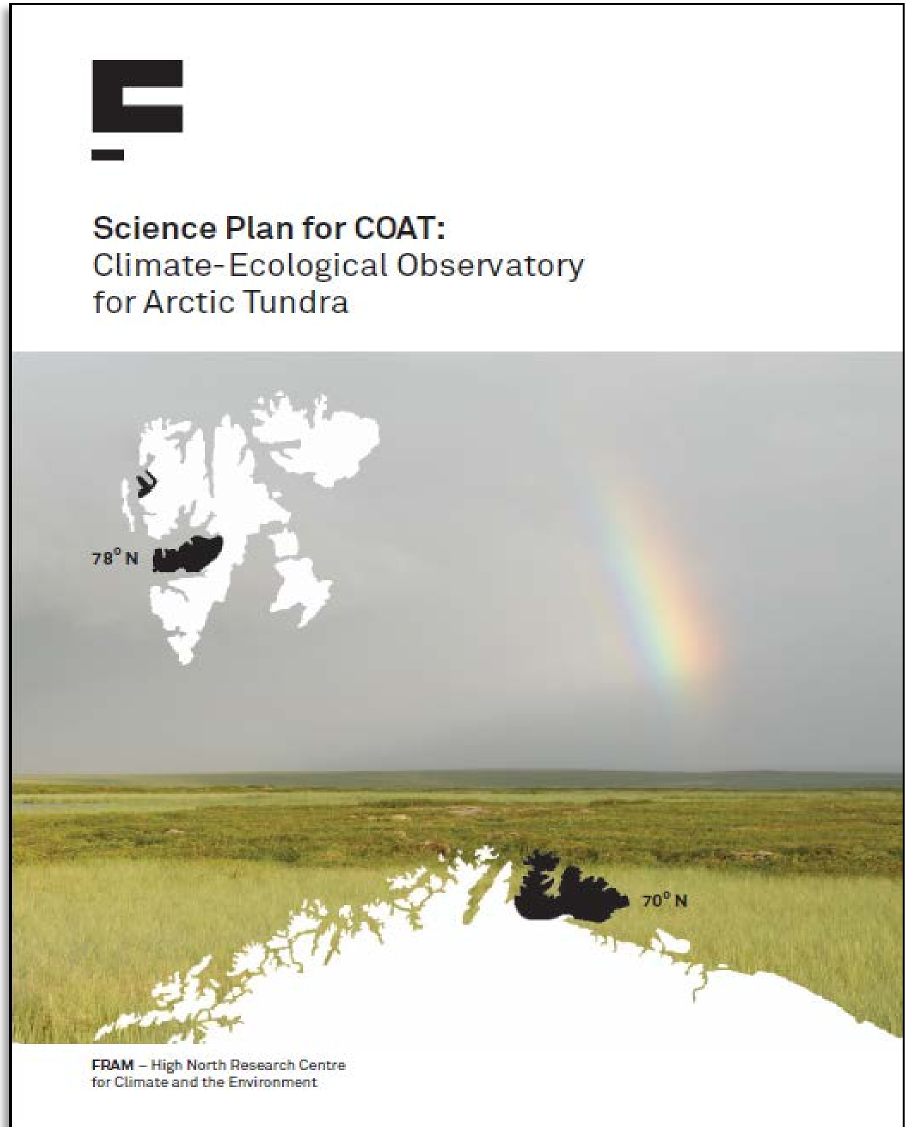
2012 : Draft Science Plan

2012 : Review by international panel of experts

2013 : Revising / finalizing the plan

Many institutions: UiT, NINA, NPI, met.no

2013 : Final Plan Published Fram Centre report series no.1, pp.177



Conceptual Models (according to Lindenmayer & Likens)

- Outline of the expected relation between *Monitoring targets*, *management actions*, *climatic drivers* and strongly linked *internal biotic components* in the ecosystem
- Should be kept simple; “Should convey the key attributes of the system”

The Guiding model for Gene Likens’ Hubbard Brook Ecosystem Study during half a century:

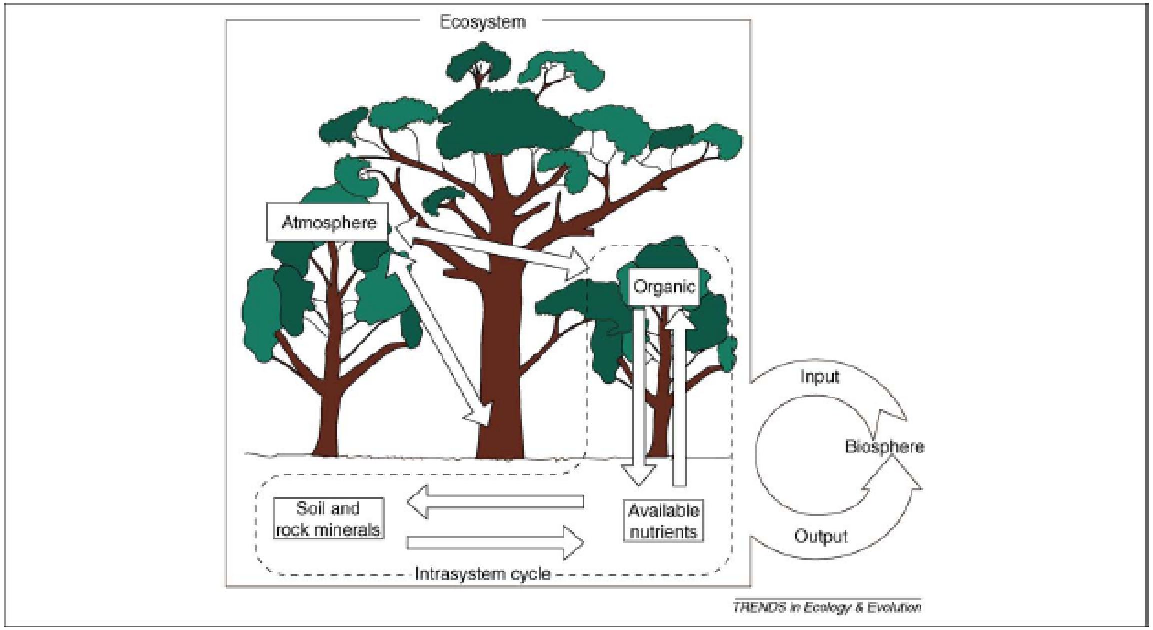


Figure 2. A conceptual model for biogeochemical relationships and input and output fluxes in a terrestrial ecosystem. This conceptual model was used successfully for decades to guide thinking and research for the Hubbard Brook Ecosystem Study in the White Mountains of New Hampshire, USA, in particular how management interventions might alter the ecosystem and how carefully formulated questions might be used to guide tests of the impacts of management practices. Redrawn, with permission, from Ref. [30].

Conceptual models of Tundra Ecosystems;
what sort of theoretical framework was most suited for COAT?

Food web approach

1) **Management perspective:**
   Humans manage/impact ecosystems often by their involvements in food webs (Strong and Frank 2010, McCann 2011)

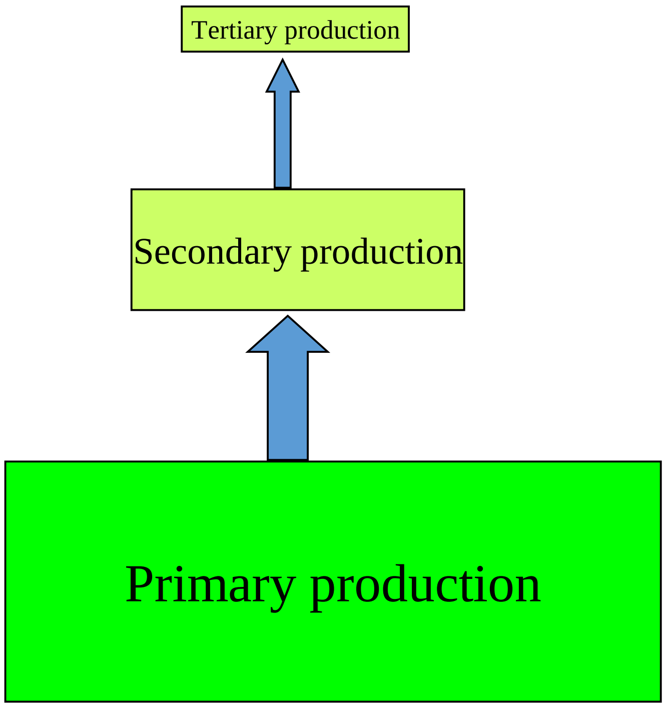
2) **Climate perspective:**
   Climate impacts in tundra ecosystems are often mediated through changed trophic interactions (Post et al. 2009, Ims et al. 2013)

What sort of Conceptual food web models?

