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Economic-Ecological System Analysis of the Costs of Predation and Difficult Winter Conditions on Reindeer Husbandry

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Projects: POVAUS, ReiGN

Structure of this presentation:

1. **Economic-ecological system analysis**
    1. Our approach - Bioeconomics
    2. Economic-ecological model of reindeer husbandry
2. **Costs of predation**
    1. How to adapt optimally to predation pressure?
    2. What are the costs of predation under optimal management?
3. **Costs of difficult winter conditions:**
    1. Under normal variation of winter conditions
    2. Extremely difficult winters (on going research)

1. Economic-ecological system analysis

Bioeconomics

- Study of economically optimal utilization of biological resources
- Multidisciplinary (*economics, biology, mathematics*)
- Colin Clarkin: "*Mathematical bioeconomics: the optimal management of renewable resources*" *– 1976*

  → Economic-ecological models, optimization

Benefits modelling approach:

- Transparent
- Possible to study various assumptions
- Describes how causal effects flow through the system

  → What affects what and how much?

However:

- Does not create new empirical observations
- Model is only as good as its assumptions

Economic-ecological model of reindeer husbandry

Functions (assumptions of the interactions within the system)

+ Parameter values (data)

$$d_t^b = \min\left[60, \frac{A_Q}{0.03X_tF_t^b}\right] \quad t = 0, 1, \ldots. \tag{1}$$

$$d_t^a = d^W - d_t^b, \quad t = 0, 1, \ldots, \tag{2}$$

$$x_{1,t+1}^i = \left(1 - m_0^i\right) u_i x_{0,t} - h_{0,t}^i, \quad i = f, m, \quad t = 0, 1, \ldots, \tag{3}$$

$$x_{s+1,t+1}^i = \left[1 - m_s^i(\mathrm{wd}_t)\right] x_{s,t}^i - h_{s,t}^i, \quad i = f, m, \quad s = 1, \ldots, n_i - 1, \quad t = 0, 1, \ldots, \tag{4}$$

$$\mathrm{wd}_t = 0.5\exp\left(-\exp\left(\frac{E_t^T - 0.72}{0.22}\right)\right), \quad t = 0, 1, \ldots. \tag{5}$$

$$E_t^T = \sum_{k=a}^{b} \frac{d_t^k I_t^k F_t^k}{d^W}, \quad k = a, b, \quad t = 0, 1, \ldots. \tag{6}$$

$$F_t^k = \min\left\{\frac{1.4}{I_t^k}, \left\{1.8508 + 8.1492\left[1 + \exp\left(\frac{I_t^k - 0.0953}{0.0013}\right)\right]^{-0.0066}\right\}\right\}, \quad t = 0, 1, \ldots, \quad k = a, b. \tag{7}$$

$$x_{0,t} = \sum_{s=1}^{n_f} \beta_{t-1} f_s(\mathrm{wd}_t)\left[1 - m_s^f(\mathrm{wd}_t)\right] x_{s,t}^f, \quad t = 0, 1, \ldots$$

$$\beta_t = \min\left\{1, \frac{2X_t^{em}}{X_t^{ef} + X_t^{em}}\right\}, \quad t = -1, 0, 1, \ldots \tag{T2}$$

$$X_g^{ef} = \sum_{s=1}^{n_f}\left[1 - m_s^t(\mathrm{wd}_t)\right] x_{s,t}^f \tag{T3}$$

$$X_t^{em} = \sum_{s=1}^{n_m}\left[1 - m_s^m(\mathrm{wd}_t)\right] x_{s,t}^m \tag{T4}$$

$$f_s(\mathrm{wd}_t) = \hat{f}_s\left\{1 - \left[1 + \exp\left(\frac{0.2715 - \mathrm{wd}_t}{0.0239}\right)\right]^{-0.1488}\right\} 1.2272 \tag{T5}$$

$$\mathrm{mo}_t^i(\mathrm{wd}_t) = \left[1 + \exp\left(\frac{0.36 - \sigma_i \mathrm{wd}_t}{0.011}\right)\right]^{-0.25}, \quad \sigma_f = 1, \quad \sigma_m = 1.1 \tag{T6}$$

$$m_{st}^i = \min\left\{1, mo_t^i + ma_s^i\right\}, \quad s = 1, \ldots, n_i, \quad i = f, m, \quad t = 0, 1\ldots \tag{T7}$$

$$\mathrm{wc}_{st}^i = \alpha^i w_s^c 1.0275\left[1 + \exp\left(\frac{\mathrm{wd}_t - 0.3146}{0.0876}\right)\right]^{-1} \quad i = f, m, \quad s = 1, \ldots, n_f \tag{T8}$$

$$\bar{w}_0^i(z_t, \mathrm{wd}_t, \mathbf{x}_t^f) = \frac{8\sum_{s=1}^{n_f}\left[1 - m_{st}^f(\mathrm{wd}_t)\right]\beta_{t-1} f_s(\mathrm{wd}_t) x_{st}^f \mathrm{wc}_{st}^i}{x_{0t}} \quad i = f, m, \quad s = 1, \ldots, n_f \tag{T9}$$

$$I_t^k = \sum_{j=Z}^{V} T_{j,t}^k I_{j,t}^k, \quad k = a, b, \quad j = Z, Q, V, \quad t = 0, 1, \ldots, \tag{8}$$

$$I_{Z,t}^a = \frac{\mu_t^a}{3}\left(0.055 + 5 \times 10^{-5} z_t\right), \quad t = 0, 1, \ldots, \tag{9}$$

$$\mu_t^a = \frac{3.3 \times 121 + 2.4\left(d_t^a - 121\right)}{d_t^a}, \quad t = 0, 1, \ldots. \tag{10}$$

$$I_{Z,t}^b = \frac{\mu^b}{3}\left(0.05 + 5 \times 10^{-5} z_t\right)\left(\frac{T_{Z,t}^b}{T_{Z,t}^b + T_{Q,t}^b}\right)^{-0.2} \quad t = 0, 1, \ldots, \tag{11}$$

$$I_{Q,t}^b = \frac{0.03 \times 10.8q}{17.6}\left(\frac{T_{Q,t}^b}{T_{Z,t}^b + T_{Q,t}^b}\right)^{-0.2} \quad t = 0, 1, \ldots, \tag{12}$$

$$I_{Z+Q,t}^k = \frac{I_{Z,t}^k T_{Z,t}^k + I_{Q,t}^k T_{Q,t}^k}{T_{Z,t}^k + T_{Q,t}^k} \quad t = 0, 1, \ldots, \quad k = a, b. \tag{13}$$

$$T_{V,t}^k = \min\left\{\left\{0.3\left[0.2 + \frac{0.9}{1 + \exp\left(I_{Z+Q,t}^k - 1/0.5\right)}\right]\right\}, \left(\frac{[illegible]}{\sum_{i=f}^{m}\sum_{s=1}^{n_i} x_{s,t}^i Ed_s^i}\right)\right\} \quad t = 0, 1, \ldots, \quad k = a, b \tag{14}$$

$$T_{Z,t}^a = 1 - T_{V,t}^a, \quad t = 0, 1, \ldots, \tag{15}$$

$$T_{Z,t}^b = \frac{\left(1 - T_{V,t}^b\right)\left(\left(\mu_t^b/3\right)\left(0.05 + 5 \times 10^{-5} z_t\right)\right)^5}{[illegible]}, \quad t = 0, 1, \ldots, \tag{16}$$

$$T_{Q,t}^b = 1 - T_{V,t}^b - T_{Z,t}^b, \quad t = 0, 1, \ldots. \tag{17}$$

$$z_t^{wi} = z_t, \quad t = 0, 1, \ldots, \tag{18}$$

$$z_t^{sp} = z_t^{wi} - l_t^{wi}, \quad t = 0, 1, \ldots, \tag{19}$$

$$z_t^{su} = z_t^{sp} - l_t^{sp}, \quad t = 0, 1, \ldots, \tag{20}$$

$$z_t^{au} = z_t^{su} - l_t^{su} + G\left(z_t^{su}\right), \quad t = 0, 1, \ldots, \tag{21}$$

$$z_{t+1} = z_t^{au} - l_t^{au}, \quad t = 0, 1, \ldots. \tag{22}$$

$$G\left(z_t^{su}\right) = g\left[-0.7008\left(z_t^{su}\right) + \left(z_t^{su}\right)\left(1 + \frac{z_t^{su}}{100.5832}\right)^{-0.0853}\right], \tag{23}$$

$$l_{s,t}^{i,e} = w^e \frac{Ed_s^{i,e} E_t^{L,e}}{10.8} d^e, \quad t = 0, 1, \ldots, \quad i = f, m, \quad s = 1, \ldots, n_i, \quad e = \mathrm{wi, sp, su, au}, \tag{24}$$

$$l_{0,t}^{i,au} = w^{au} \frac{Ed_0^{i,au} E_t^{L,au}}{10.8} d^{au}, \quad t = 0, 1, \ldots, \quad i = f, m. \tag{25}$$

$$E_t^{L,wi} = L(z_t) \frac{\sum_{k=a}^{b} d_t^k F_t^k T_{Z,t}^k I_{Z,t}^k}{d^W}, \quad t = 0, 1, \ldots, \quad k = a, b. \tag{26}$$

$$L_t = 0.3621\left(1 - e^{-0.0048985 z_t}\right) + 0.5603\left(1 - e^{-0.0015299 z_t}\right), \quad t = 0, 1, \ldots. \tag{27}$$

$$E_t^{L,e} = \tau^e\left(1.3242 - 4.0292\left[1 + \exp\left(\frac{z_t^e + 1000}{495.3806}\right)\right]^{-0.522}\right), \quad t = 0, 1, \ldots, \quad e = \mathrm{sp, su, au}, \tag{28}$$

$$Ed_s^{i,wi} = 0.683\left(w_{s-1}^i\right)^{0.75}, \quad i = f, m, \quad s = 1, \ldots, n_i, \tag{29}$$

$$Ed_s^{i,e} = 0.683\left(w_s^i\right)^{0.75}, \quad i = f, m, \quad s = 0, \ldots, n_i, \quad e = \mathrm{sp, su, au}, \tag{30}$$

$$l_t^{wi} = \frac{\sum_{i=f}^{m}\sum_{s=1}^{n_i} l_s^{wi,i}(E_t^{L,wi}) x_{st}^i}{A}, \quad i = f, m, \quad s = 1, \ldots, n_i, \quad t = 0, 1, \ldots, \tag{31}$$

$$l_t^{sp} = \frac{\sum_{i=f}^{m}\sum_{s=1}^{n_i} l_s^{sp,i}(E_t^{L,sp})\left[1 - m_s^i(wd_t)\right] x_{st}^i}{A}, \quad i = f, m, \quad s = 1, \ldots, n_i, \quad t = 0, 1, \ldots, \tag{32}$$

$$l_t^{su} = \frac{\sum_{i=f}^{m}\sum_{s=1}^{n_i} l_s^{su,i}(E_t^{L,su})\left[1 - m_s^i(wd_t)\right] x_{st}^i}{A}, \quad i = f, m, \quad s = 1, \ldots, n_i, \quad t = 0, 1, \ldots, \tag{33}$$

$$l_t^{au} = \frac{\sum_{i=f}^{m} l_0^{au,i}(E_t^{L,au})\left(1 - m_0^i\right) x_{0,t}^i}{A} + \frac{\sum_{i=f}^{m}\sum_{s=1}^{n_i} l_s^{au,i}(E_t^{L,au})\left[1 - m_s^i(wd_t)\right] x_{st}^i}{A}, \quad i = f, m, \quad s = 1, \ldots, n_i, \quad t = 0, 1, \ldots. \tag{34}$$

$$\max_{\left\{h_{s,t}^i, v_t^k, \; t=0,1,\ldots, i=f,m, \; s=0,\ldots,n_i, k=a,b\right\}} J = \sum_{t=0}^{\infty}(R_t - C_t)^{\alpha}\left(\frac{1}{1+r}\right)^t, \tag{35}$$

$$R_t = p\gamma\left[\bar{w}_0^f\left(z_t, \mathrm{wd}_t, \mathbf{x}_t^f\right) h_{0,t}^f + \bar{w}_0^m\left(z_t, \mathrm{wd}_t, \mathbf{x}_t^f\right) h_{0,t}^m + \sum_{i=f}^{m}\sum_{s=1}^{n_i} w_s^i h_{s,t}^i\right], \quad t = 0, 1, \ldots, \tag{36}$$

$$C_t = C_s \sum_{i=f}^{m}\sum_{s=0}^{n_i} h_{s,t}^i + C_x X_t + C_L(A + K) + C_V \sum_{k=a}^{b} v_t^k, \quad t = 0, 1, \ldots, \tag{37}$$

Bioeconomic reindeer husbandry model:

