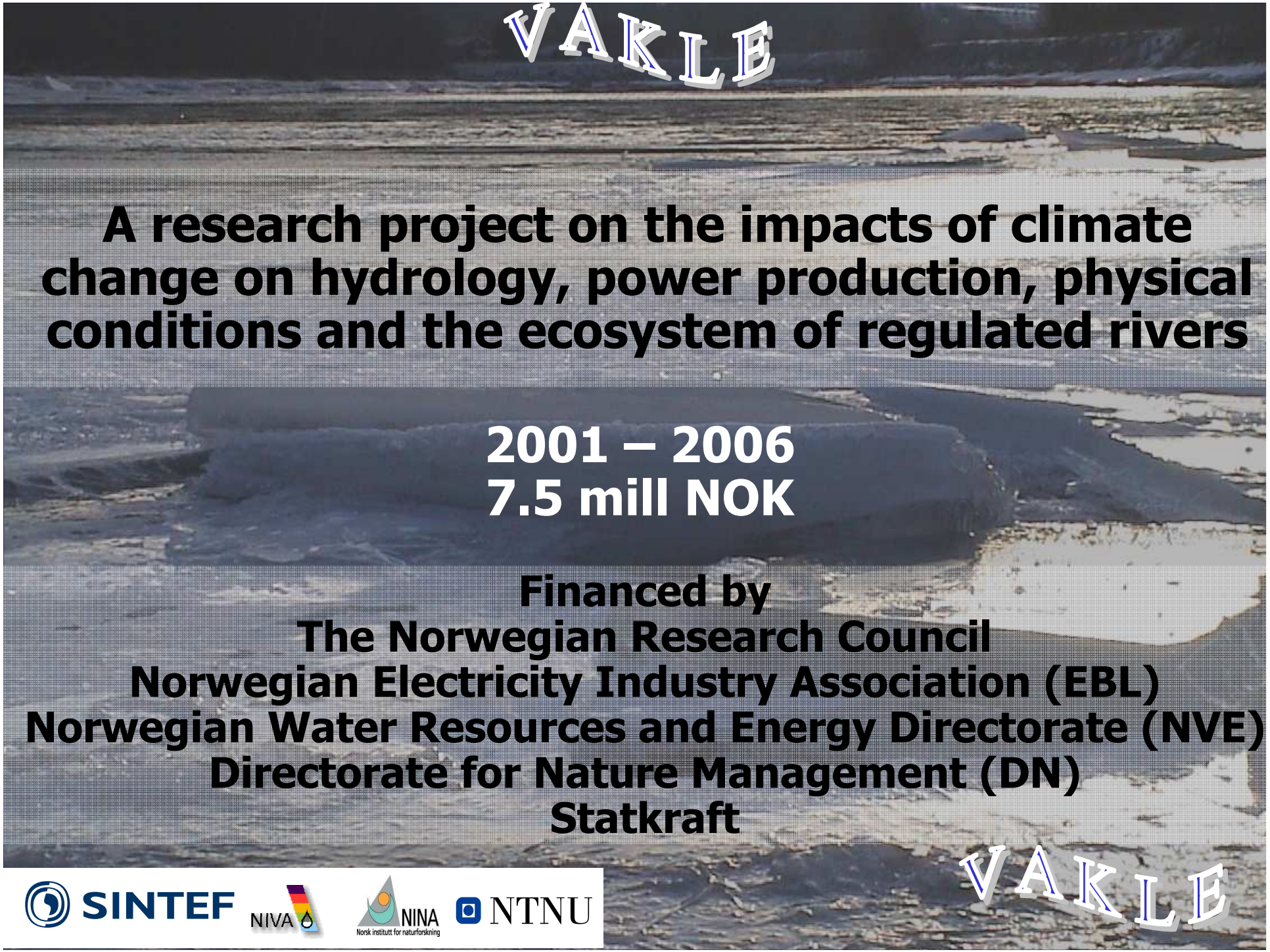


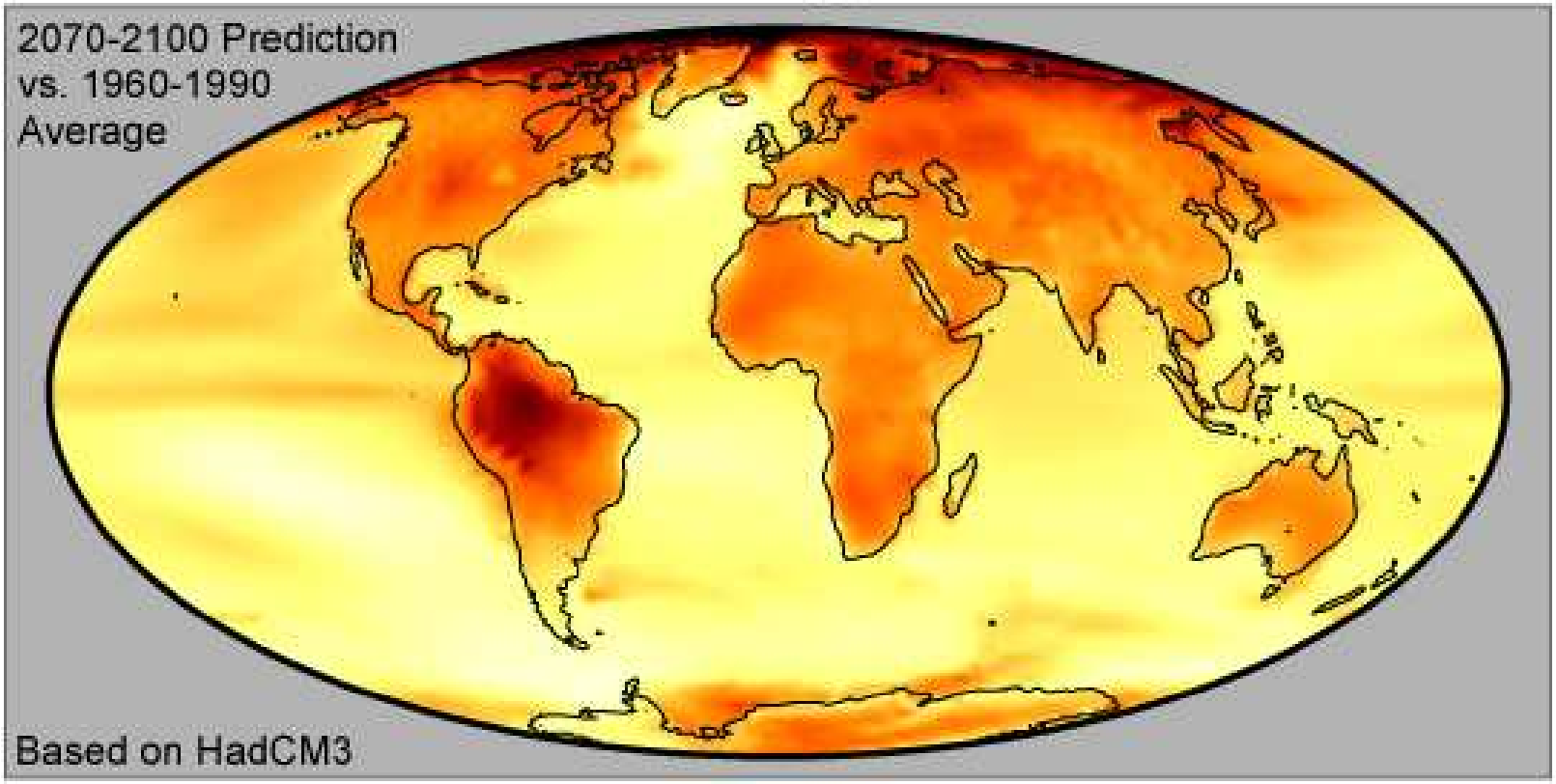
# Virkninger for liv i vassdrag av endret klima, tilsig og kraftverksdrift - Nye utfordringer for forvaltningen