Level of resolution

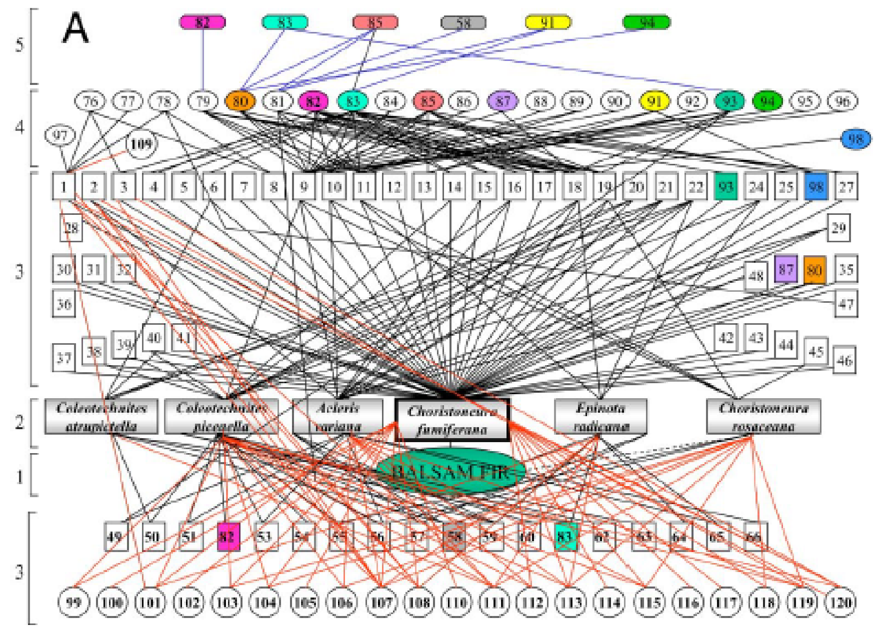
Highly aggregated ("Lindemanian")

Gross flows energy &matter flows

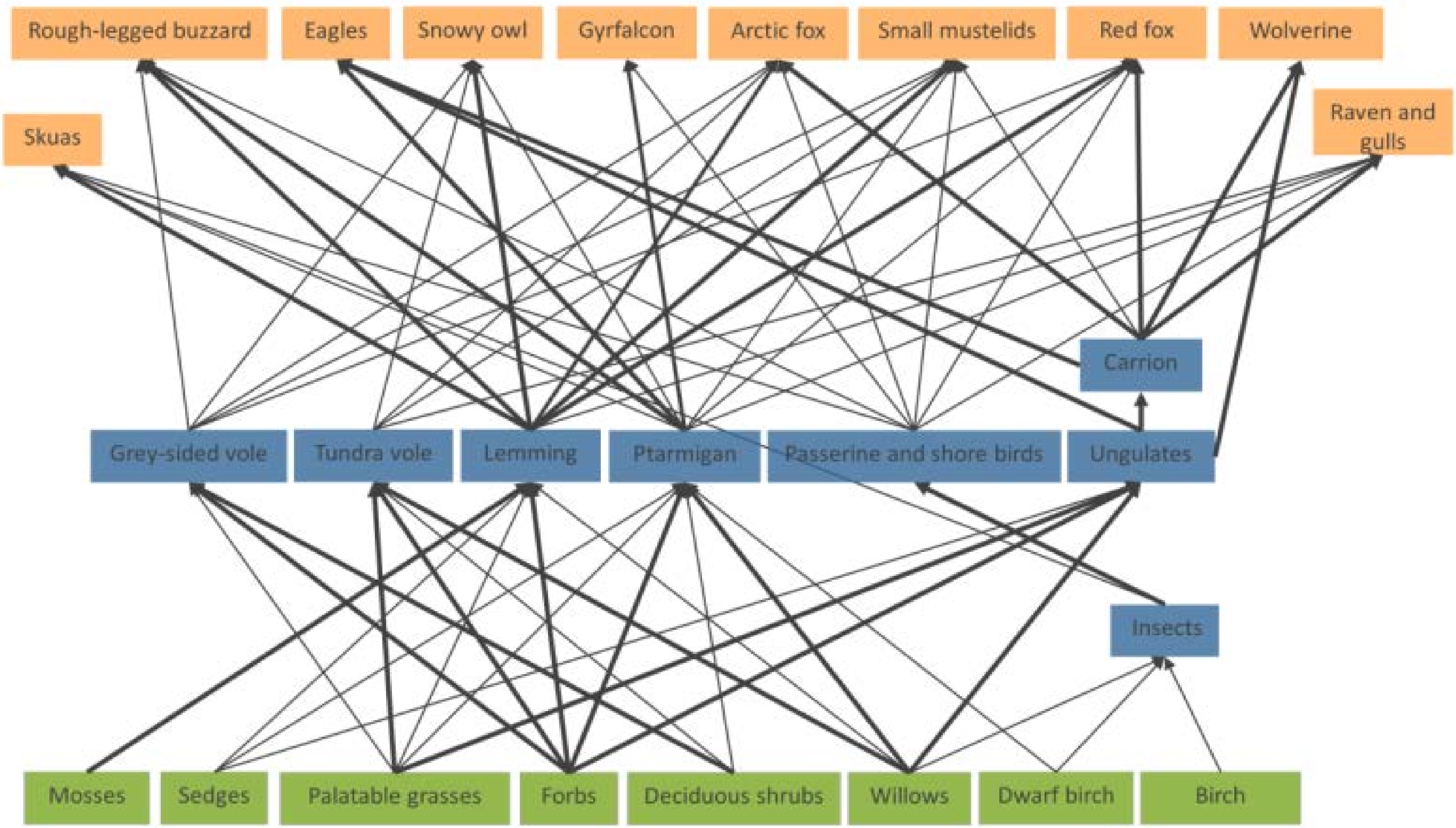


Highly resolved ("Eltonian")

Interaction strengths



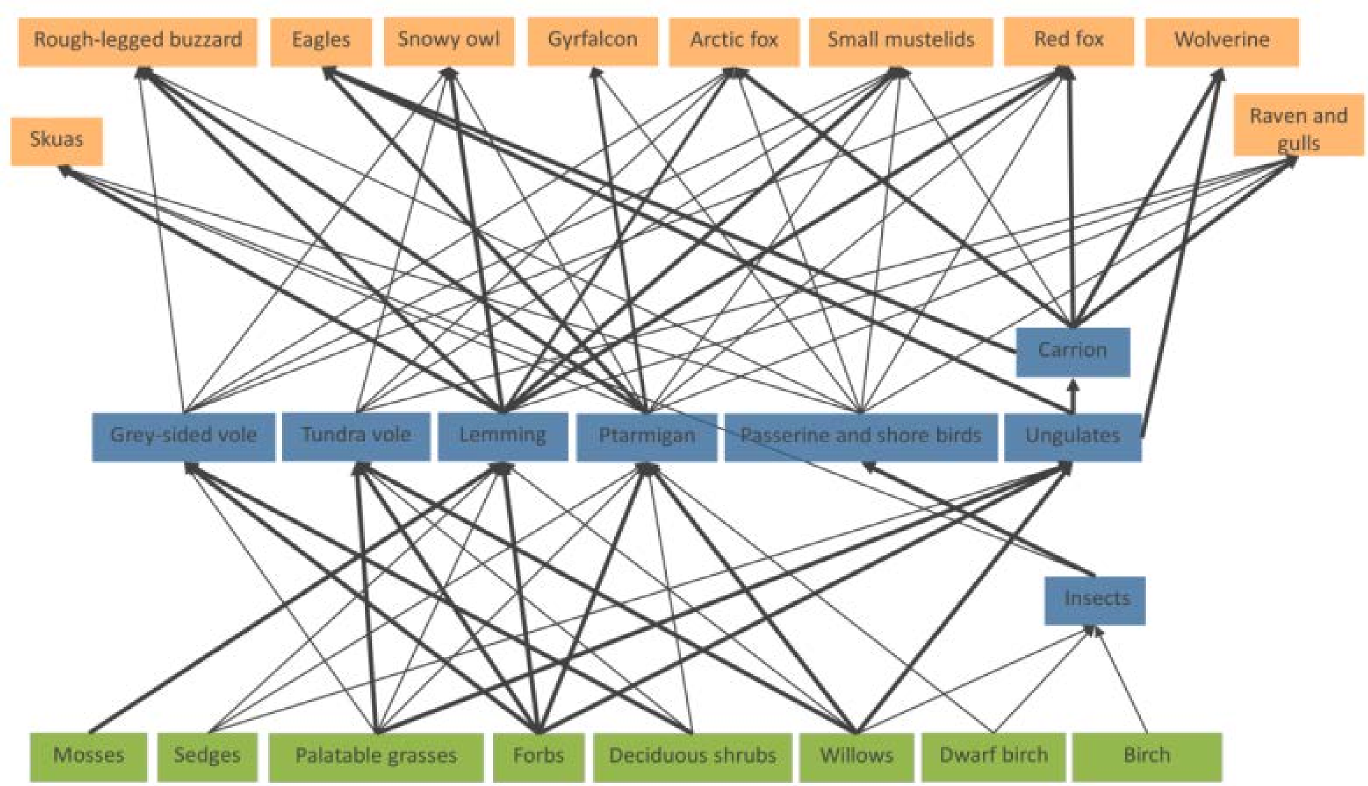
Internal structure of biotrophic tundra food webs
1) Outline low arctic food web (Varanger Peninsula)