- **Based on discrete time reindeer-lichen model**
- **Age-classes:** 16 female, 12 male
- **Population dynamics:** Winter food limitation → weight, mortality, reproduction
- **Reproduction:** Modified harmonic mean mating function + winter food
  → Including the effects of females, males and population structure
- **Diet choice:** Optimal foraging theory
  → Lichen, other cratered food, arboreal lichens, supplementary food
- **Empirical data for the functions and parameters** *(assumptions)* **:**
  → Previous research, data from LUKE and Reindeer Herders' Association.
- **Objective function:**
  → Reindeer herding district maximizes the present value of the net revenues

Publications:

Tahvonen, O, Kumpula, J and Pekkarinen A-J. 2014. Ecological Modelling 272: 348-361. *Optimal harvesting of an age-structured two sex herbivore-plant system.*

Pekkarinen,A.-J, Kumpula J. and Tahvonen O. 2015. Ecological Modelling 312: 256-271. *Reindeer management and winter pastures in the presence of supplementary...*

Pekkarinen,A.-J, Kumpula J. and Tahvonen O. 2017. Ecology and Evolution 7: 8282–8302. *Parameterization and validation of an ungulate-pasture model.*

Pekkarinen,A.-J. 2018. Dissertationes Forestales 249: 8282–8302. *Ecology and economics of reindeer herding systems.*

Objective function:

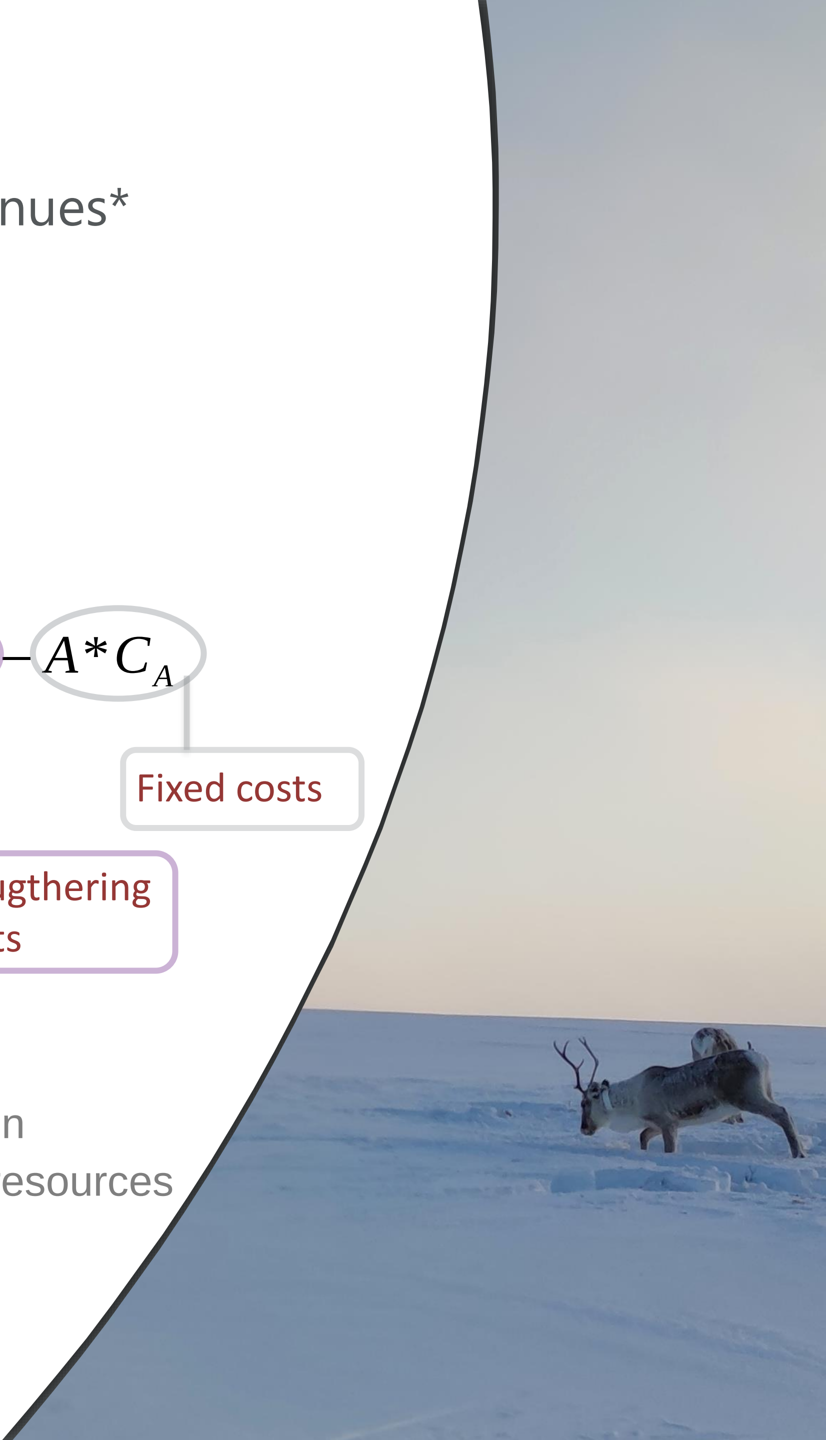
Reindeer herding district maximizes the present value of the net revenues*

$$\max_{\{b_t, h^i_{s,t}, s=0,..,n_i, i=f,m, t=0,1,...\}} \sum_{t=0}^{\infty} \left(\frac{1}{1+r}\right)^t Y_t^q$$

$$Y_t = p_h * j * \left[\sum_{s=0}^{n_f} (h^f_{s,t} * w^f_{s,t}) + \sum_{s=0}^{n_m} (h^m_{s,t} * w^m_{s,t}) \right] - p_b * b_t - X_t * C_x - H_t * C_h - A * C_A$$

Fixed costs

Annual revenues = Meat price × Total weight of the meat − Feeding costs − Management costs − Slaugthering costs



Subject to:

- **Population model:** development of the age- and sex-structured reindeer population
- **Energy intake model:** daily winter energy intake of reindeer from various energy resources
- **Lichen model:** growth, consumption, and wastage of ground lichen

2. Costs of predation

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According to previous research

- **Norway: costs of predation low**
  → Food limitations more important than predation *(Tveraa et al. 2014)*
  → Predation may improve economic lot in unmanaged settings *(Skonhoft et al. 2017)*

- **Finland and Sweden: costs of predation high**
  → Biological basis for compensations *(Hobbs et al. 2012)*
  → Marginal costs of increasing the wolverine density high *(Bostedt and Grahn 2008)*
  → During years of high predation calving and slaughtering percentages smaller *(Heikkinen et al. 2011 and Kumpula et al. 2017)*

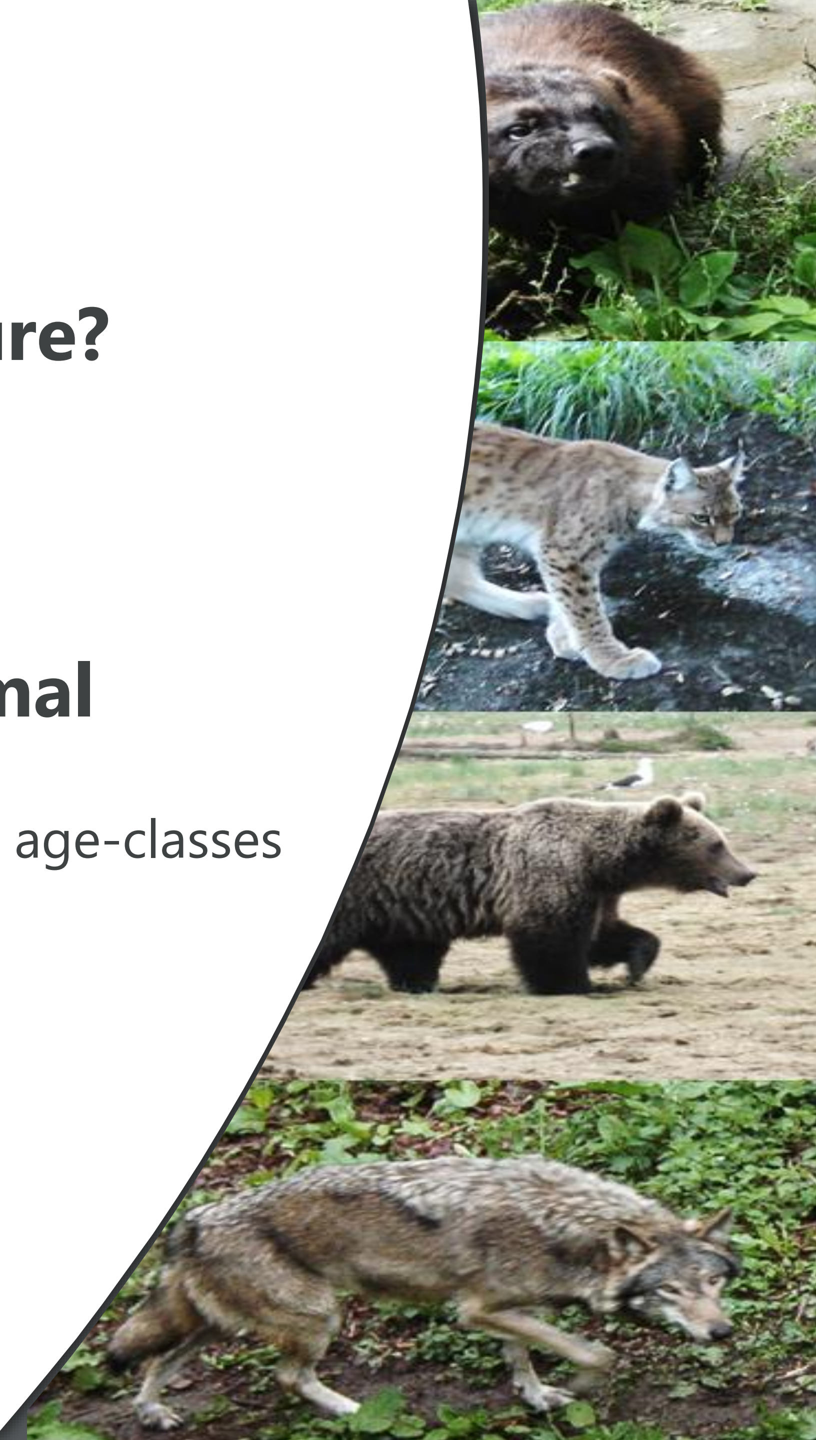
Compensation systems

- Sweden: territorial compensation (evaluated predation pressure)
- Finland and Norway: mainly based on observed/proven damages

2. Research questions

1. **How to adapt optimally to predation pressure?**
   - Age- and sex-structured model
   - Consumer-resource model → pasture dynamics
   - The importance of adaptation

2. **What are the costs of predation under optimal management?**
   - Different types of predators → predation targeting different age-classes
   - Different compensation schemes:
     1. **Territorial system:**
        - *Known predation pressure* *(assumption!)*
        - *No searching costs*
     2. **Observed/proven damages:**
        - *Unknow predation pressure*
        - *Searching costs*