**Atle Harby**, Lena S. Tøfte, Knut Alfredsen, Anders G. Finstad, Torbjørn Forseth, Nils Arne Hvidsten, Arne J. Jensen, Matthias Nester, Nils Roar Sælthun, Torulv Tjomsland and Ola Ugedal

SINTEF NINA Norsk institutt for naturforskning NTNU NIVA


VAKLE
A research project on the impacts of climate change on hydrology, power production, physical conditions and the ecosystem of regulated rivers
2001 – 2006
7.5 mill NOK
Financed by
The Norwegian Research Council
Norwegian Electricity Industry Association (EBL)
Norwegian Water Resources and Energy Directorate (NVE)
Directorate for Nature Management (DN)
Statkraft
SINTEF
NIVA
NINA
Norsk institutt for naturforskning
NTNU
VAKLE

# Global Warming Predictions



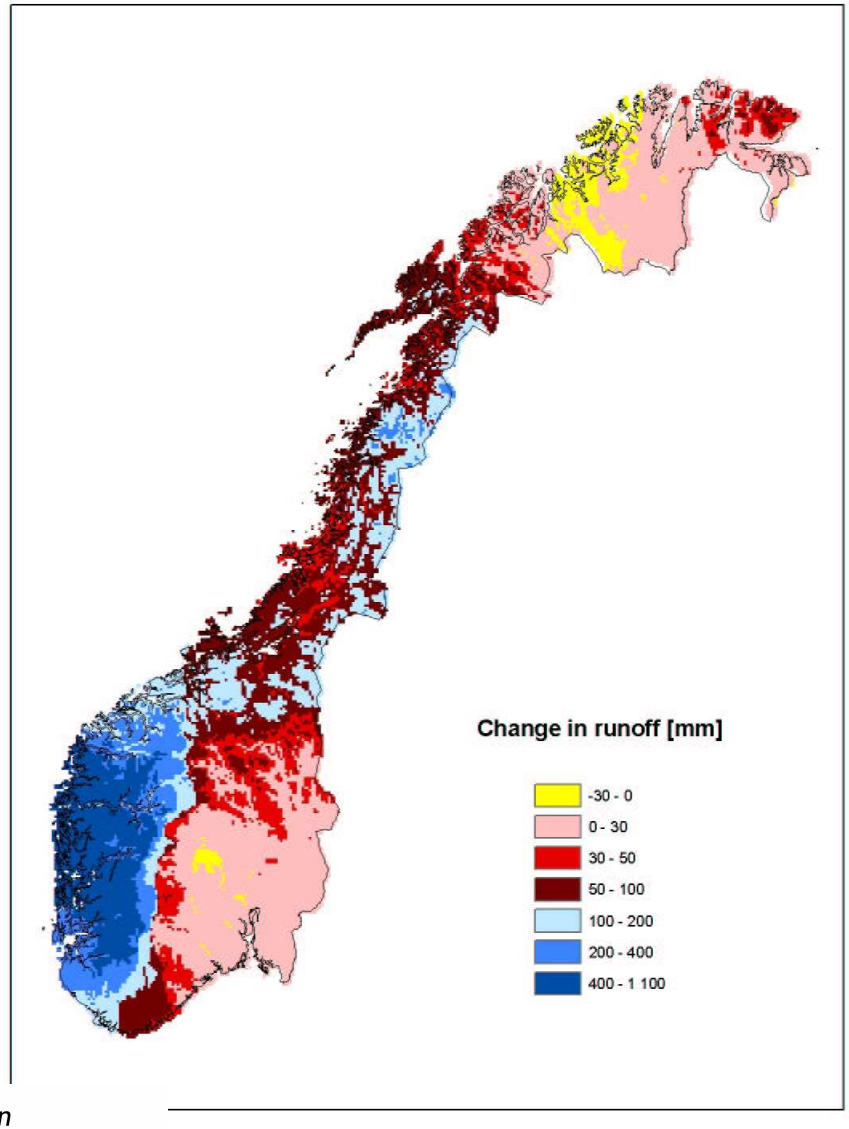




SINTEF NIVA NINA Norsk institutt for naturforskning NTNU

VAKLE

Data og figur fra NVE og met.no




Endringer i nedbør, lufttemperatur, fordampning og naturlig avrenning er beregnet av met.no og NVE i et annet prosjekt.

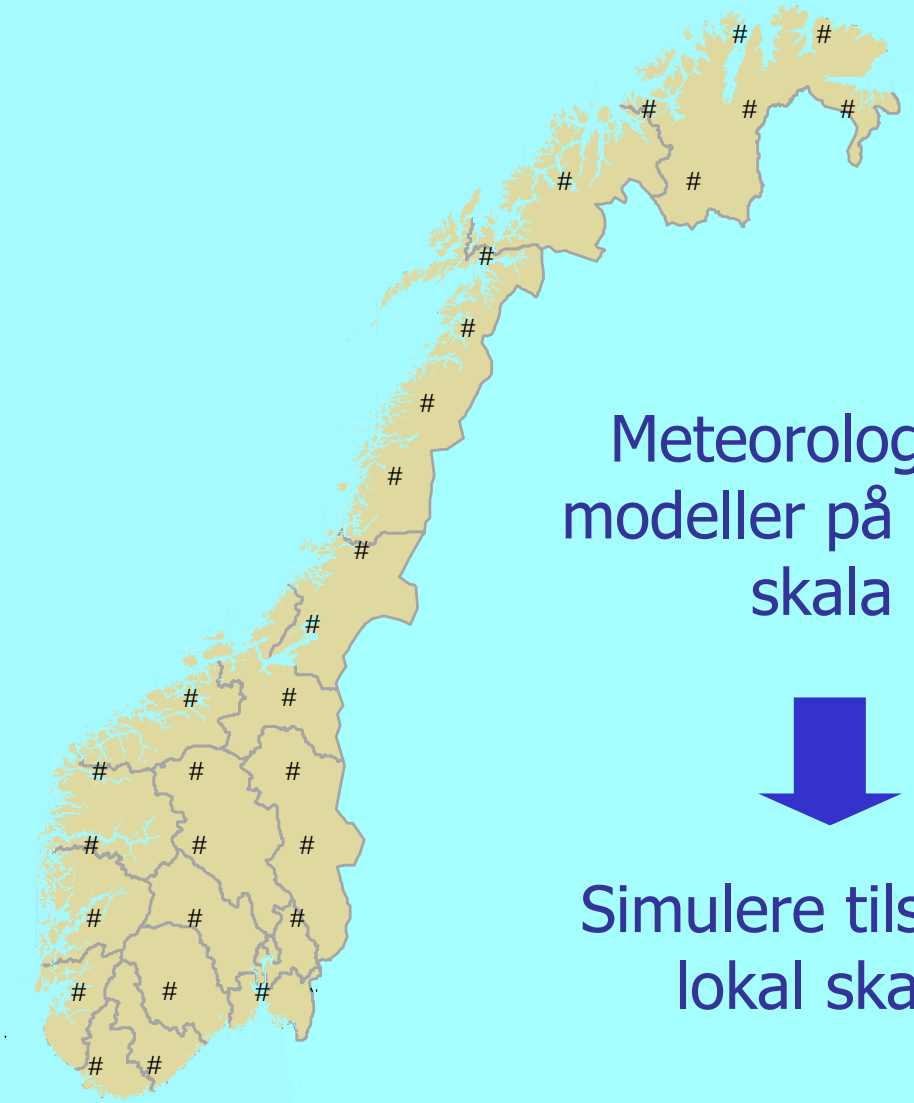
I VAKLE bruker vi hydrologiske modeller for å beregne simulert vannføring for prøvevassdrag i perioden 1980-2009 (referanse) og 2020-2049 (scenarie).