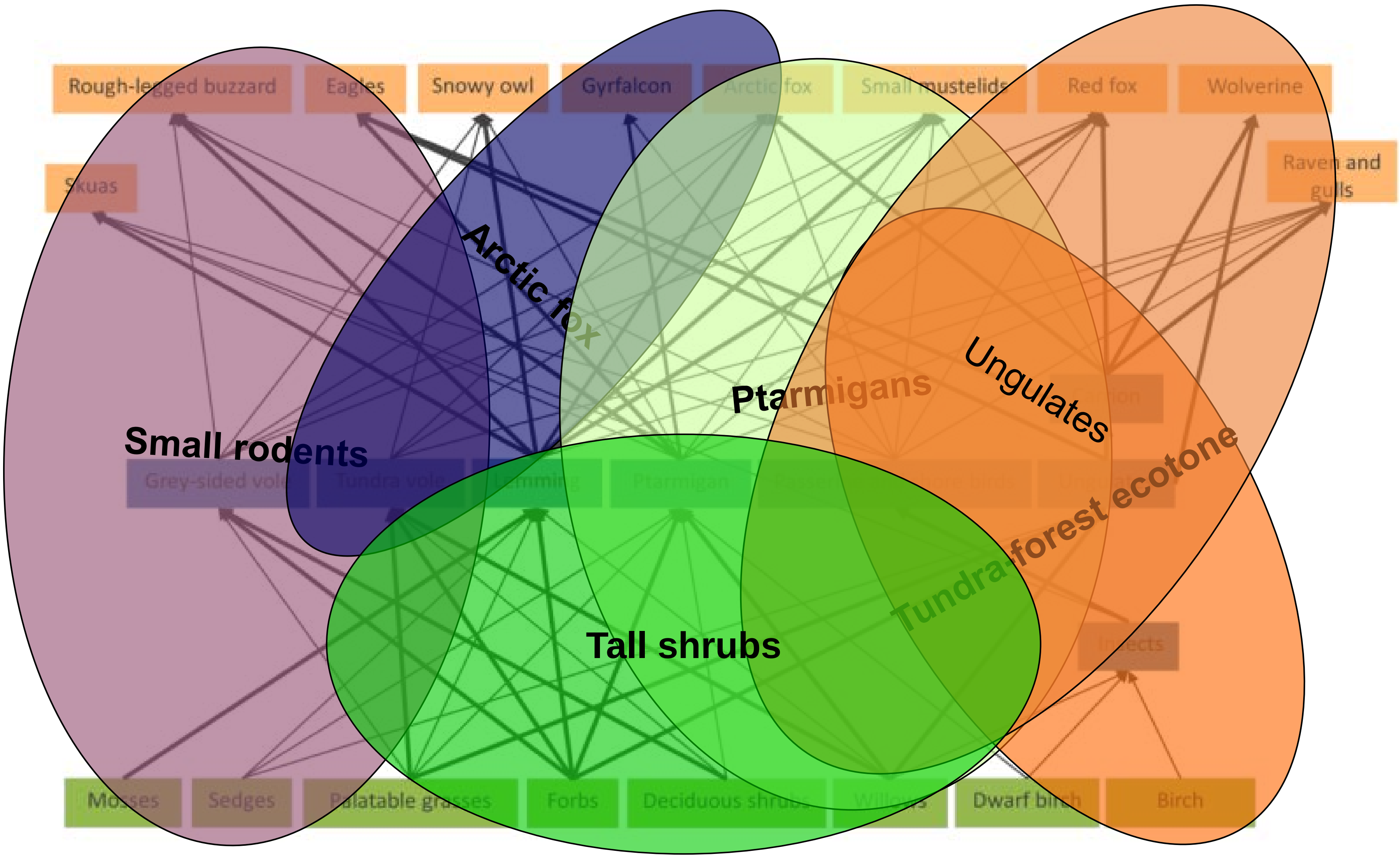
Internal structure of biotrophic tundra food webs

1) Outline low arctic food web (Varanger Peninsula)

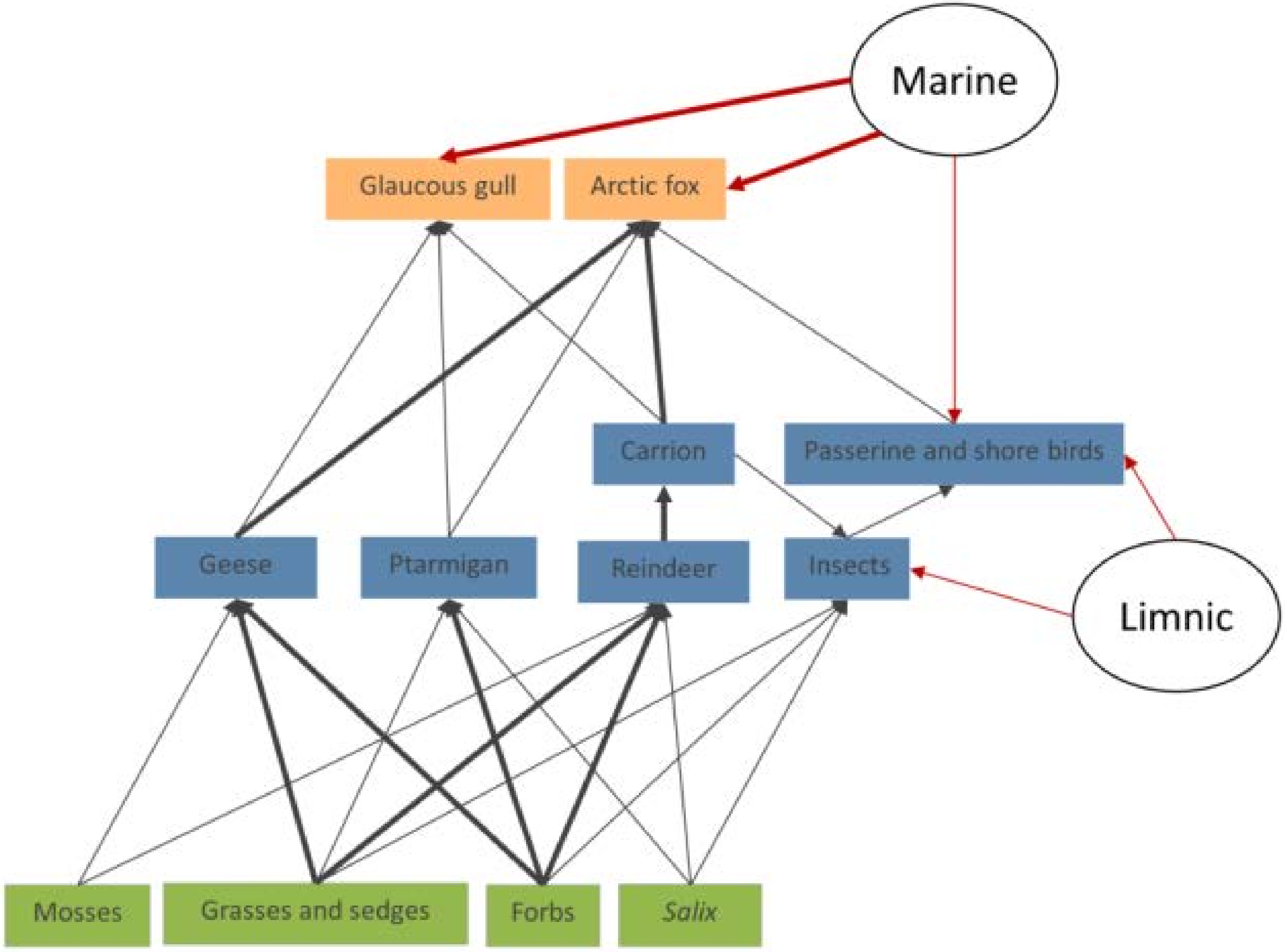
2) Food web modules: compartments of the food web with strong links (interactions) with an ***ecosystem service***, ***ecosystem function*** or ***conservation target***