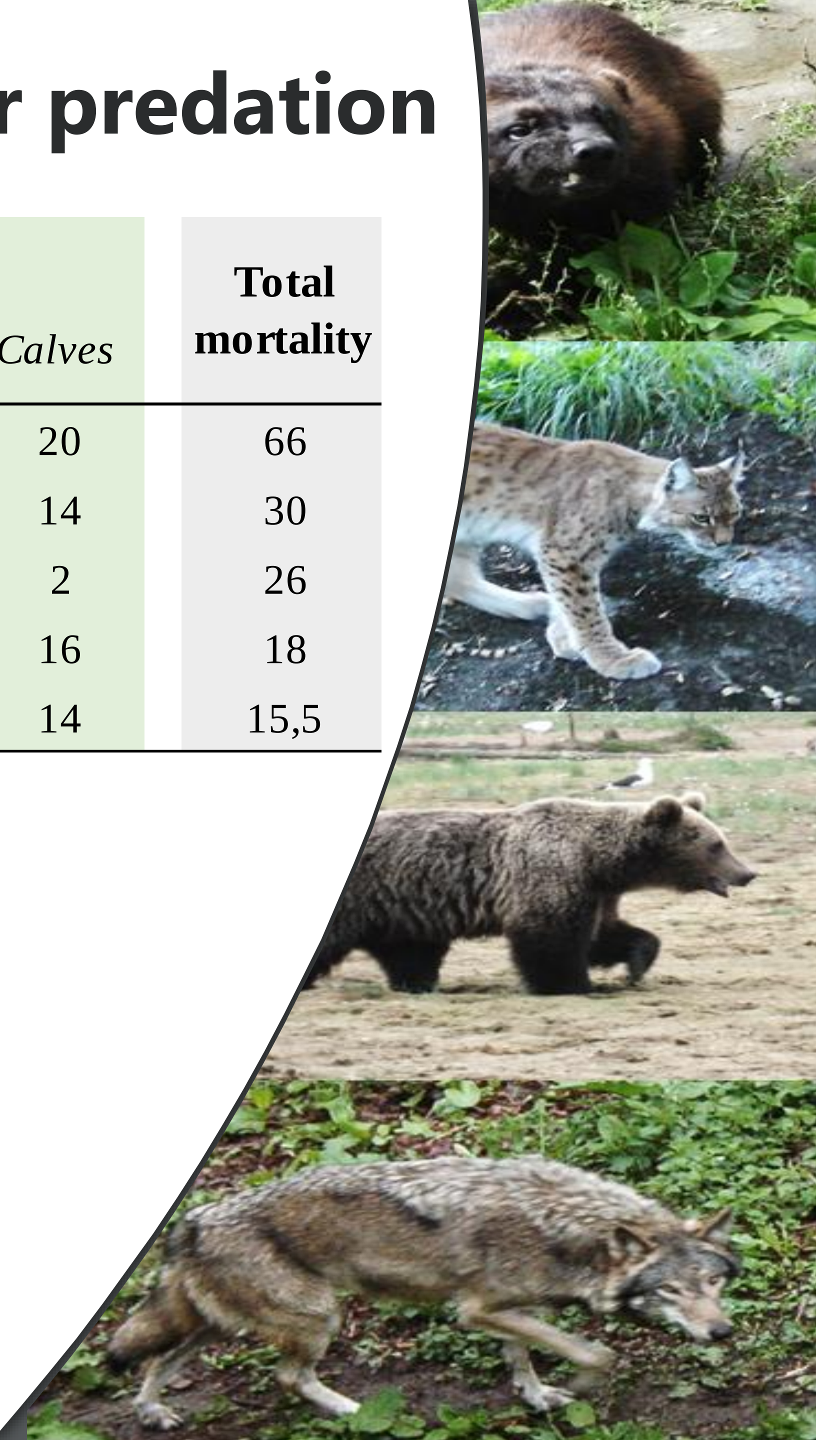


Age- and sex-class specific mortality under predation

	Winter mortality				**Summer mortality**					**Total mortality**
	Females	*Males*	*Young females*	*Young males*	*Females*	*Males*	*Young females*	*Young males*	*Calves*	
Wolf	24	4	8	2	4	1	2	1	20	66
Lynx	6	0,9	4	1	1	0,1	2	1	14	30
Wolverine	19	2	2,5	0,5	0	0	0	0	2	26
Brown bear	0	0	0	0	1	0,1	0,8	0,1	16	18
Golden eagle	0	0	0,8	0,2	0	0	0,4	0,1	14	15,5

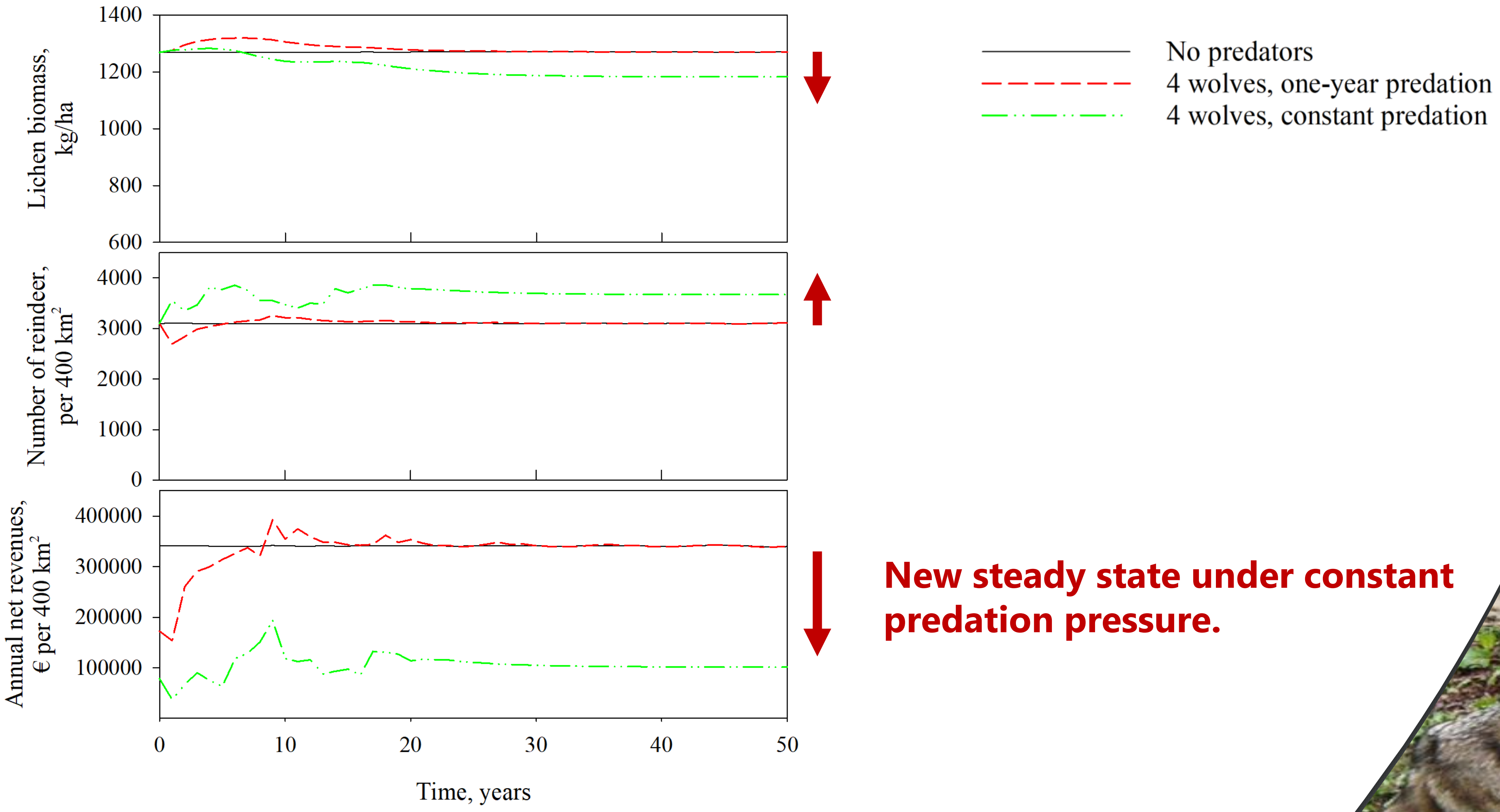
Based on estimations by experts and studies below

Brown bear: *Karlsson et al. 2012, 2014, Åhman et al. 2015*
Wolf: *Kojola et al. 2004, 2009, Kojola 2007,*
Lynx: *Pedersen et al. 1999, Mattisson et al. 2011, 2014, Hobbs et al. 2012*
Wolverine: *Landa et al. 1997, Hobbs et al. 2012, Koskela et al. 2013*
Golden eagle: *Kvam et al. 1998, Nybakk 1999, Nordberg et al. 2006, Nieminen et al. 2011*
Predation in general: *Nybakk et al. 2002, Mattisson et al. 2011, Nieminen et al. 2013*



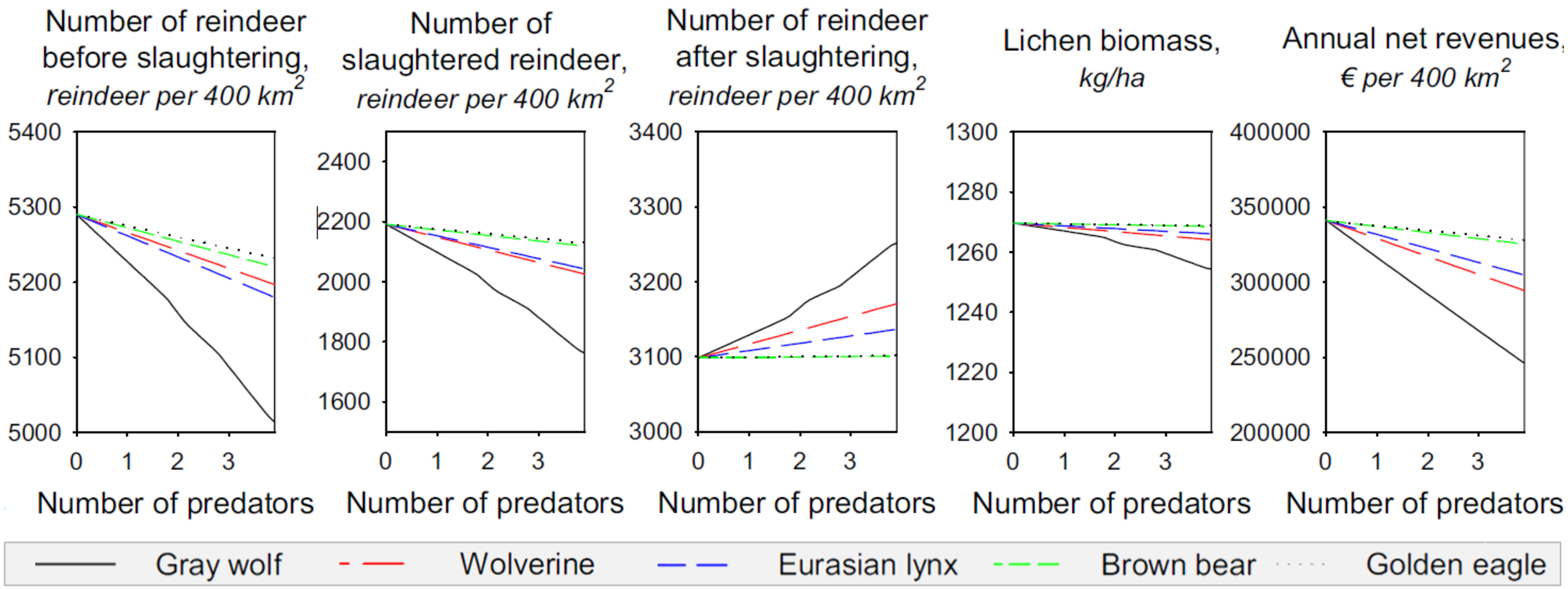
How to adapt optimally to predation

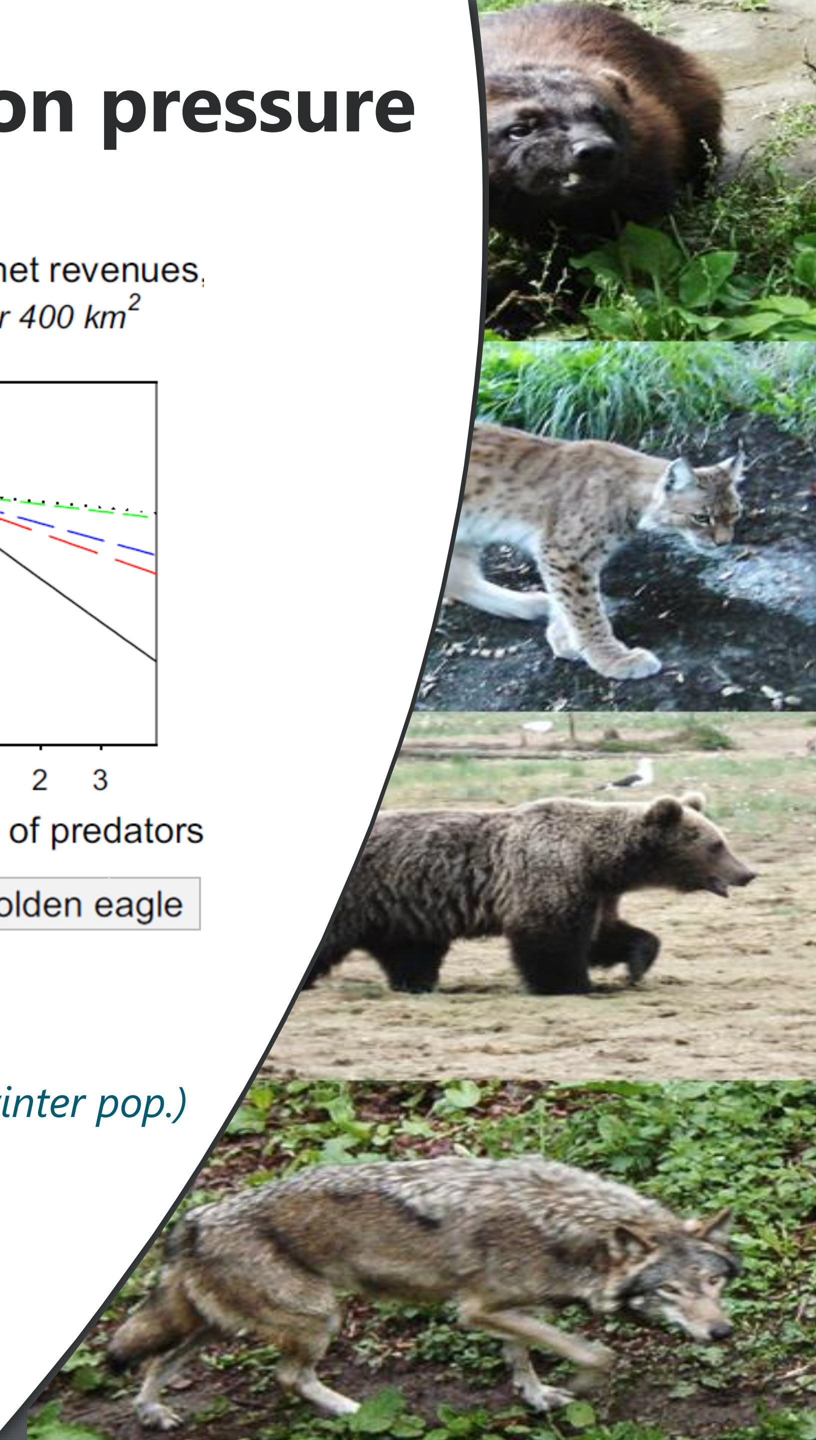
How to adapt optimally to predation
- dynamic solutions and steady states



New steady state under constant predation pressure.