Norwegian Meteorological Institute
met.no

SINTEF NIVA NINA Norsk institutt for naturforskning NTNU

VAKLE

Data
og
figur
fra
NVE
og
met.no



Meteorologiske modeller på global skala

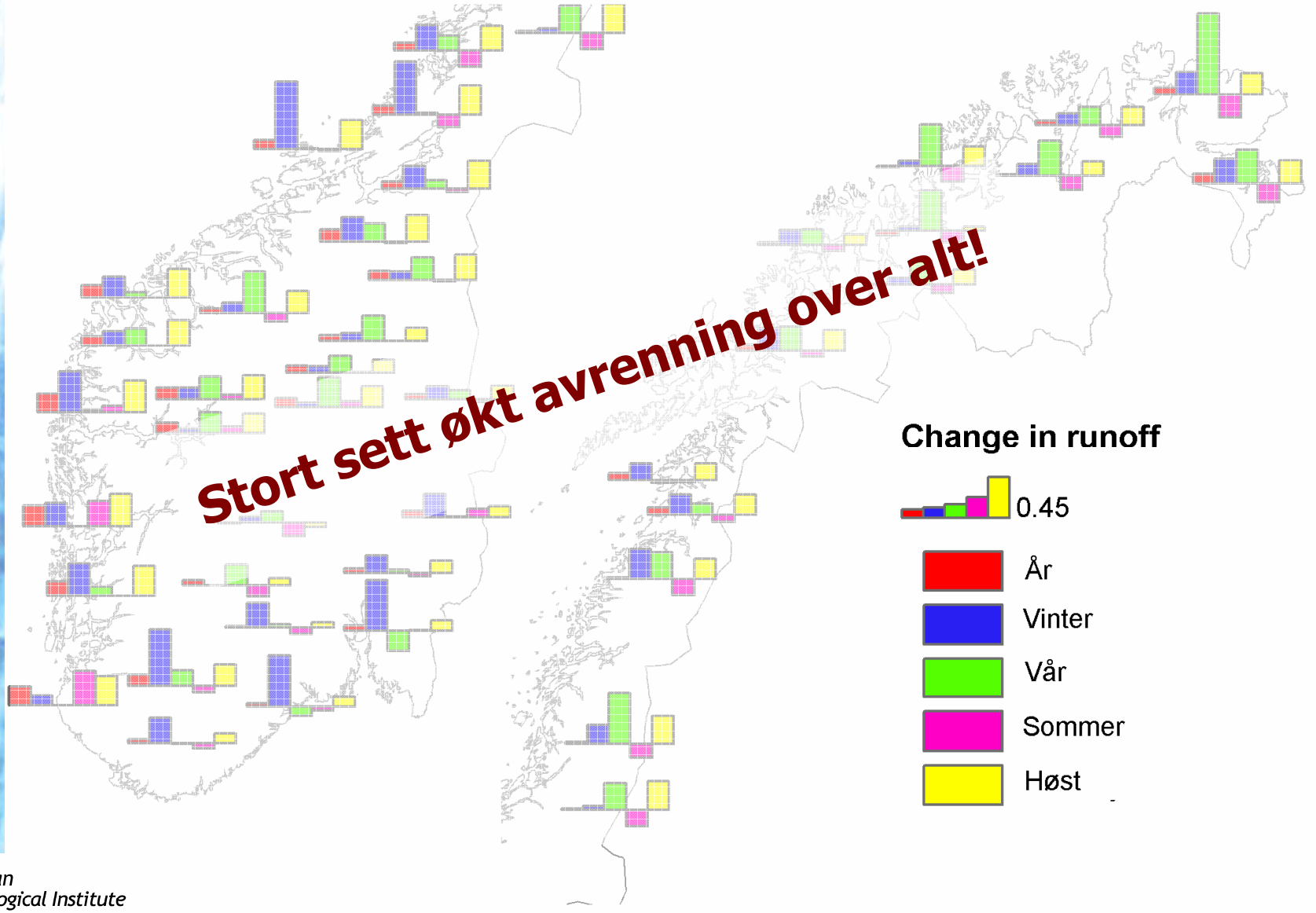
Simulere tilsig på lokal skala

Norwegian Meteorological Institute
met.no

SINTEF NIVA NINA Norsk institutt for naturforskning NTNU

VAKLE

Data
og
figur
fra
NVE
og
met.no



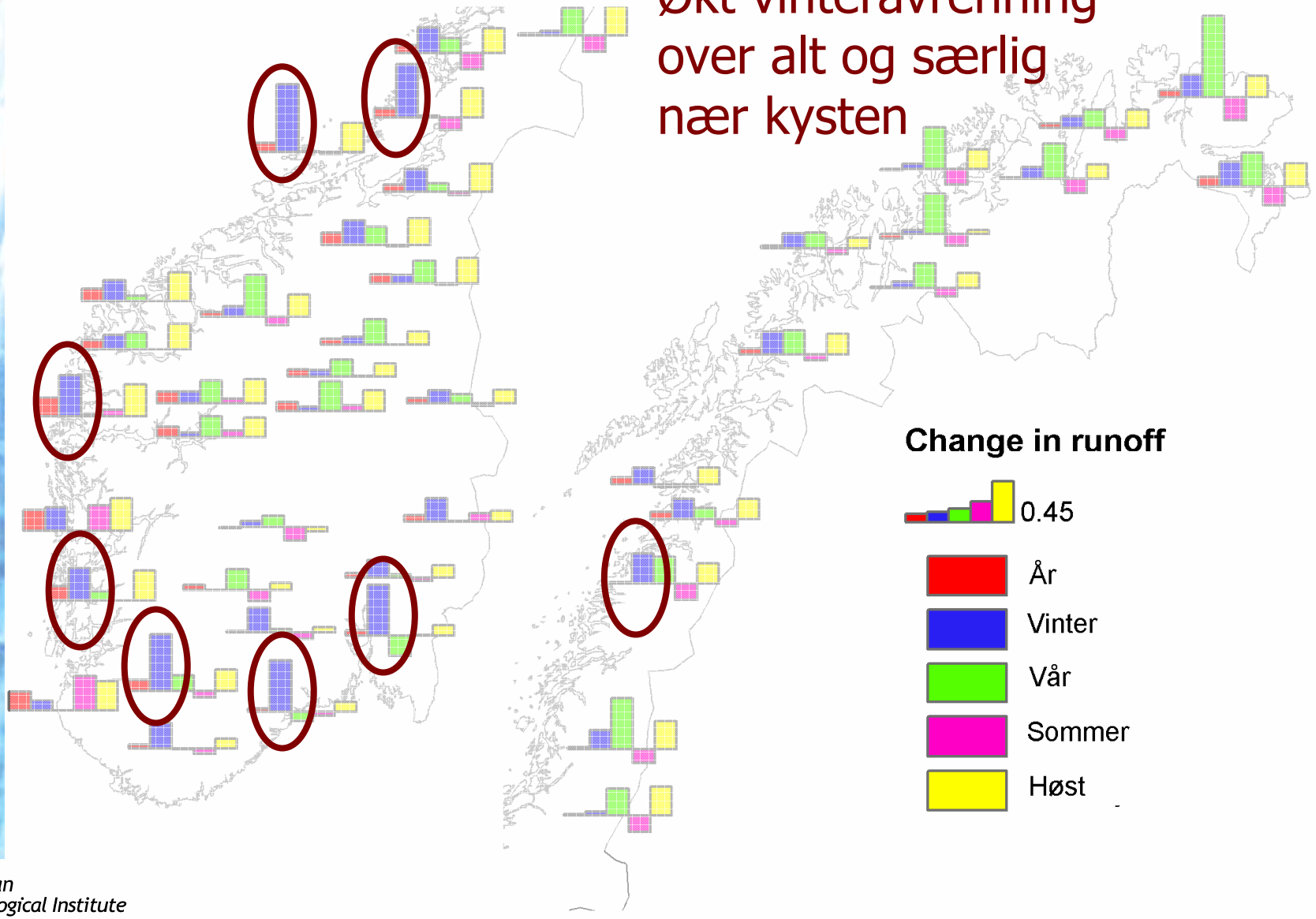

Norwegian
Meteorological Institute
met.no

SINTEF NIVA NINA Norsk institutt for naturforskning NTNU

VAKLE