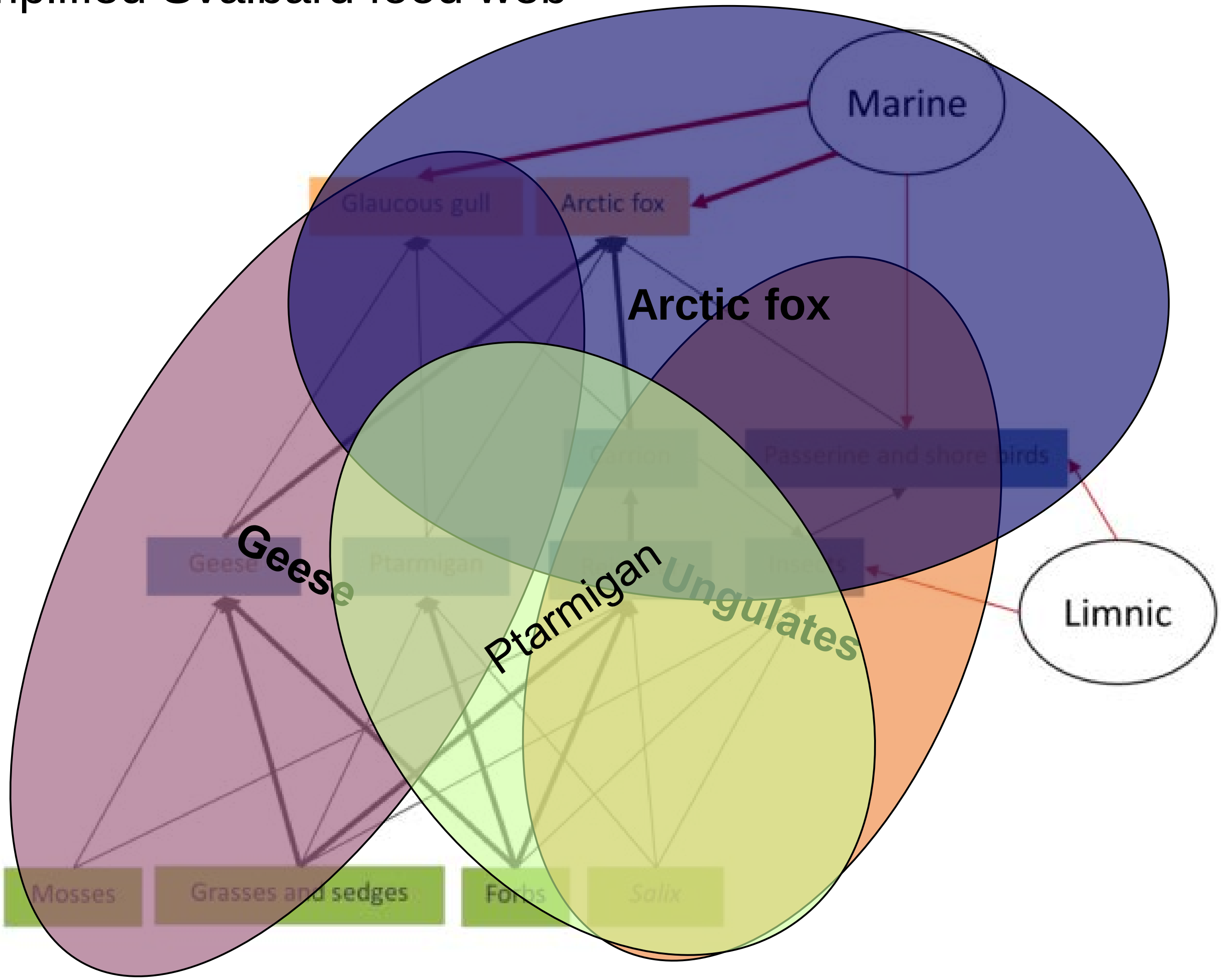
6 Food web Modules for Varanger peninsula



Simplified Svalbard food web



Simplified Svalbard food web



Overlap between modules:

Modules are linked by trophic and non-trophic interactions

->climate impact pathways

->management impact pathways

Defines potential tradeoff between management goals/mitigation options

Criteria for selection of modules and monitoring targets

- Should be centered on monitoring targets which represents:
  - -Key species in terms of ecosystem functions/services, conservation targets
- Targets should have (expected) process relations to:
  - -Climate change
  - -Management options and their impacts

Criteria for constructing “module models”:

- Should be simple, effective (powerful) and easy to communicate
- Should ***identify status of knowledge*** (models are representations of knowledge!)
- Should be continuously improved (according to “the adaptive framework”)
- Tailored to focal ecosystem: “one size will not fit all”
- But also highlight some circumpolar issues

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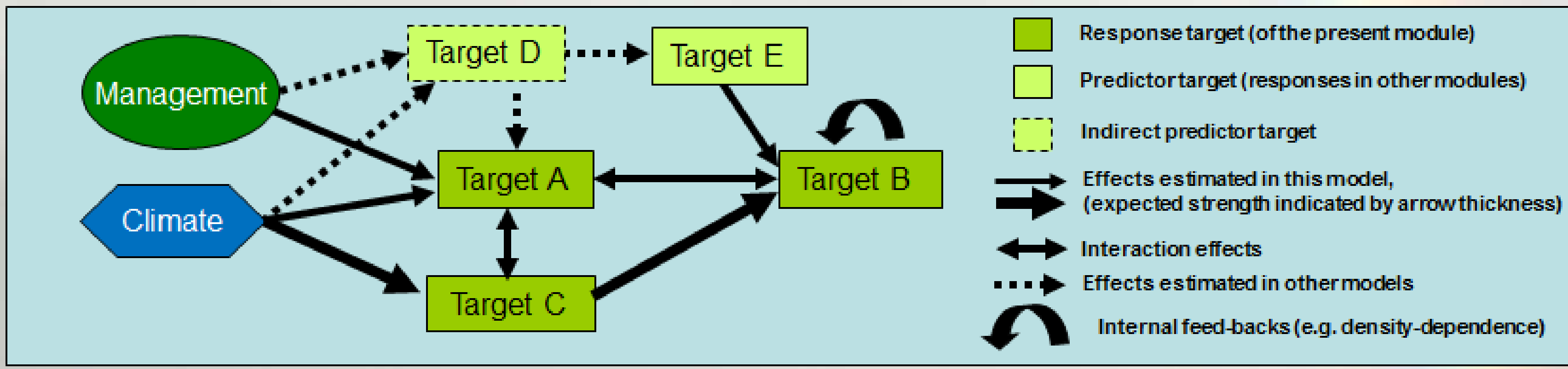
COAT conceptual "module models": 6 Varanger Peninsula, 4 Svalbard

Common structural/notational model framework:



- Climate impact pathways
- Management impact pathways

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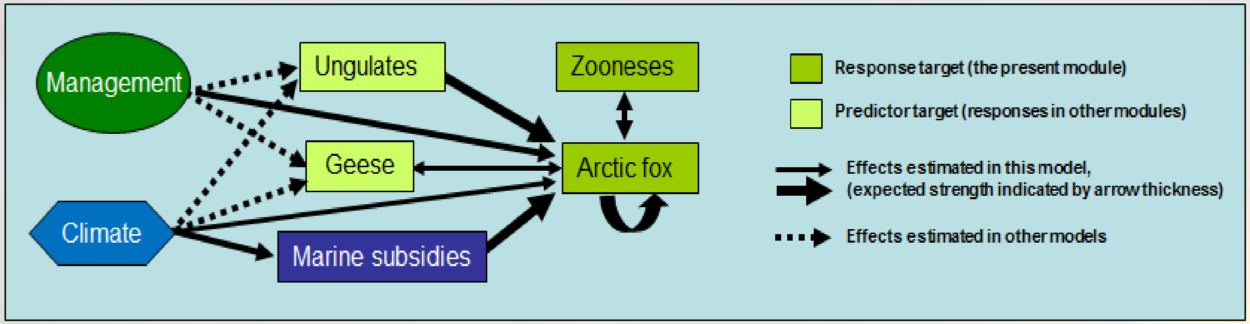
Example: Arctic fox module

General Criterion for module selection:

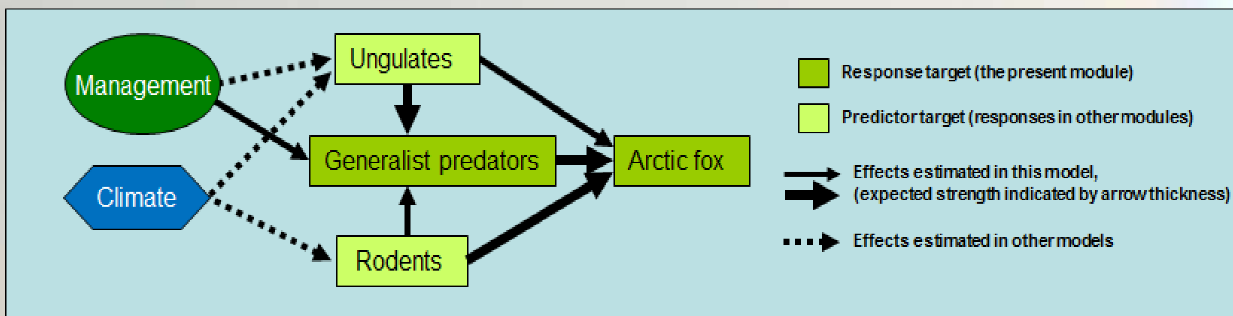
On IUCN red list of 10 globally selected “climate change species”