Optimal solution (adaptation) under predation pressure

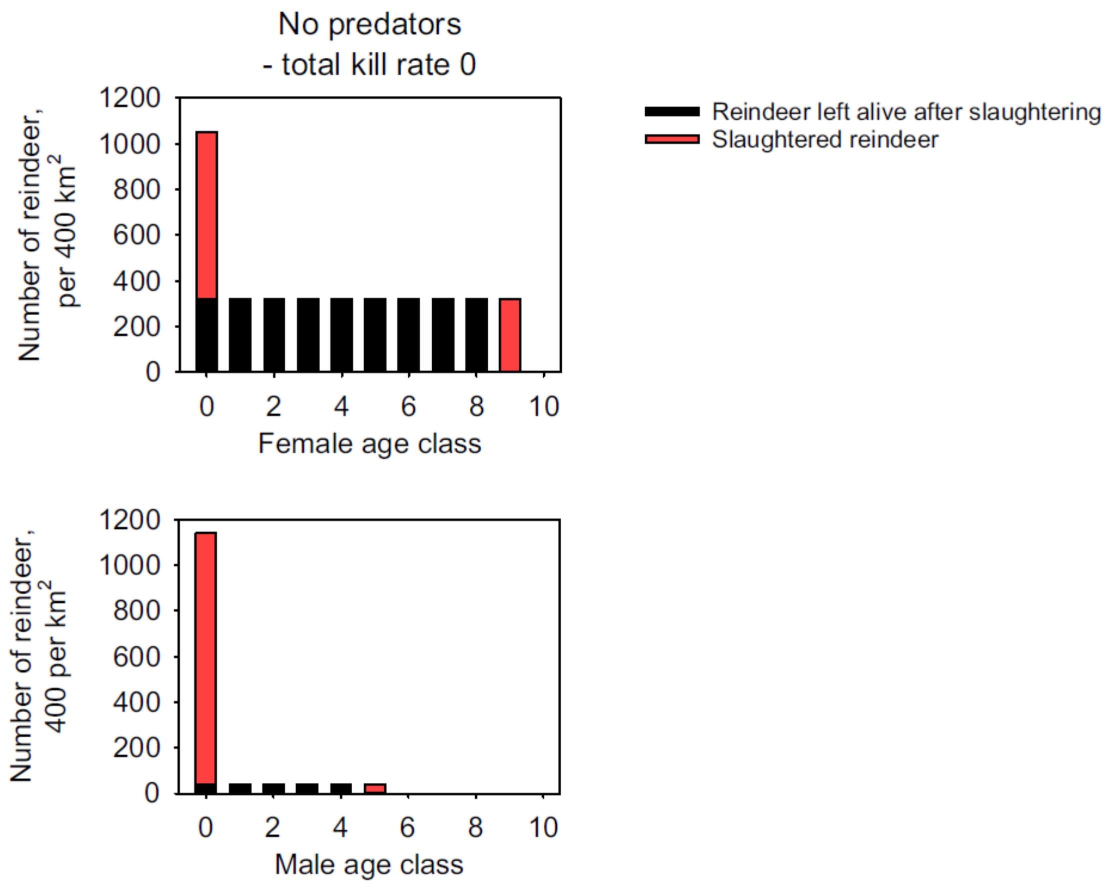




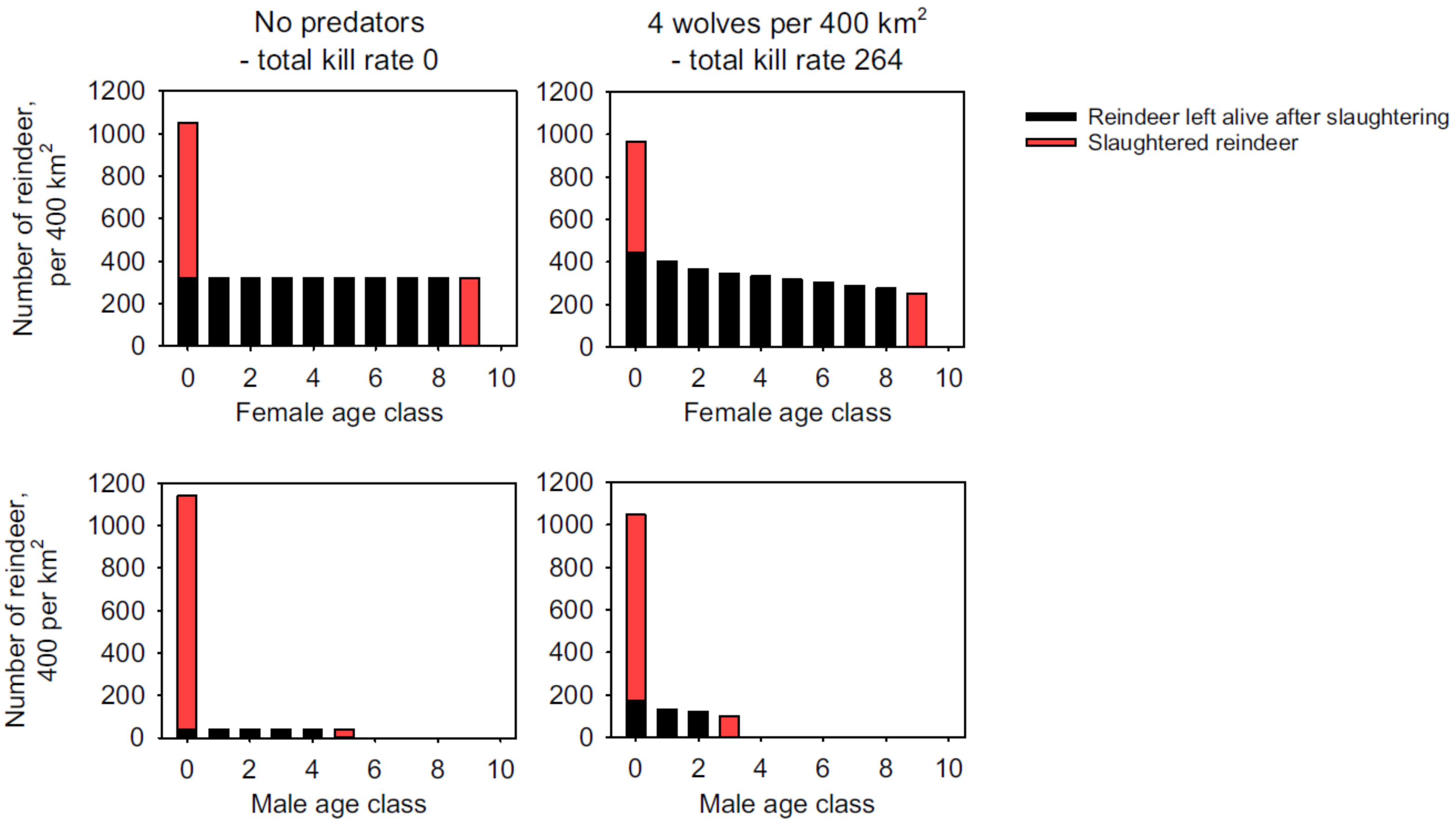
When predation pressure increases (steady state)**:**

- Reindeer population size: → decreases *(autumn pop.)*, → increases *(winter pop.)*
- Number of slaughtered reindeer: → decreases
- Net revenues: → decrease
- Lichen biomass: → minor decrease

Optimal slaughter strategy without predation



Optimal solution under high predation pressure



1. adult males are slaughtered earlier
2. importance of calf slaughtering decreases

→ Leaving calves alive compensates the high predation mortality

Importance of adaptation:

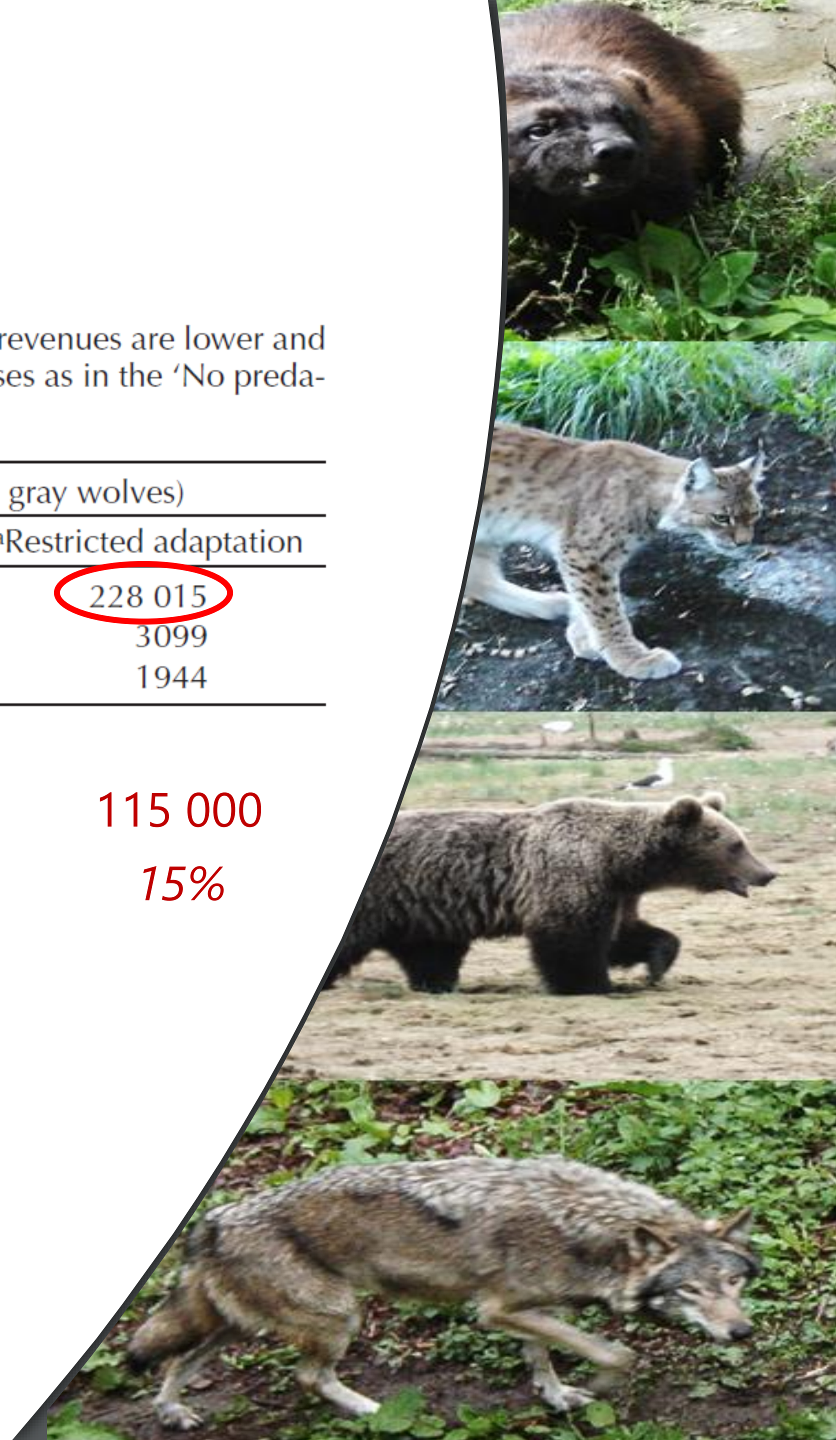
Table 6. Adaptation of slaughtering strategy reduces the costs of predation. With restricted adaptation the annual net revenues are lower and lichen biomass higher than with full adaptation. In restricted adaptation slaughtering is targeted at the same age classes as in the 'No predation' – situation. The number of reindeer left alive is also the same.

		Predation (10 gray wolves)		Predation (4 gray wolves)	
	No predation	Full adaption	[a]Restricted adaptation	Full adaption	[a]Restricted adaptation
Annual net revenues, €	341 141	101 710	58 635	243 651	228 015
Number of reindeer	3099	3443	3099	3255	3099
Lichen biomass, kg ha^{-1}	1270	1237	2556	1254	1944

[a] Fixed slaughtering percentages from age classes and fixed number of reindeer left alive after slaughtering.