# Økt vinteravrenning over alt og særlig nær kysten

Data og figur fra NVE og met.no



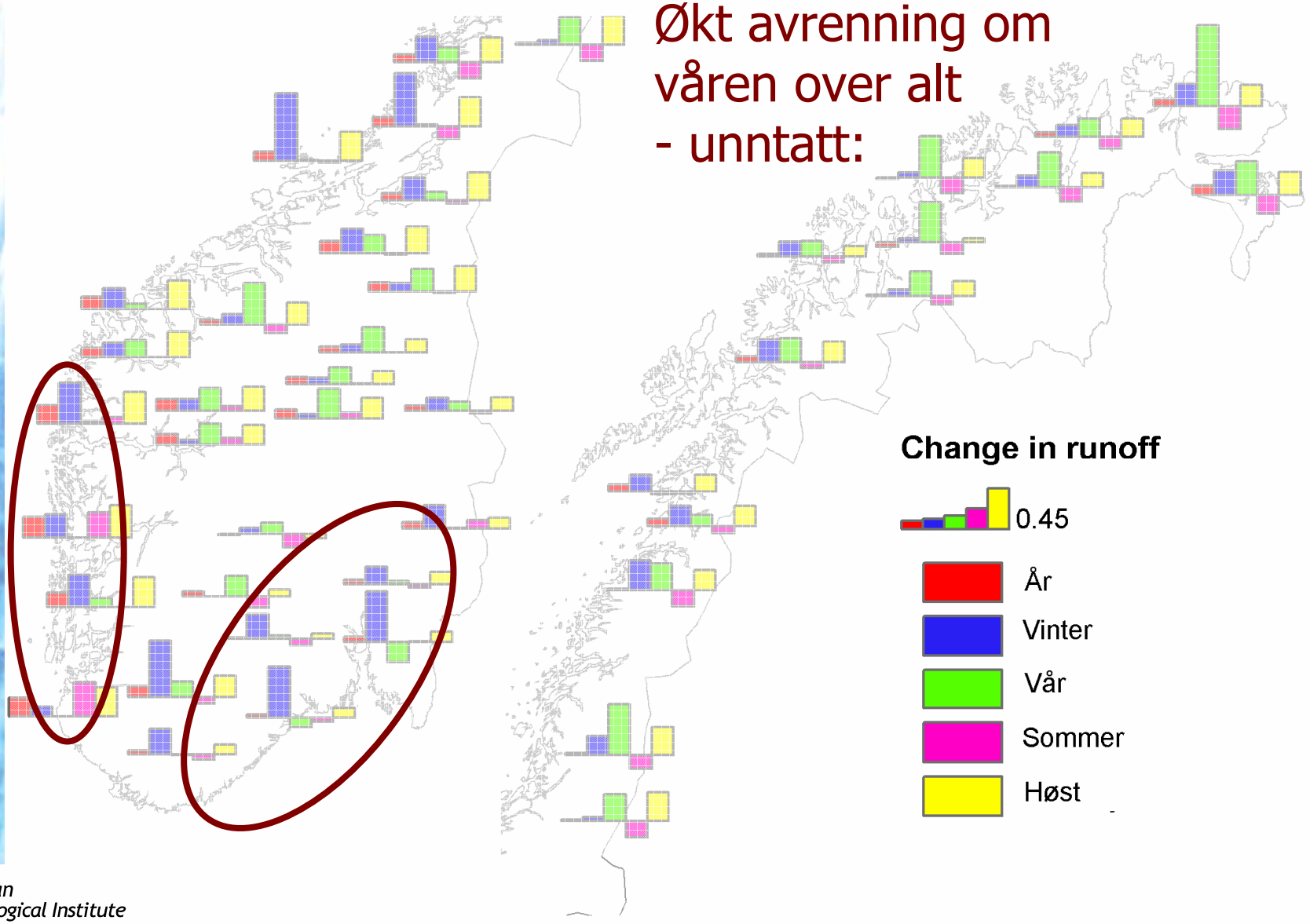

Norwegian Meteorological Institute
met.no

SINTEF NIVA NINA Norsk institutt for naturforskning NTNU

VAKLE

# Økt avrenning om våren over alt - unntatt:

Data og figur fra NVE og met.no



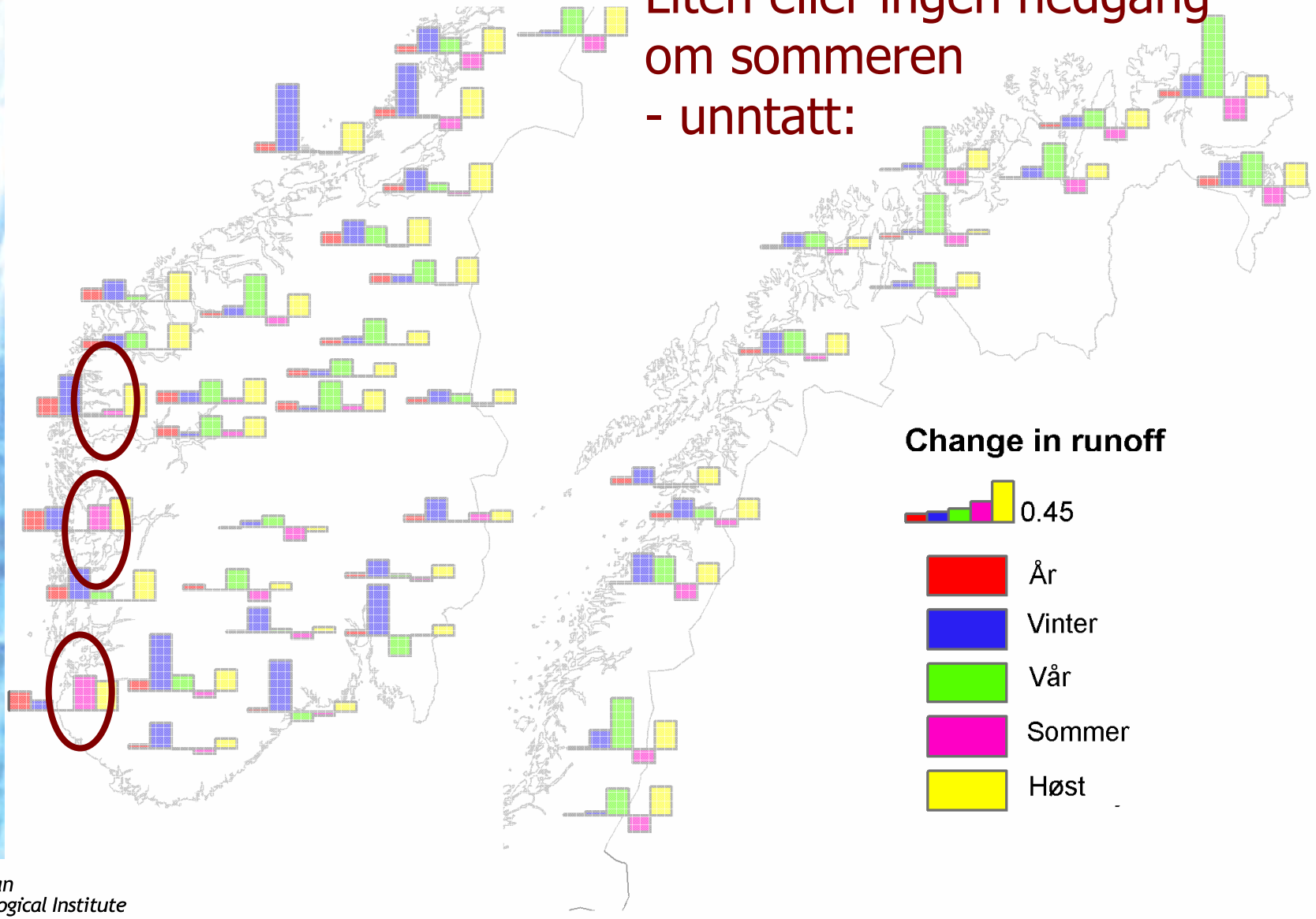

Norwegian Meteorological Institute
met.no

SINTEF NIVA NINA Norsk institutt for naturforskning NTNU

VAKLE

# Liten eller ingen nedgang om sommeren - unntatt:

Data og figur fra NVE og met.no