- **Varanger Peninsula:** investigate processes and assess management actions at the edge of the species range – red-listed **conservation target**
- **Svalbard**: investigate processes associated with sea ice retreat, harvesting and zoonoses (rabies) – **ecosystem service – dis-service**

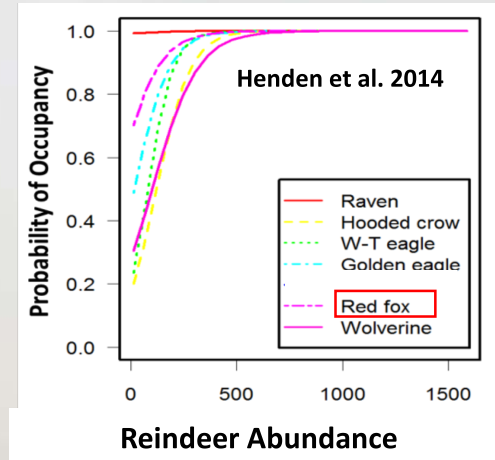
Arctic fox Svalbard: Ecosystem service/dis-service

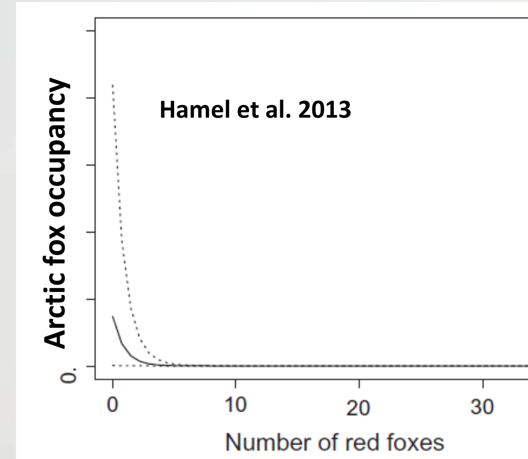


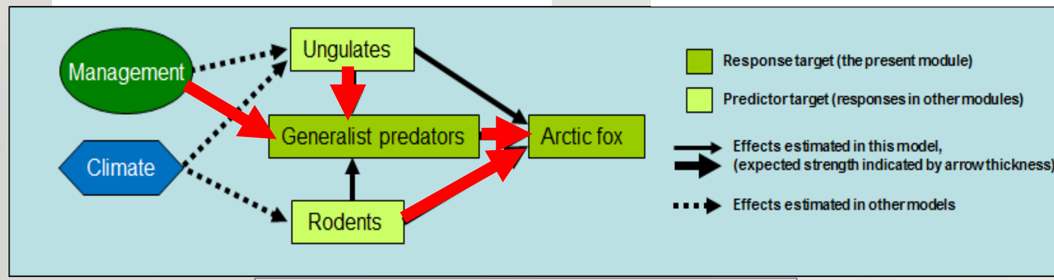
Arctic fox Varanger: *Critically endangered conservation target*