Costs of predation →		240 000	280 000	100 000	115 000
	higher costs (%) →		*17 %*		*15%*

→ Without adaptation net revenues are clearly lower



Costs of predation

Loss of net revenues per predator:

(in a predictable (steady-state) situation = constant known predation)

Predator	Loss of net revenues *Steady state, €*
Gray wolf	24 625
Wolverine	12 007
Eurasian lynx	9341
Brown bear	4039
Golden eagle pair	3327

Loss of net revenues per predator:

(in unanticipated (one-year predation) situation = <u>unknow predation pressure</u>)

Predator	Loss of net revenues: *Steady state,* €	Loss of net revenues: *One-year predation,* €	Increase in losses due to unanticipated predation, %
Gray wolf	24 625	29 292	19
Wolverine	12 007	13 146	9
Eurasian lynx	9341	9916	6
Brown bear	4039	4092	1
Golden eagle pair	3327	3332	0

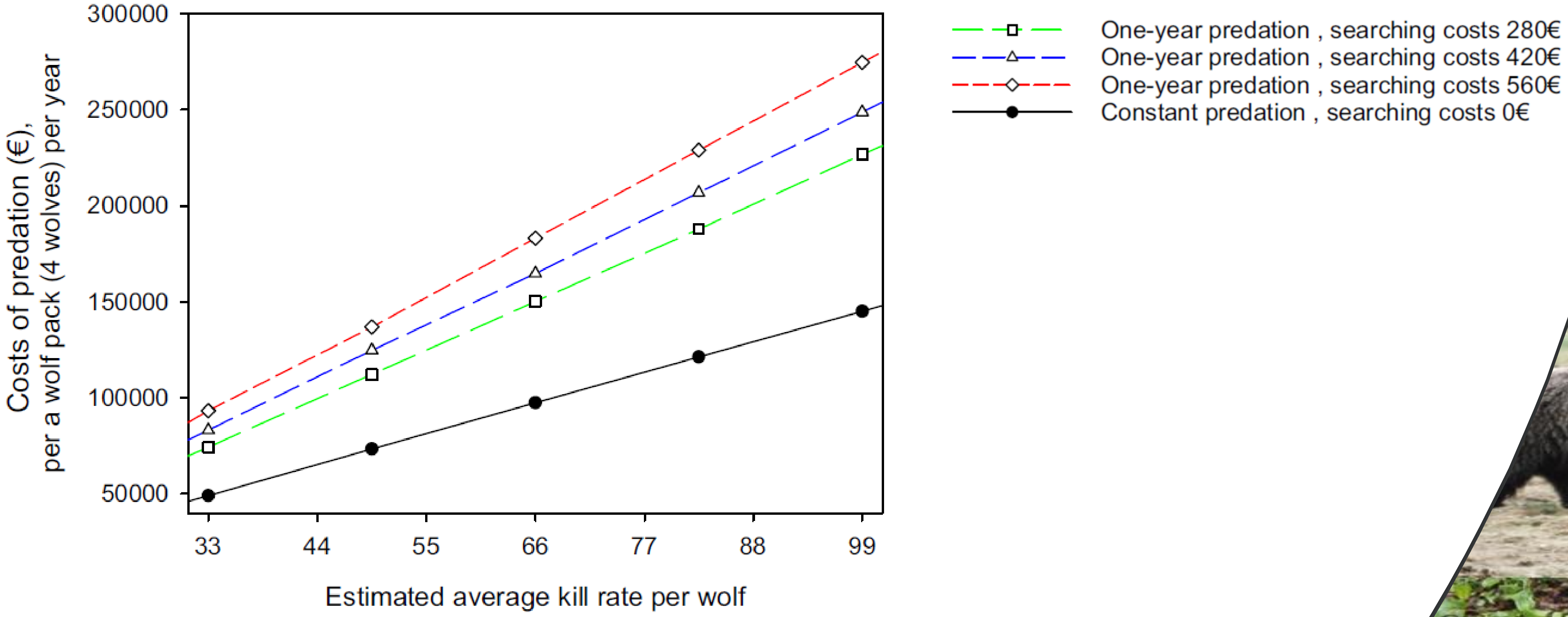
Loss of net revenues per predator:

with and without searching costs*

Predator	Loss of annual revenues due to predation: *Without searching costs, €*	*With searching costs, €*	*Increase in losses due to searching costs, %*
No predation			
Gray wolf	24 625	36 805	49
Wolverine	12 007	19 063	59
Eurasian lynx	9341	13 355	43
Brown bear	4039	4291	6
Golden eagle pair	3327	3684	11

*420€/located killed reindeer (Järvenpää 2014, Kumpula et al. 2017)

Costs of predation (wolf pack):



→ co-existence of a viable gray wolf population and profitable reindeer husbandry seems to be extremely difficult.

3. Costs of difficult winter conditions

3. Costs of difficult winter conditions

- **Effects of typical variation in winter conditions**

  (excluding extremely difficult winters)

  **Pekkarinen, A. J., Rasmus, S., Kumpula, J., & Tahvonen, O. (2022).*
  Winter condition variability decreases the economic sustainability of reindeer husbandry. Ecological Applications, https://doi.org/10.1002/eap.2719

- **Effects of very or extremely difficult winters**
  Ongoing research

Including the effects of difficult winters:

- Once per every ten years *(extremely difficult once per 25 years)**

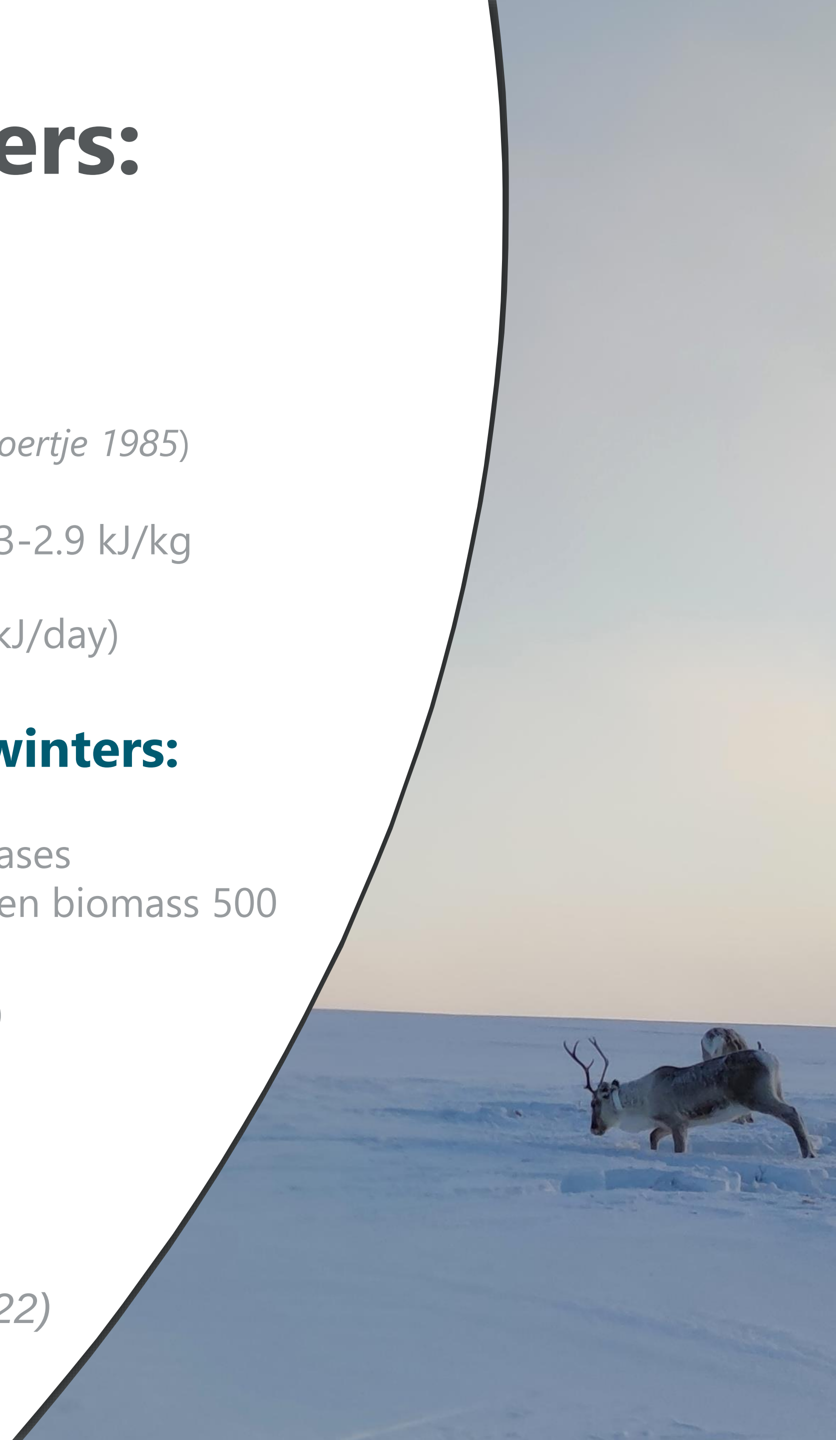
Energy need of reindeer increases 6% during difficult winters :

- difficult cratering conditions increase the energy expenditure about 5% (*Boertje 1985*)
- Gotaas et al. (2000): factorial models underestimate the energy need
- hourly energy expenditure: uncrusted snow 1.2-1.5 kJ/kg, crusted snow 2.3-2.9 kJ/kg (*Fancy and White 1985*)
- 8h cratering time and energy need of adult reindeer in our model (15-20 kJ/day)

Daily cratering area of reindeer decreases 4 m2 during difficult winters:

- average cratering area of 30 m2 per day
- As far as we know there are no studies on how much cratering area decreases
- Assuming 4 m2 decrease in cratering area → 20% decrease in calf% if lichen biomass 500 kg/ha (in line with our estimation from reindeer data)

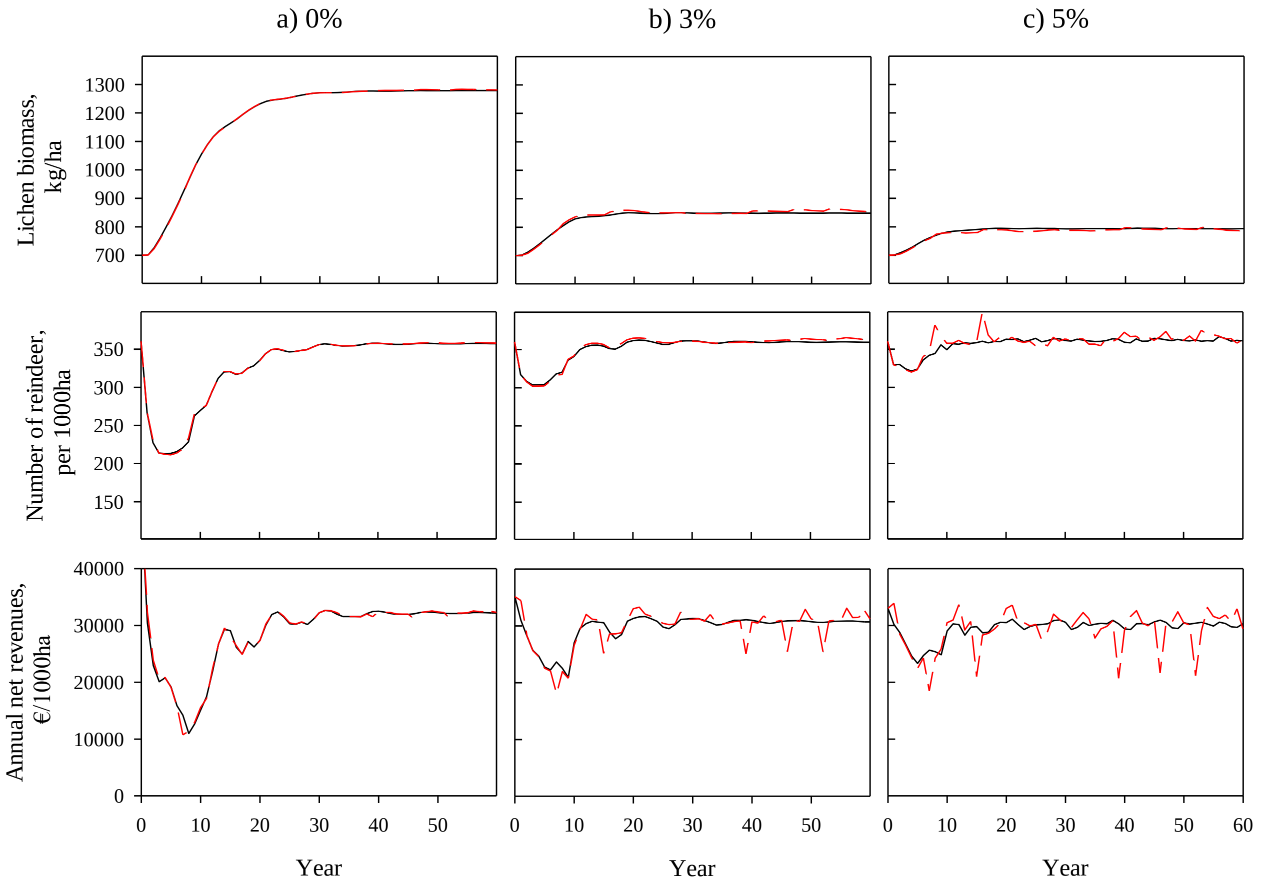
→ Cratering area decreases 4 m^2 during difficult winters (from 30 m^2 to 26 m^2)