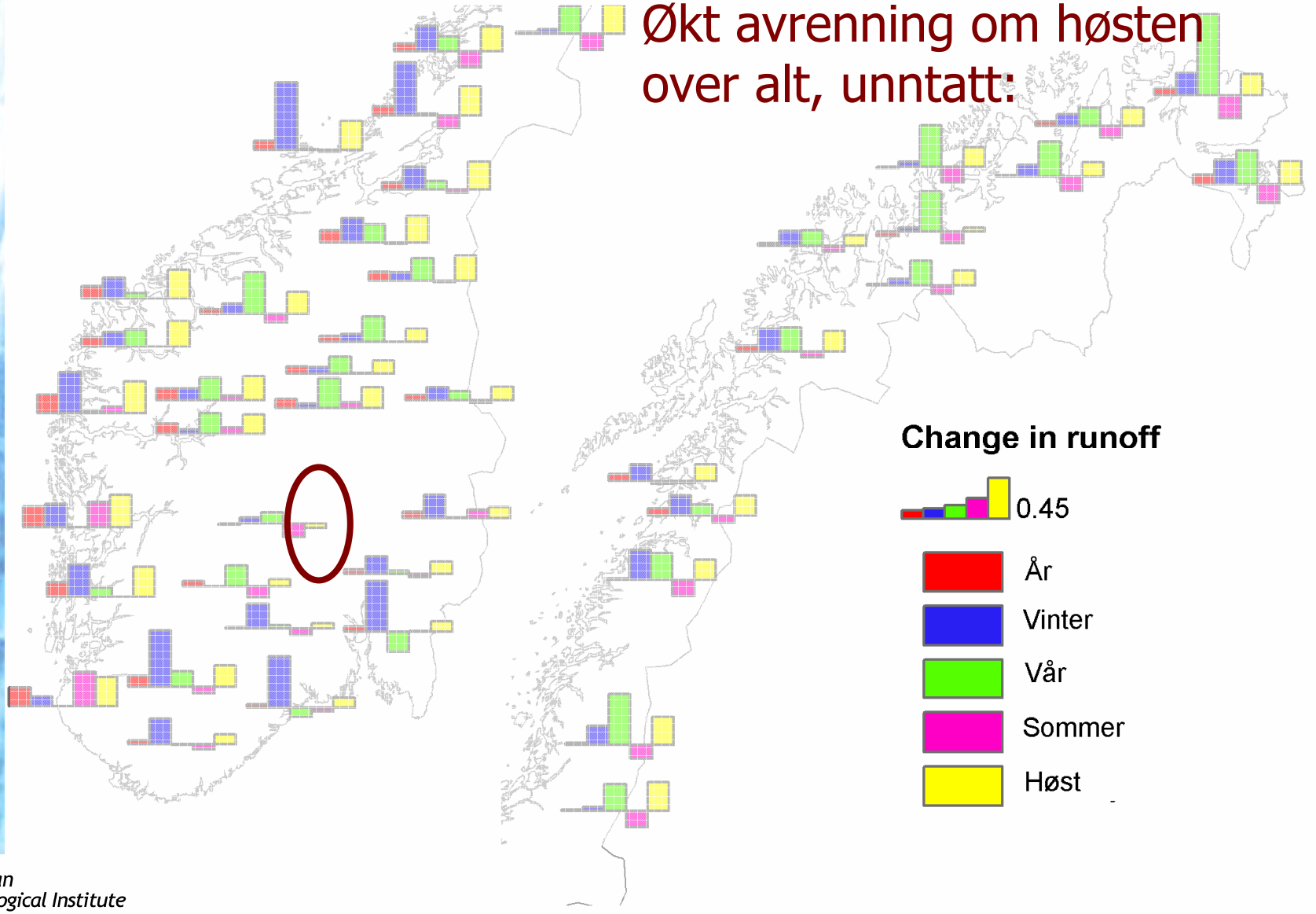

Norwegian Meteorological Institute
met.no

SINTEF NIVA NINA Norsk institutt for naturforskning NTNU

VAKLE

# Økt avrenning om høsten over alt, unntatt:

Data og figur fra NVE og met.no

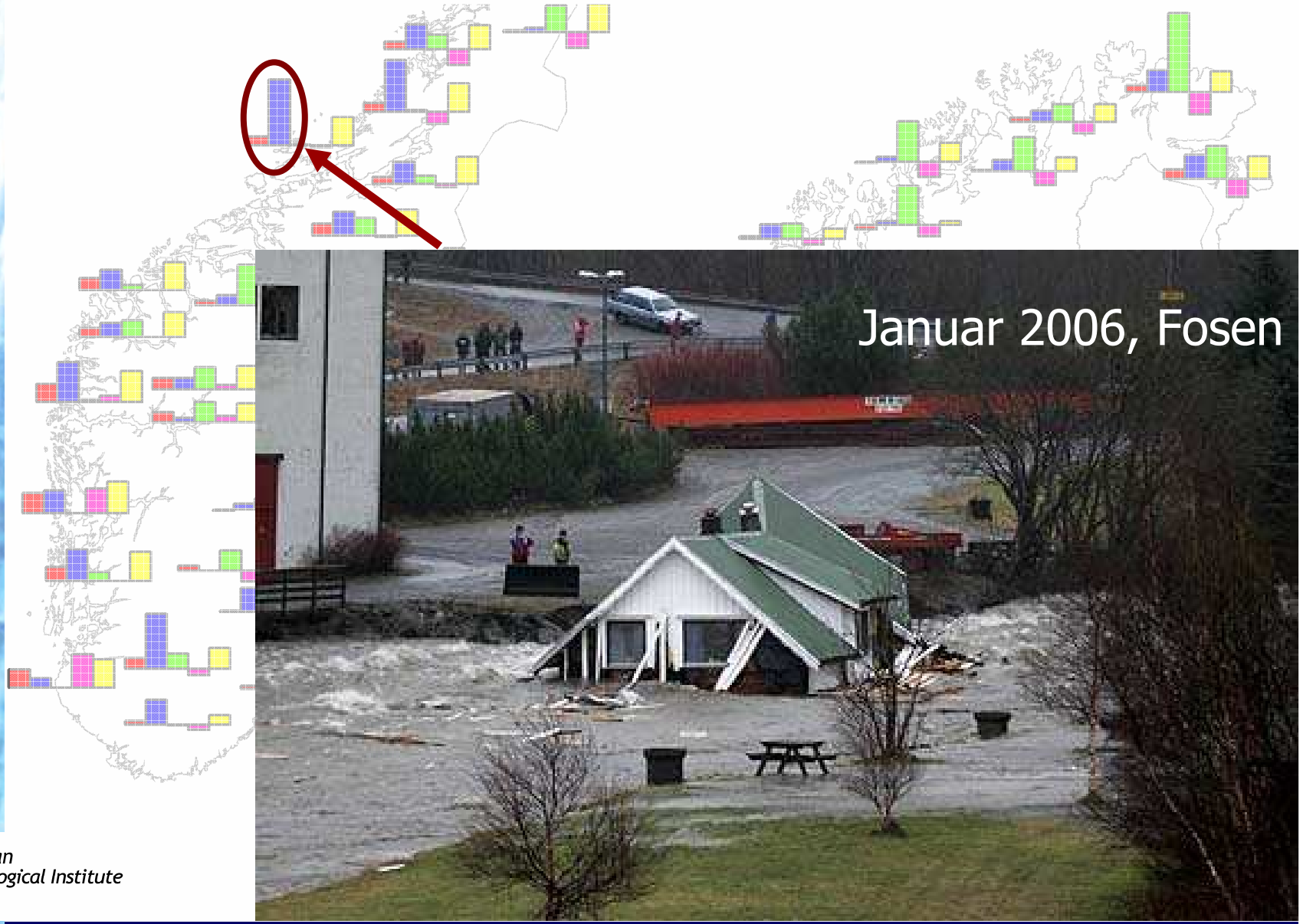



Norwegian Meteorological Institute
met.no

SINTEF NIVA NINA Norsk institutt for naturforskning NTNU

VAKLE

Data
og
figur
fra
NVE
og
met.no



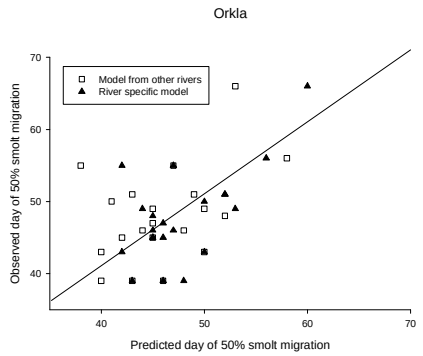

Norwegian
Meteorological Institute
met.no

SINTEF NIVA NINA Norsk institutt for naturforskning NTNU

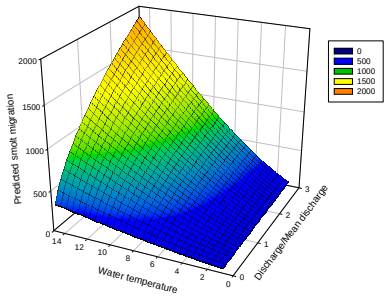