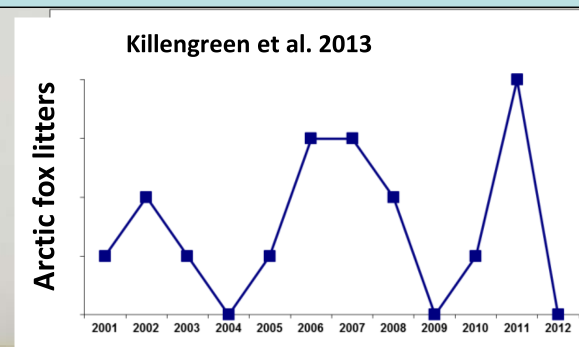


Empirical basis for Arctic fox Varanger model



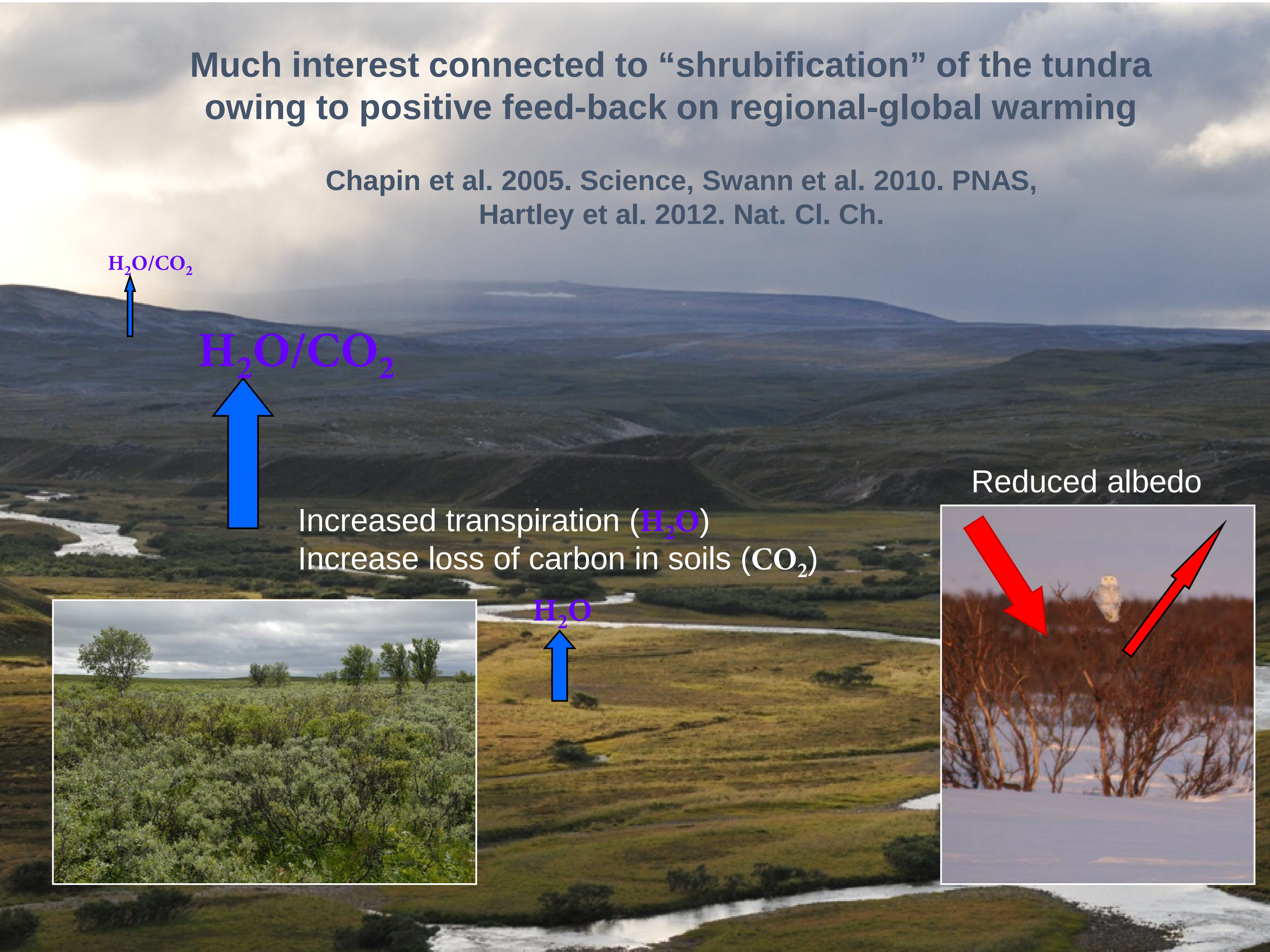




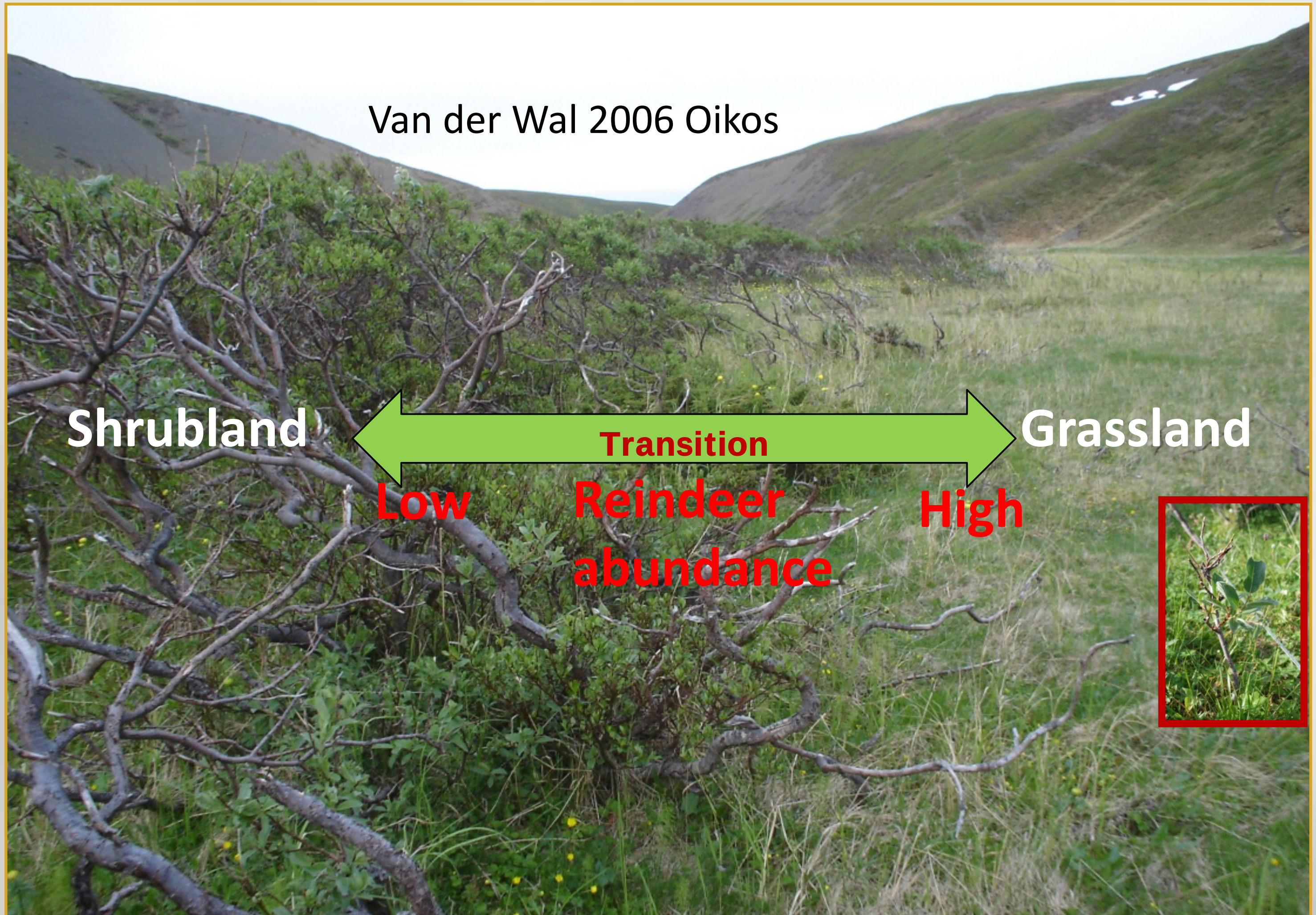


Tall shrub module Varanger

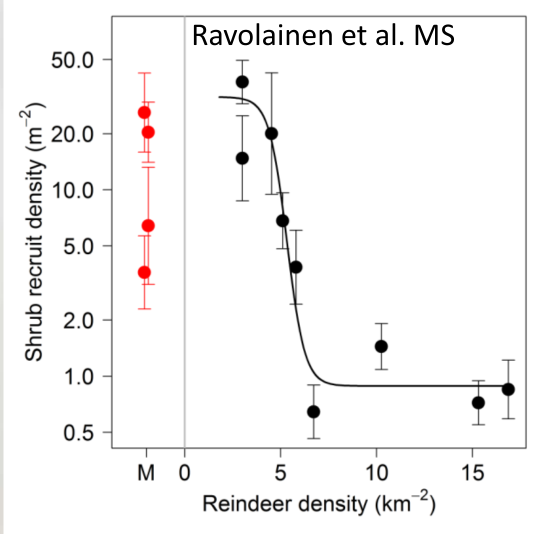
Tall shrubs (Salix, Alnus, Betula) increasing in circumpolar low-arctic tundra

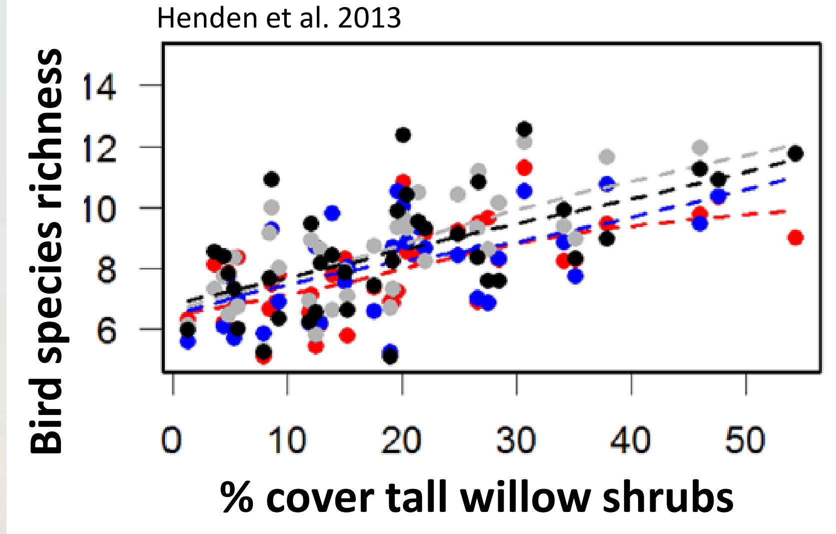

Much interest connected to “shrubification” of the tundra owing to positive feed-back on regional-global warming
Chapin et al. 2005. Science, Swann et al. 2010. PNAS, Hartley et al. 2012. Nat. Cl. Ch.
H_2O/CO_2
H_2O/CO_2
Increased transpiration (H_2O)
Increase loss of carbon in soils (CO_2)
H_2O
Reduced albedo

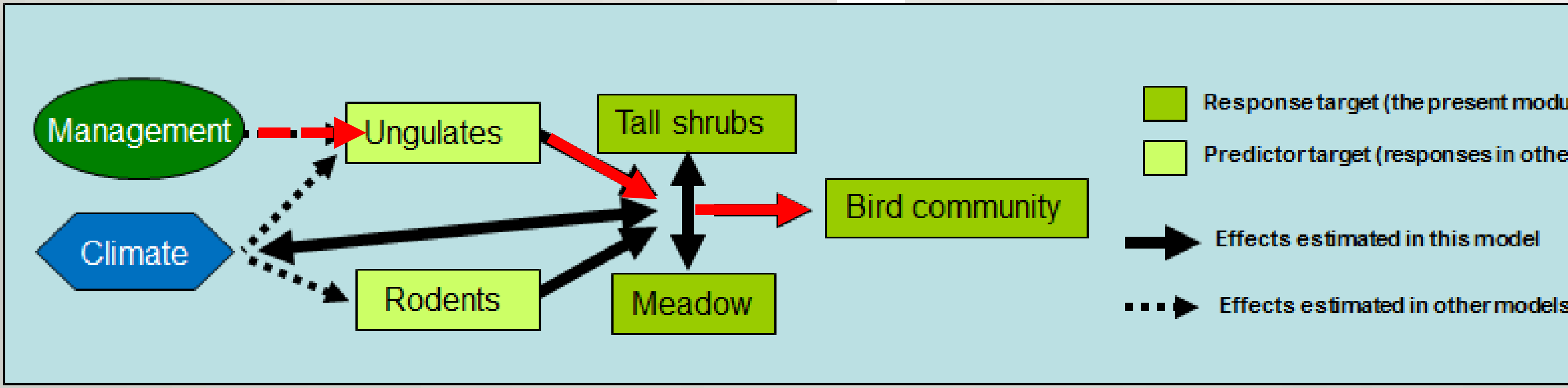

Potential management option:
Can semi-domestic reindeer counteract tall shrub expansion?



Ramets
Recruits
Propagules


Ravolainen et al. MS
Shrub recruit density (m^{-2})
50.0
20.0
10.0
5.0
2.0
1.0
0.5
M
0
5
10
15
Reindeer density (km^{-2})


Henden et al. 2013
Bird species richness
14
12
10
8
6
0
10
20
30
40
50
% cover tall willow shrubs