**Analysis of the annual herding district reports (Pekkarinen et al. 2022)*

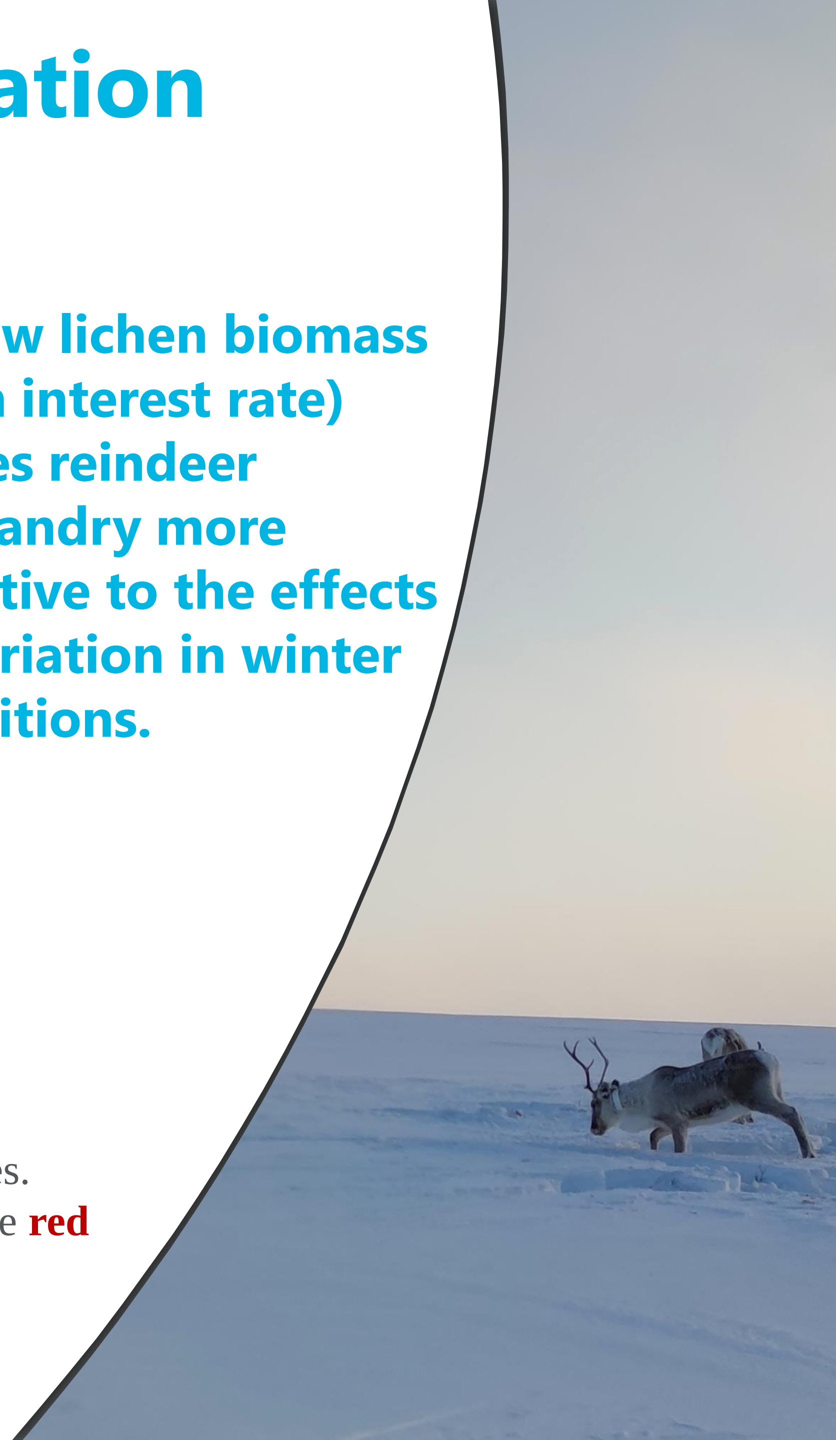
RESULTS

Optimal solutions under typical variation of winter conditions:

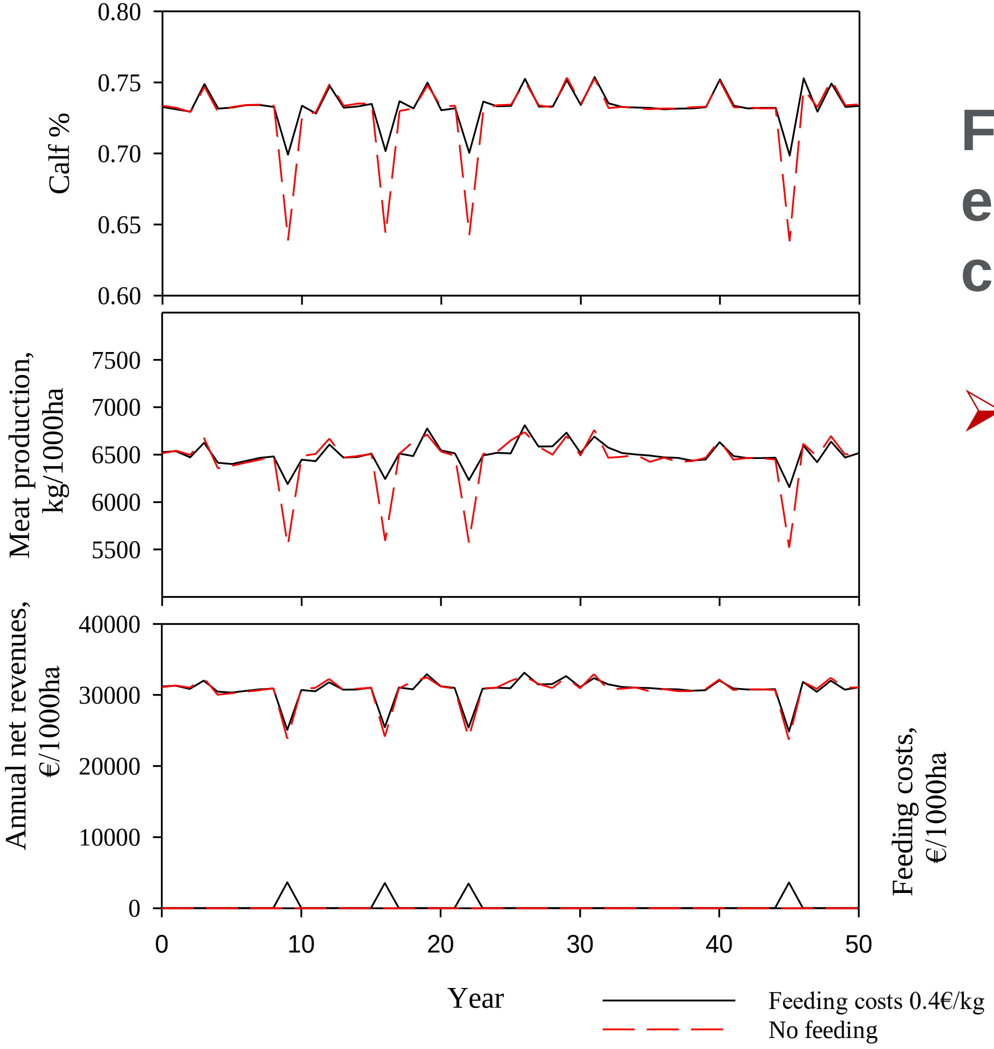


→ **Low lichen biomass (high interest rate) makes reindeer husbandry more sensitive to the effects of variation in winter conditions.**

Figure. Examples of dynamic economically optimal solutions with 0%, 3%, and 5 % interest rates. **The black line represents a solution with constant winter conditions** (average winters) and the **red dashed line a solution with stochastic winter conditions.**



3. Supplementary feeding under typical variation of winter conditions



Feeding during difficult winters ensures higher meat production and calf % than without feeding:

- **However, due to high feeding costs, net revenues remain low.**

Benefits of feeding are low when pasture conditions are good and variation in winter conditions is typical/normal

RESULTS

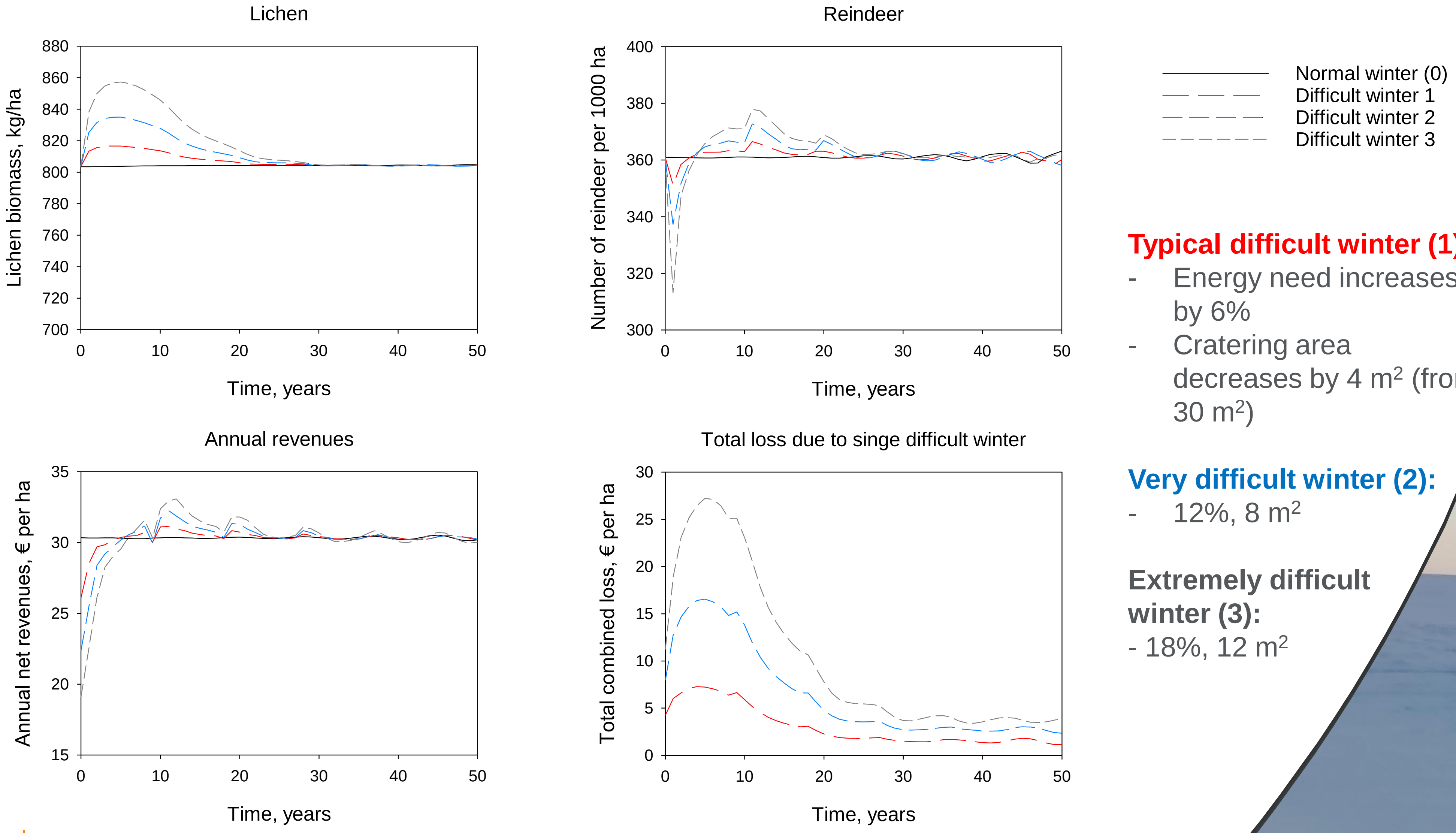
- **Effects of typical variation in winter conditions**
  (excluding extremely difficult winters)

  **Pekkarinen, A. J., Rasmus, S., Kumpula, J., & Tahvonen, O. (2022). Winter condition variability decreases the economic sustainability of reindeer husbandry. Ecological Applications, https://doi.org/10.1002/eap.2719*

- **Effects of very/extremely difficult winters**
  (Ongoing research)

Preliminary results (with feeding):

- Single difficult, very difficult or extremely difficult winter



Typical difficult winter (1):

- Energy need increases by 6%
- Cratering area decreases by 4 m^2 (from 30 m^2)

Very difficult winter (2):