VAKLE

# How we work

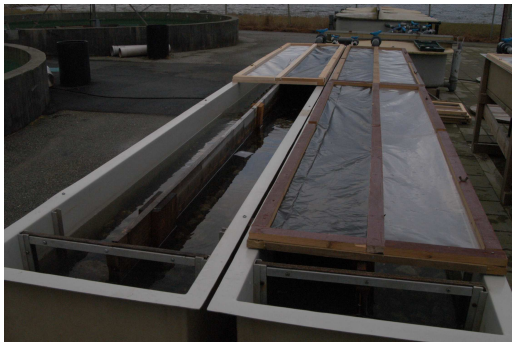
## Improve existing models




## Building new models and relationships





Experimental studies



Field studies

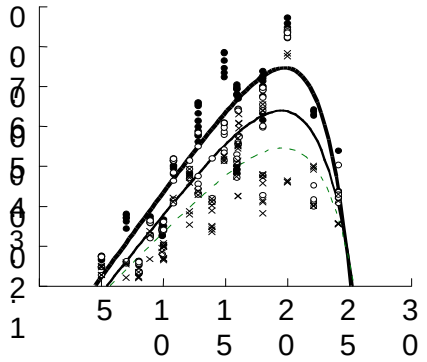
Apply to Orkla

SINTEF NIVA NINA Norsk institutt for naturforskning NTNU

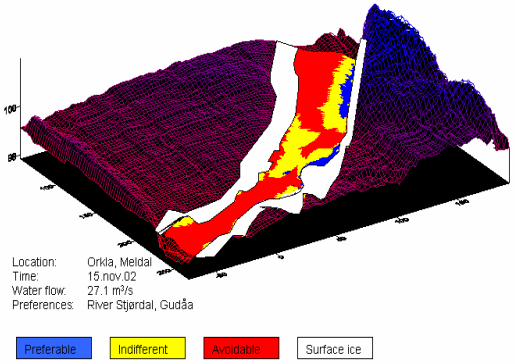
VAKLE

# Climate, water temperature, flow conditions

## Fish growth




## Habitat conditions

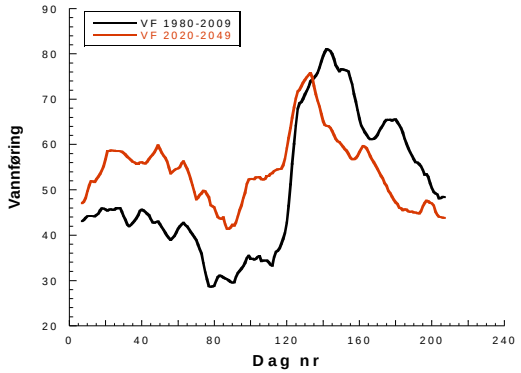



## Orkla salmon





## Winter energetics



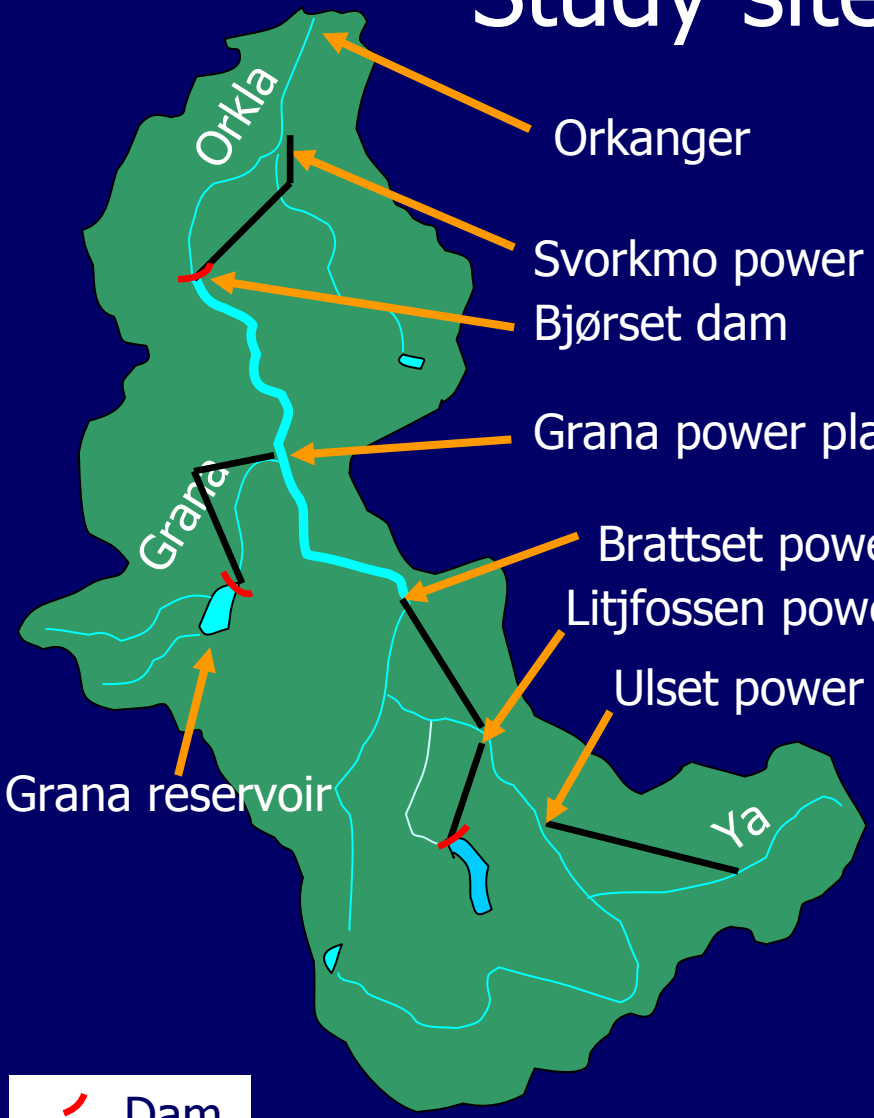