Management
Climate
Ungulates
Rodents
Tall shrubs
Meadow
Bird community
Response target (the present modu
Predictor target (responses in othe
Effects estimated in this model
Effects estimated in other models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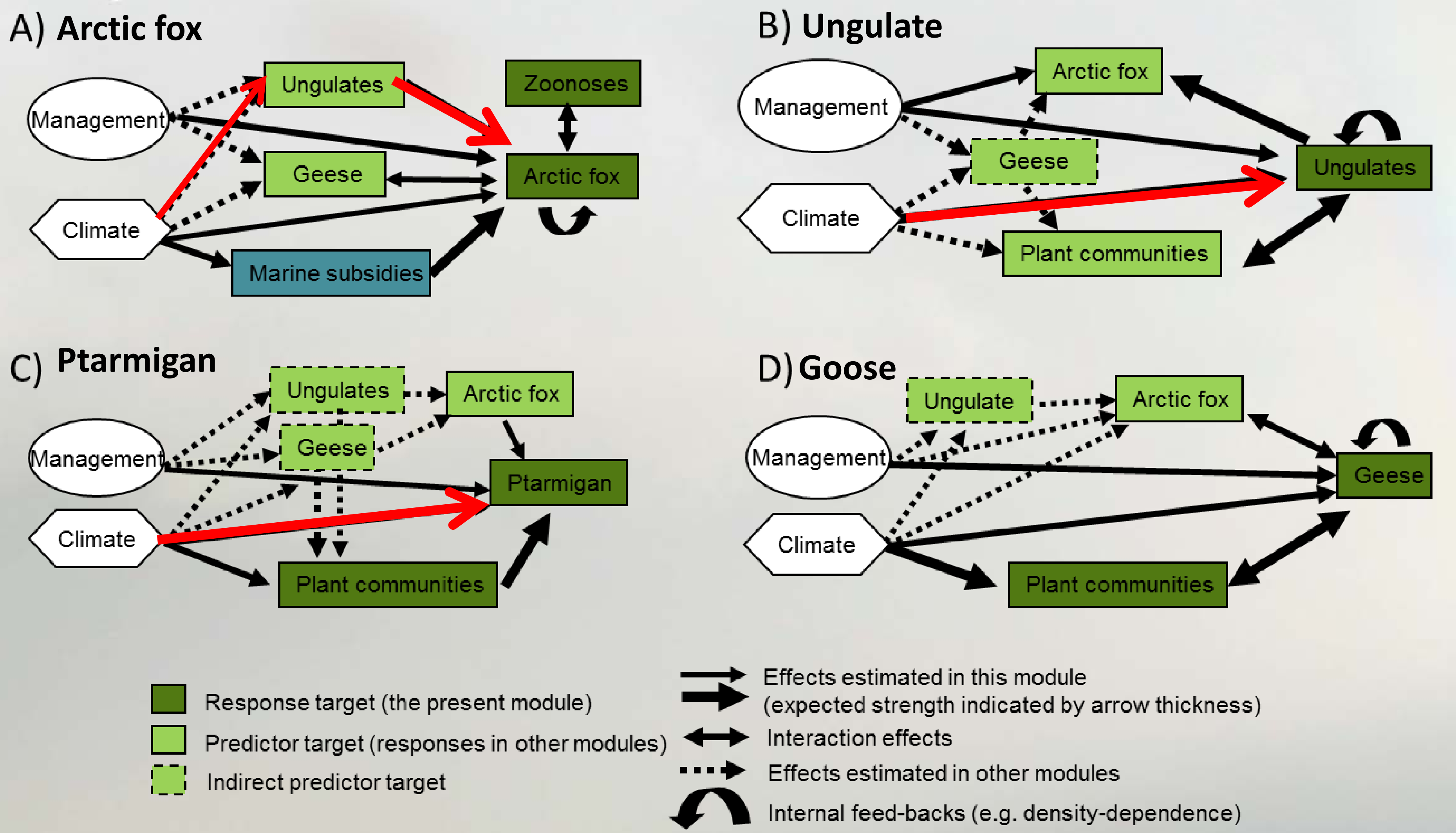
Svalbard module models

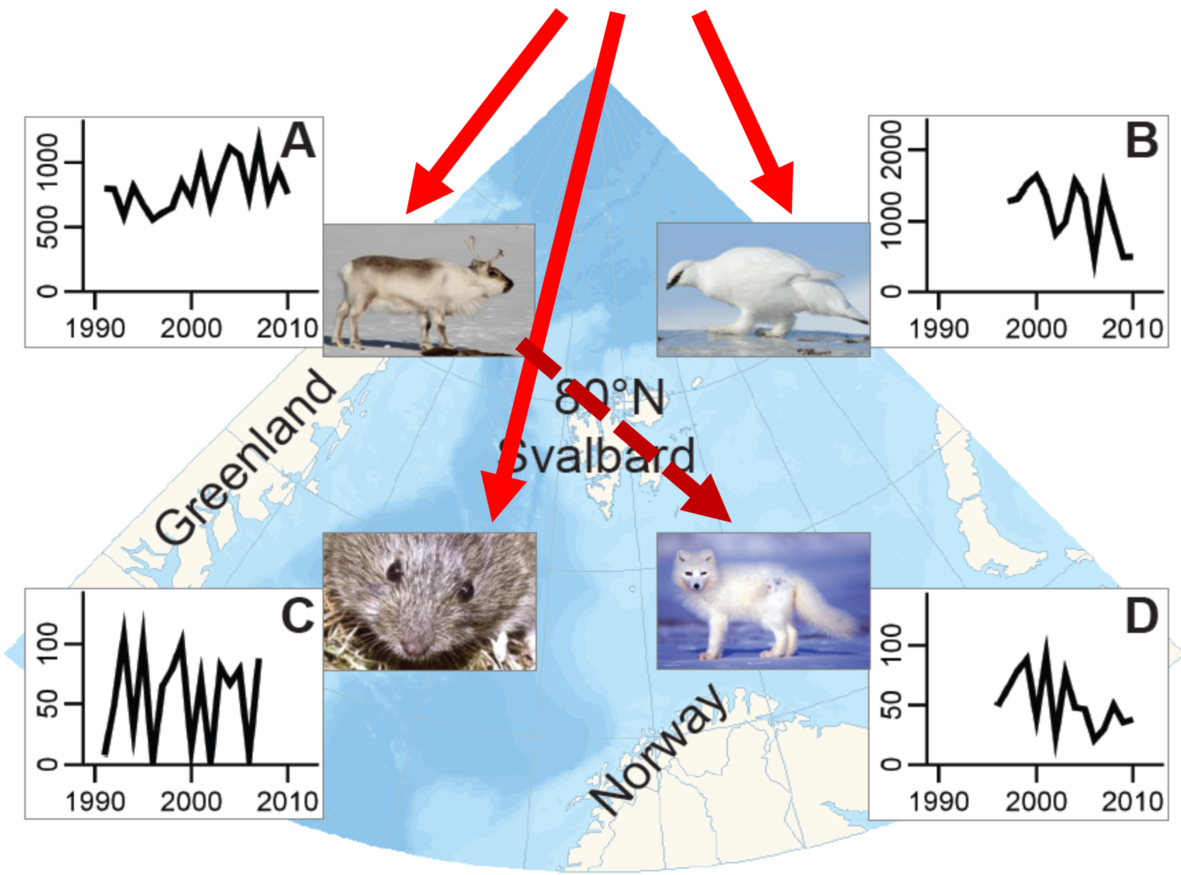


Empirical base-line Svalbard:
A common climate impact on 3 modules

Empirical base-line Svalbard:
A common climate impact on 3 modules

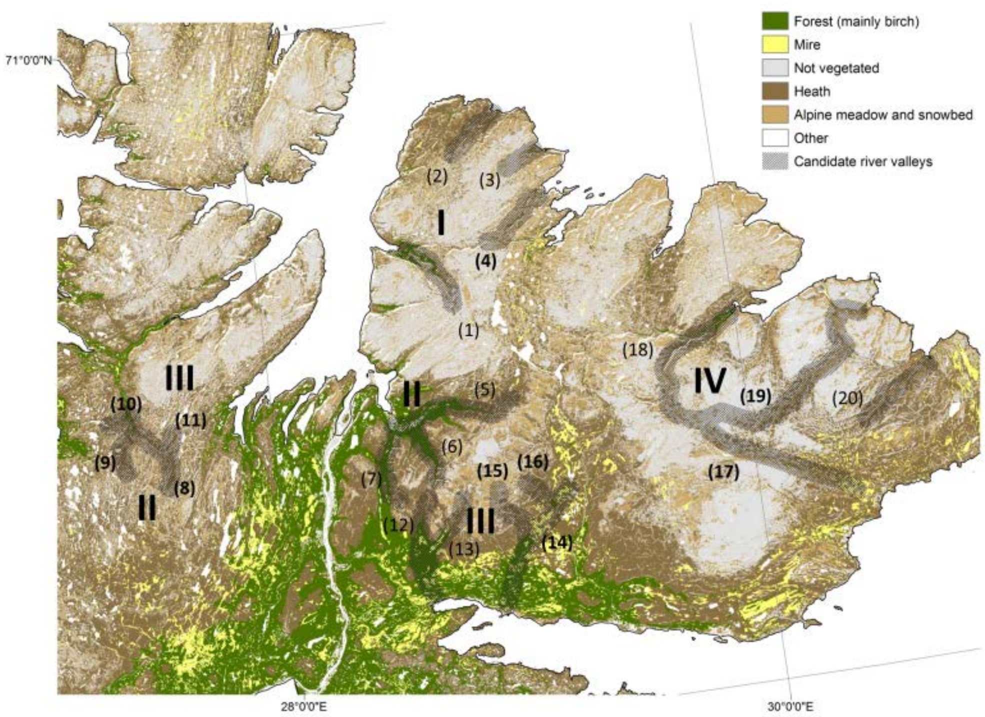
Hansen et al. 2013 Science

<u>Rain on snow</u>



Monitoring design:

A hierarchical monitoring design with two main levels of sampling intensity



Intensive sites: targets with rapid response to climate impacts and/or large temporal variability (n=4) (Sampling: monthly – seasonal)