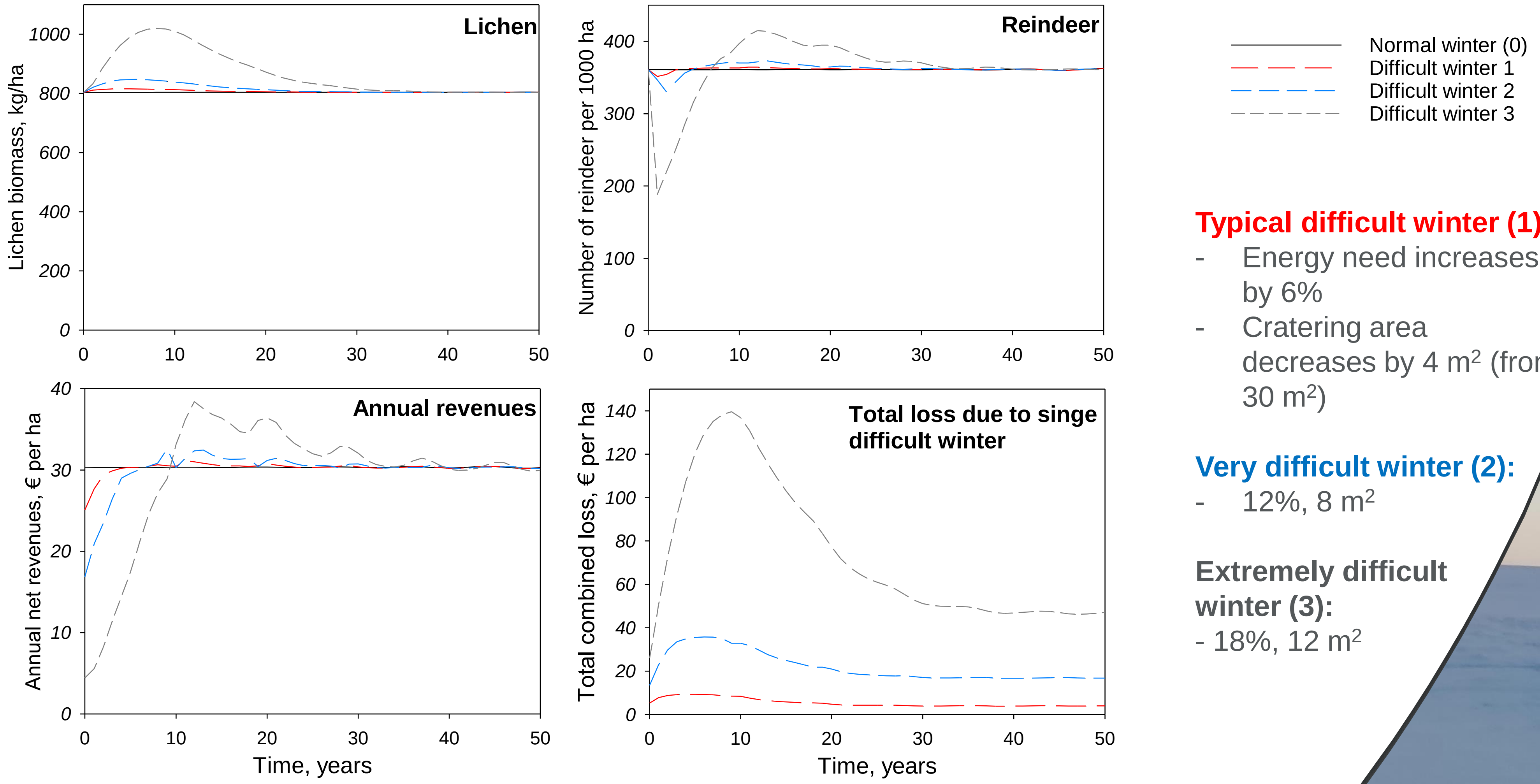
- 12%, 8 m^2

Extremely difficult winter (3):

- 18%, 12 m^2

Preliminary results (no feeding):

- Single difficult, very difficult or extremely difficult winter



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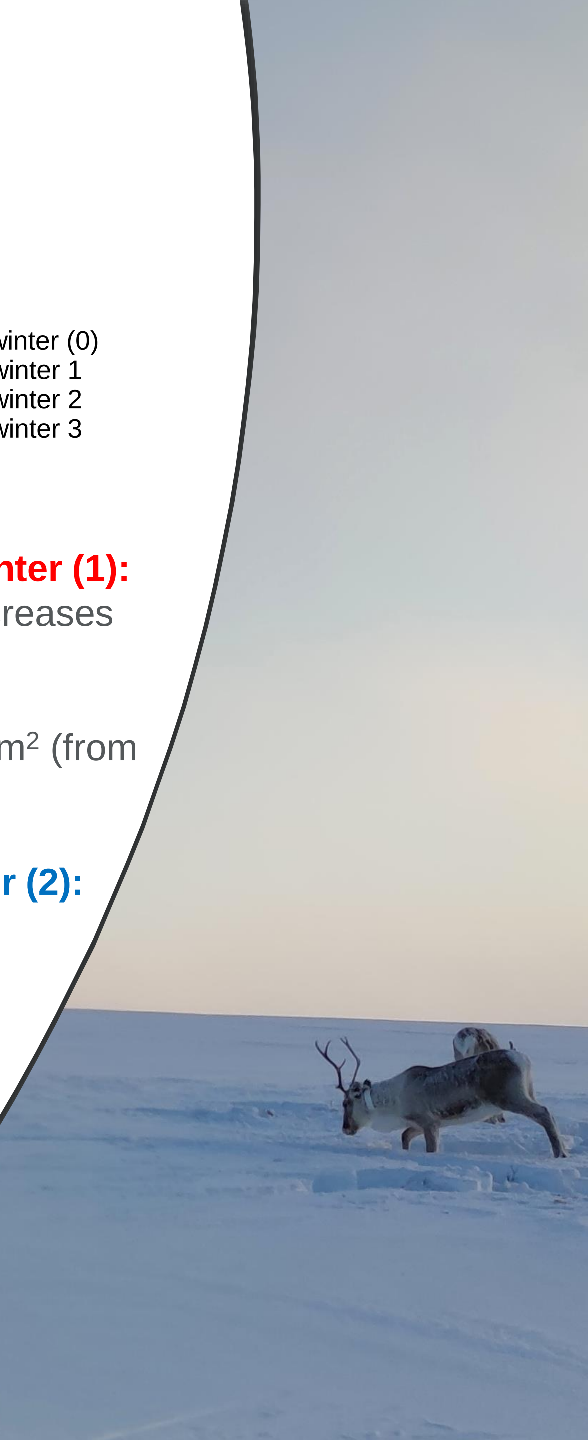
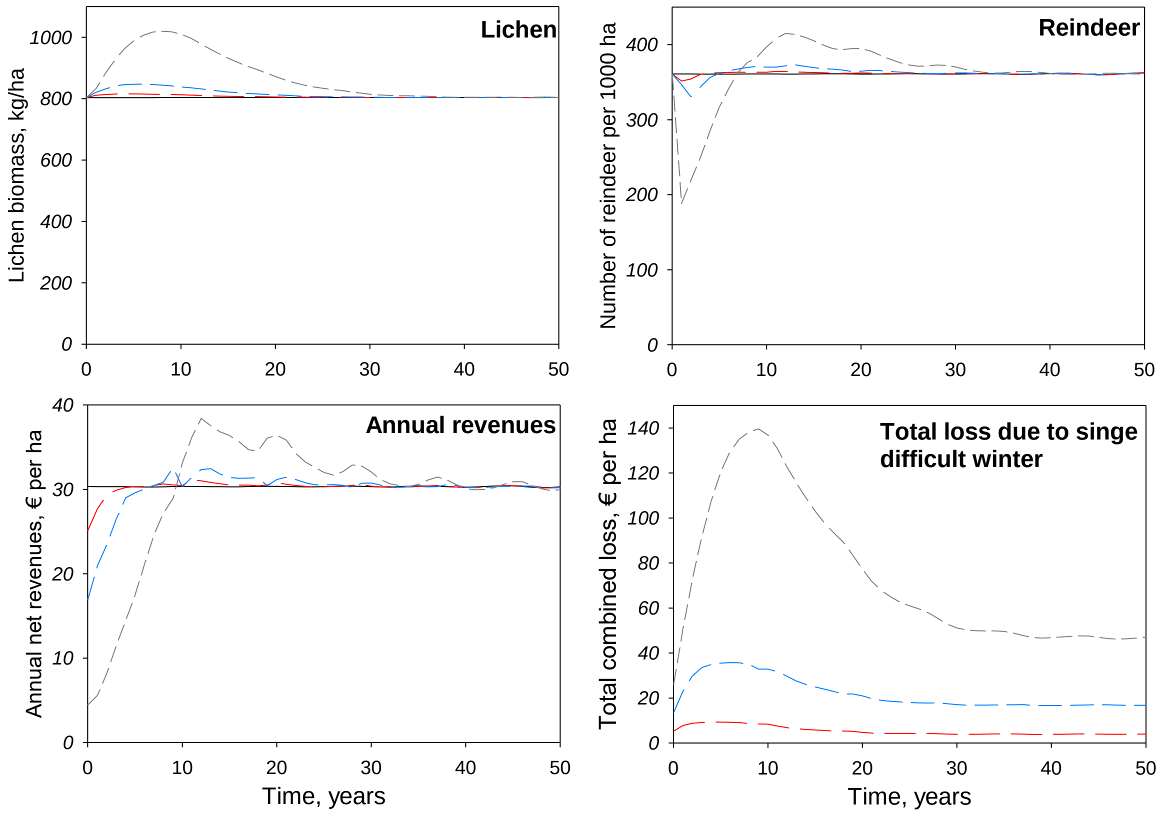
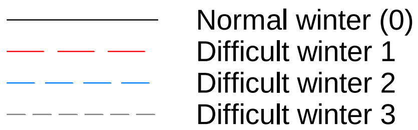


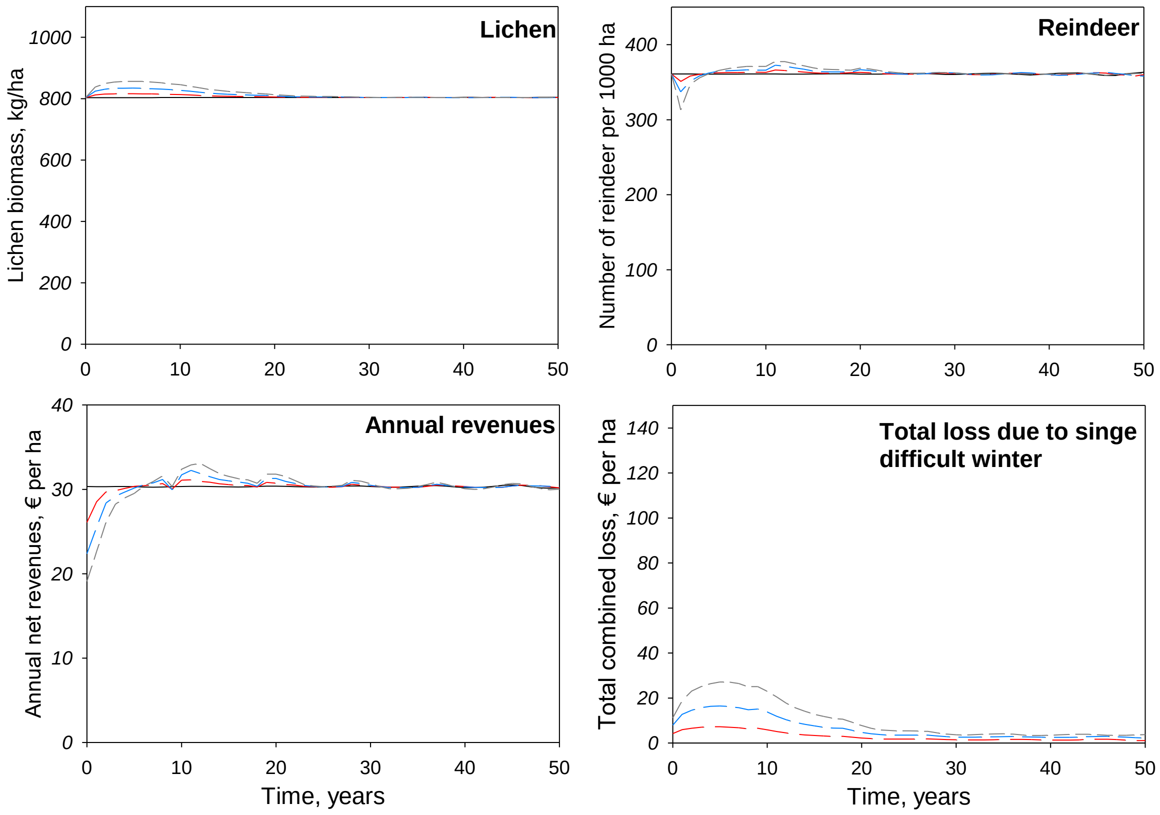
Preliminary results: visual comparison

No feeding



Feeding





→ **Feeding during very/extremely difficult winters keeps the system closer to optimal steady state.**