## Smolt migration

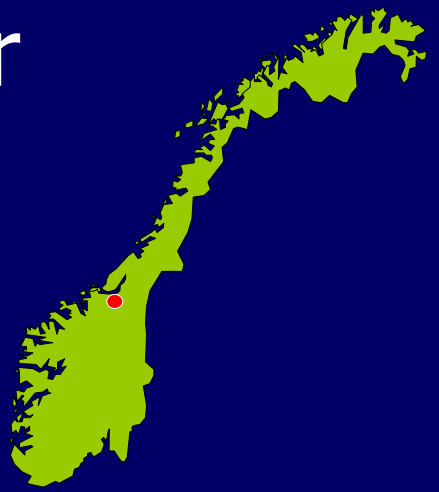
Total effect

SINTEF NIVA NINA Norsk institutt for naturforskning NTNU

VAKLE

# Study site: Orkla River



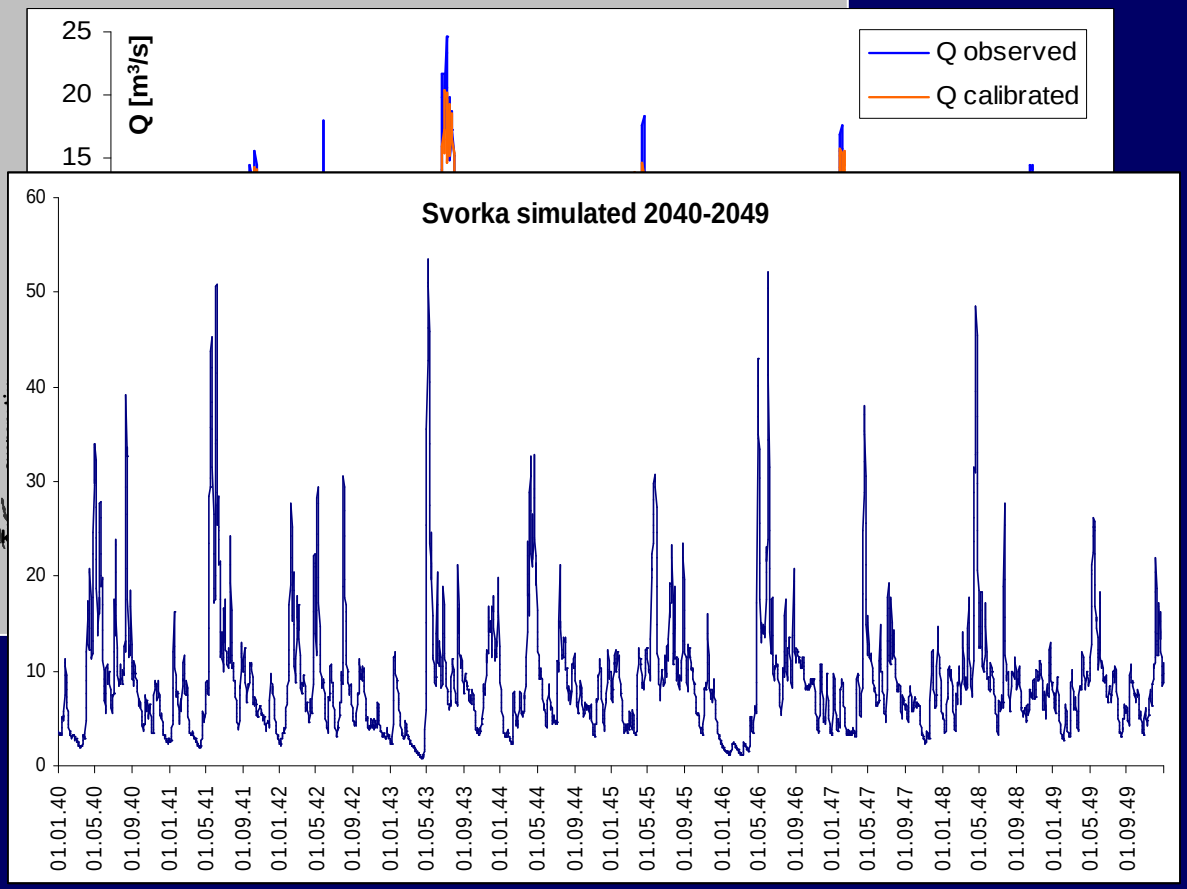





SINTEF NIVA NINA Norsk institutt for naturforskning NTNU

VAKLE

## The HBV - Model Structure




# The watershed description:

catchment area
altitude distribution
lake percentage
glacier percentage
evapotranspiration

The model is automatically calibrated (PEST) with observerded data for discharge, precipitation and temperature.