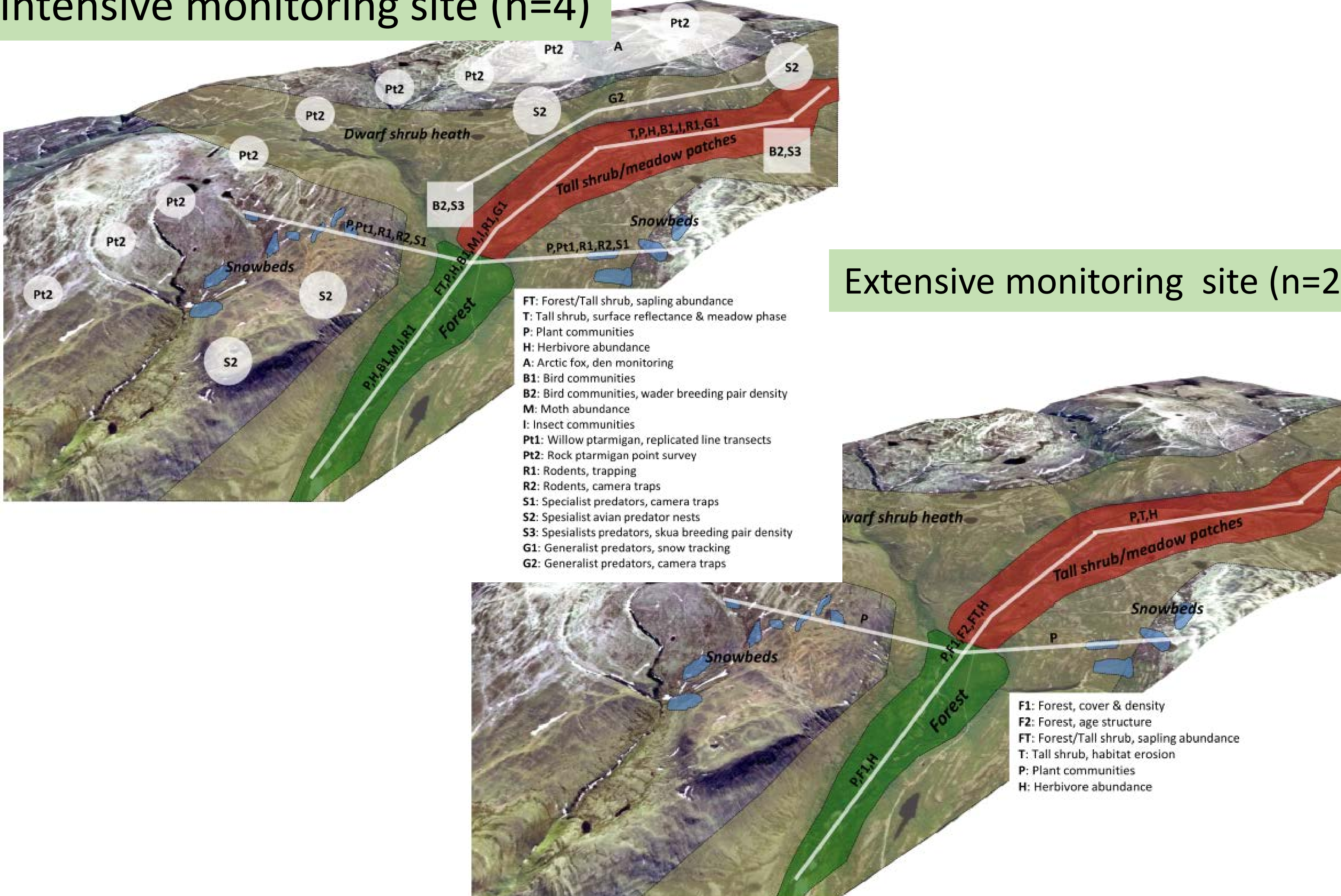
Extensive sites: targets with slower response (n=20) (sampling: 5-year intervals)

The replicate sites are placed in sub-regions with different climate (continentality) and management regimes (semi-domestic reindeer)

Stratified sampling design within sites

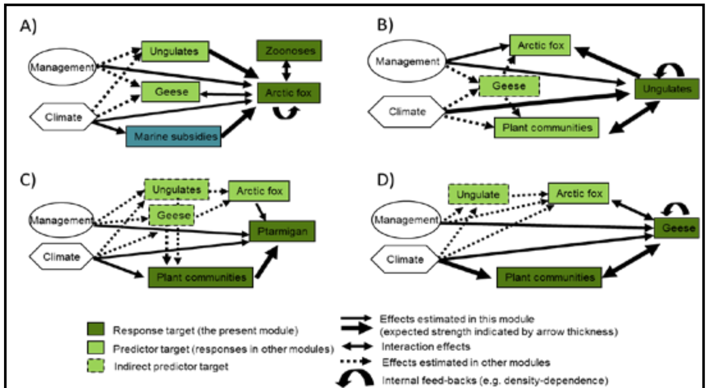
Intensive monitoring site (n=4)

Extensive monitoring site (n=20)



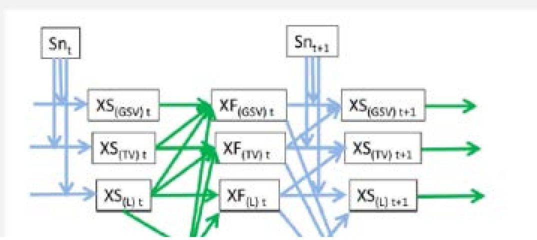
Quantitative analyses

Conceptual models:



State variables:

Target	State variable	Interval (start)	Methods (references)	Module
Plant communities	Quantity and quality of goose and reindeer forage plants in marshes: Grasses/sedges	1 yr	Biomass/leaf area index and protein content in selected plants and plots at time of hatch (Pettorelli et al. 2011; ITEX Protocol, www.geog.ubc.ca/itex; Madsen et al. in prep.)	2.5, 2.7
	Pink-footed goose grubbing impact on fen habitats	1 yr (2003)	Quadrat and point-intercept sampling of vegetation cover and composition on fixed transects along altitudinal transects (Madsen et al. 2011)	2.6, 2.7
	Abundance (biomass) and phenology of spring/summer herbivore forage plants: Altitudinal gradients: Polar willow (Salix polaris) and Bistorta (Bistorta vivipara)	1 yr	Abundance estimation by: point intercept method (Bråthen and Hagberg 2004) Estimation of phenology-temperature curves	2.6, 2.7
Geese	Pink-footed Goose (PG) and Barnacle Goose (BG) breeding	1 yr (PG 2003, BG	Colony surveys in selected plots (Madsen et al. 2007)	2.7, 2.8

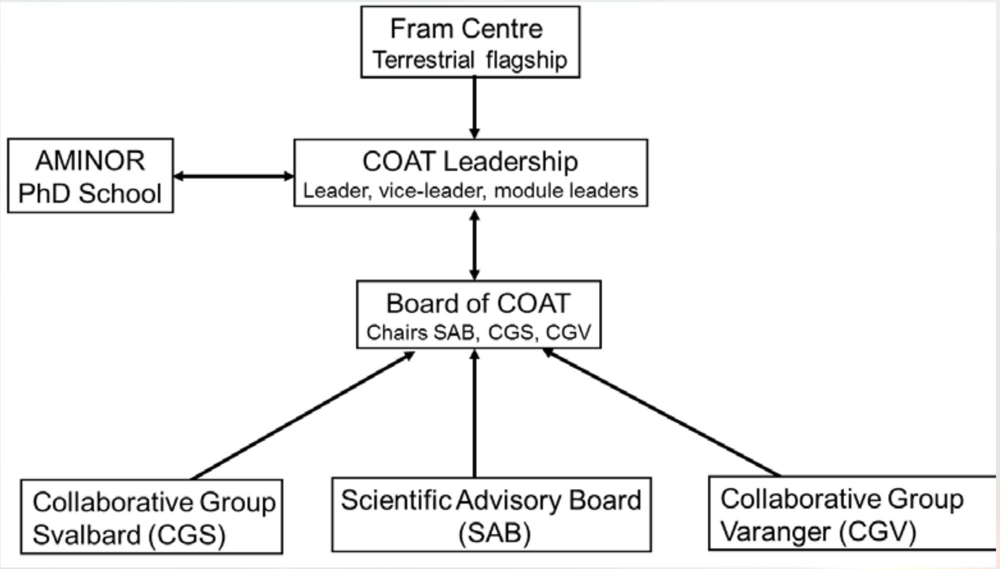


Structural equation models

- State space approach
- Measurement errors
- Autocorrelation
- Bayesian updating

Statistical models closely integrated with theoretical models

Organization



- 5-year financing & review cycle
- Building the infrastructure: 40 mill NOK (4.5 M euros) for 2016-2019 from RCN and UiT
- Financial requirement ~ 25 mill NOK (3 M euros) per year