→ **Lower economic loss and shorter recovery time.**

CONCLUSIONS

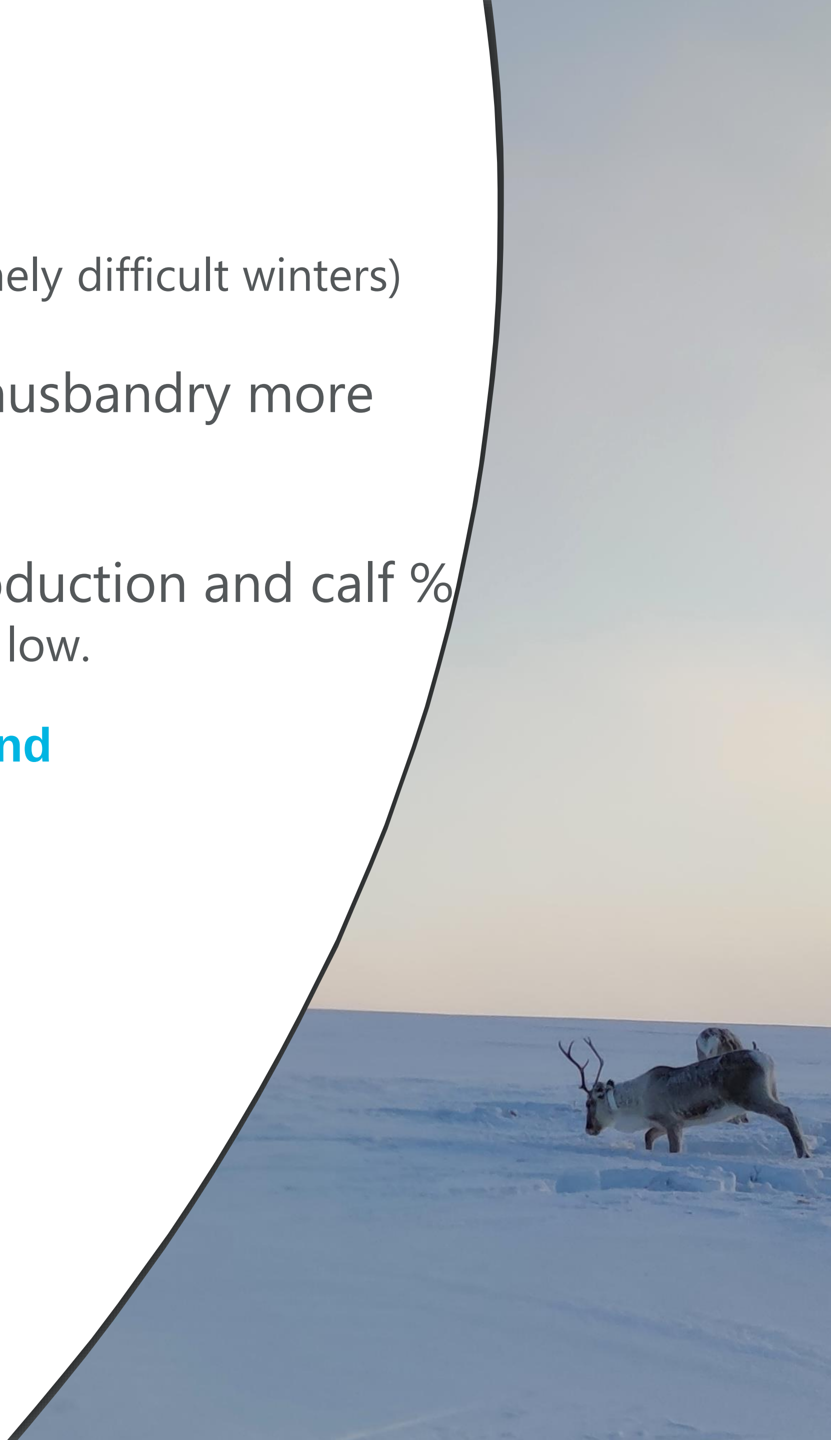
CONCLUSIONS

1. **Effects of typical variation in winter conditions** (excluding extremely difficult winters)

- Low lichen biomass (high interest rate) makes reindeer husbandry more sensitive to the effects of difficult winter conditions.

- Feeding during difficult winters ensures higher meat production and calf %
  →However, due to high feeding costs, net revenues remain low.

→ Benefits of feeding are low when pasture conditions are good and variation in winter conditions is typical/normal



CONCLUSIONS

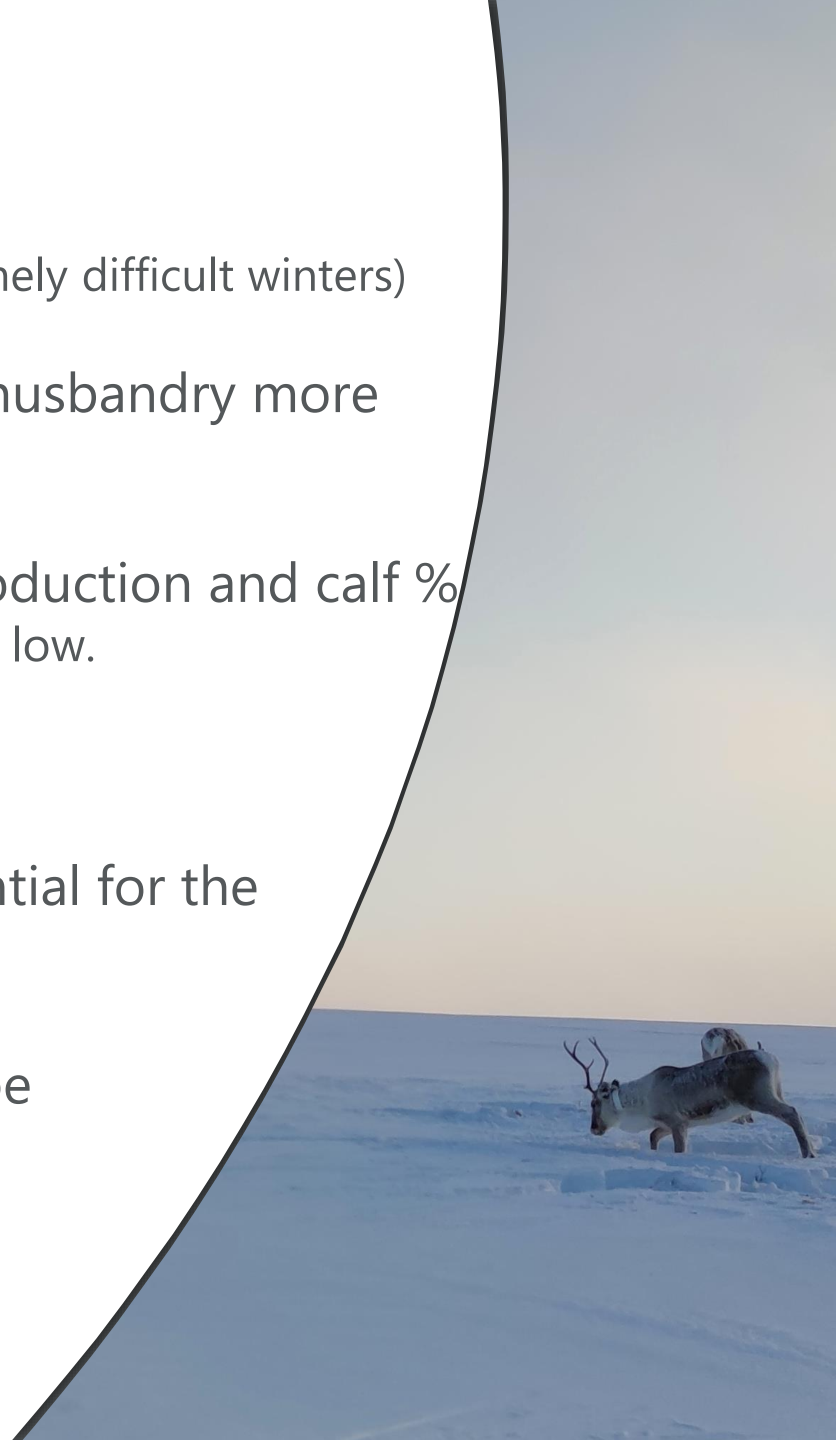
1. **Effects of typical variation in winter conditions** (excluding extremely difficult winters)

    - Low lichen biomass (high interest rate) makes reindeer husbandry more sensitive to the effects of difficult winter conditions.

    - Feeding during difficult winters ensures higher meat production and calf %
      →However, due to high feeding costs, net revenues remain low.

2. **Effects of very or extremely difficult winters** (Ongoing research)
    - Feeding during very or extremely difficult winters essential for the profitability of reindeer husbandry.

    - Without feeding (*or some other adaptation*) costs can be very high and long-lasting



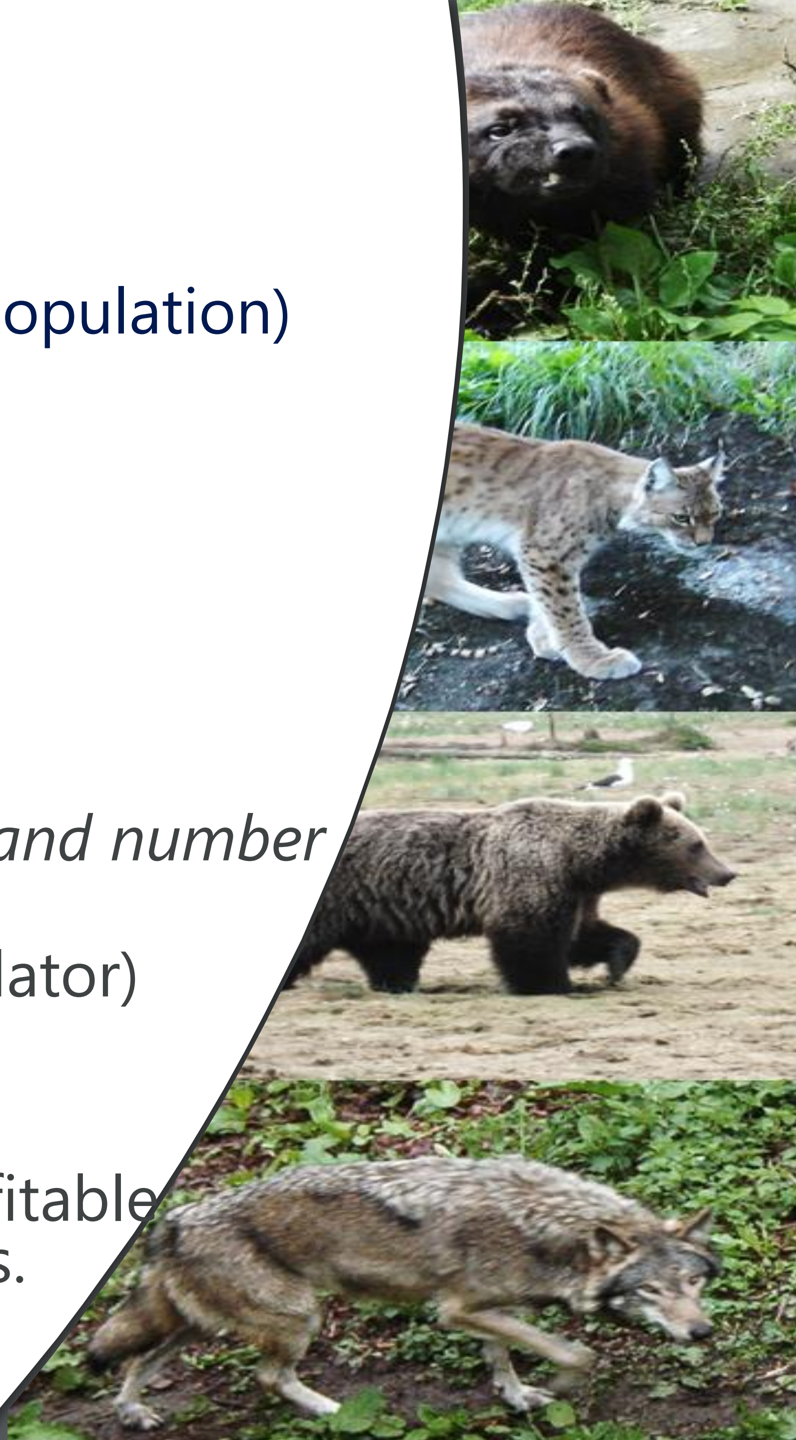
Conclusions

How to adapt optimally on predation

1. Leaving more reindeer alive after slaughter (winter population)
2. Changing slaughtering strategy
   → adult males are slaughtered earlier
   → importance of calf slaughtering decreases
3. without adaptation costs higher (> 15%)

Costs of predation

- Steady state losses when predation pressure (*kill rate and number of predators*) is known:
  →3000€ - 25 000€ per predator (depending on predator)
- Unknown predation: →costs 0- 19% higher
- Searching increases costs by 6-60%
- co-existence of a viable gray wolf population and profitable reindeer husbandry seems to be difficult in most areas.



Thank you!