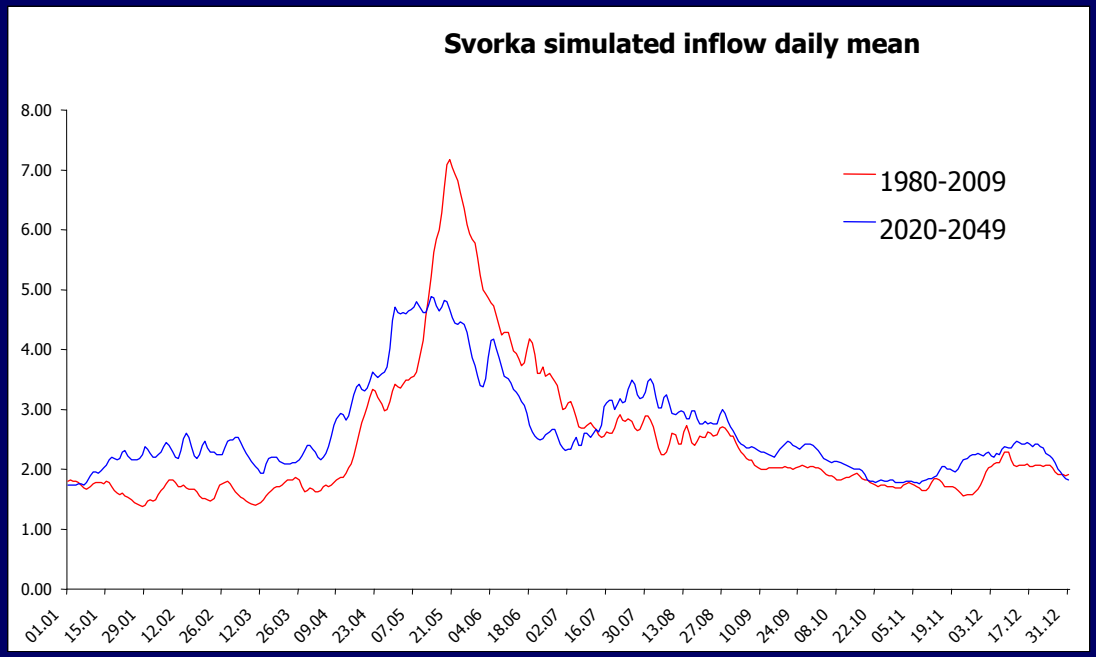
Inflow is simulated with precipitation and temperature as input data 1980-2049.

SINTEF NIVA NINA Norsk institutt for naturforskning NTNU

VAKLE

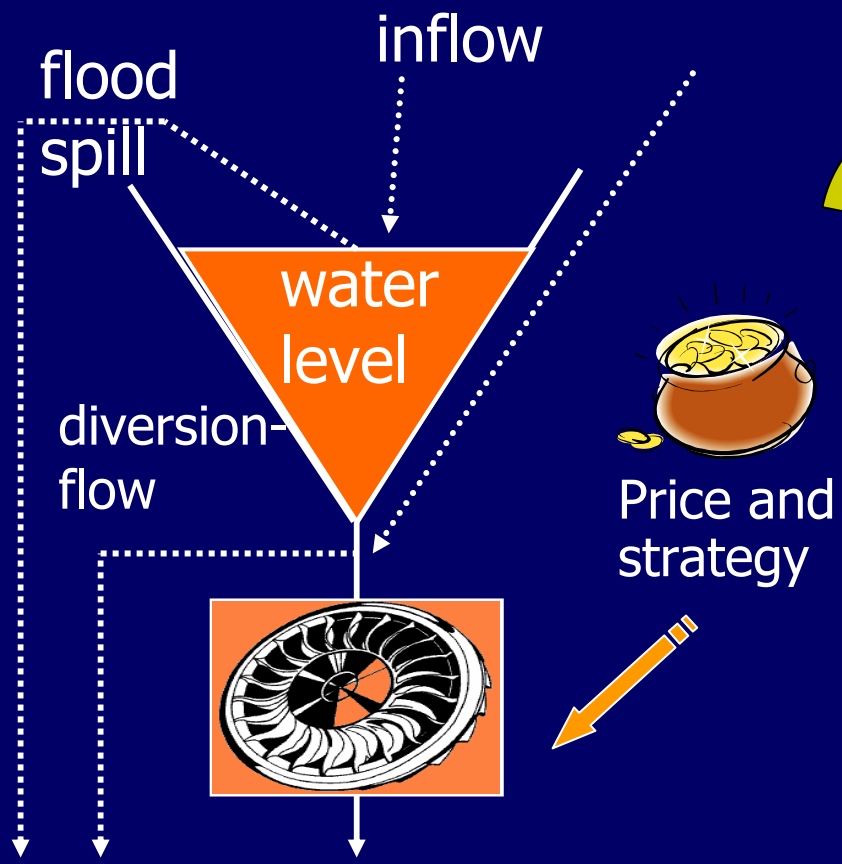
# Expected change of natural inflow

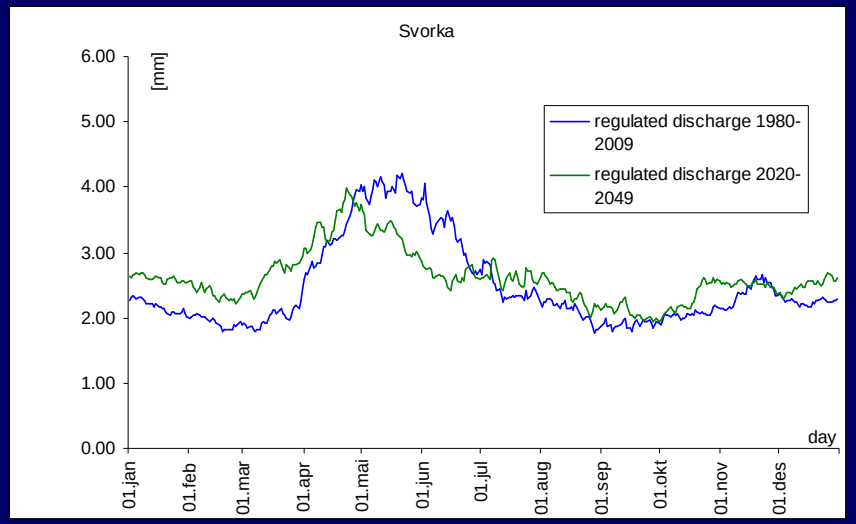
- more water in total: + 5-10 % inflow in the three catchments
- a larger portion of the total inflow comes during winter
- higher winter discharge
- earlier spring flood
- smaller spring flood
- higher summer discharge
- higher autumn discharge




SINTEF NIVA NINA Norsk institutt for naturforskning NTNU VAKLE

# Power production and operation




Regulated discharge

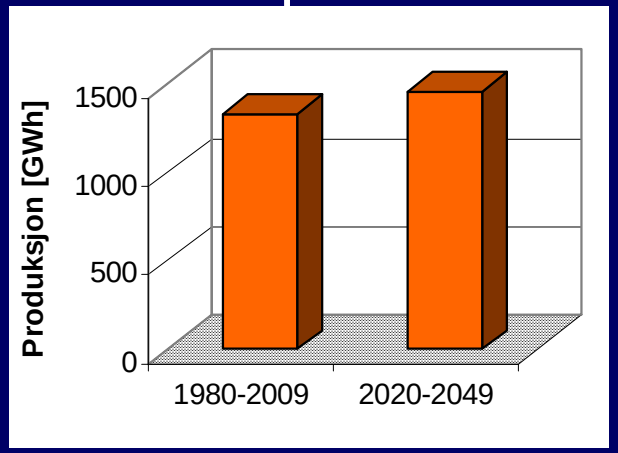
SINTEF NIVA NINA Norsk institutt for naturforskning NTNU

VAKLE

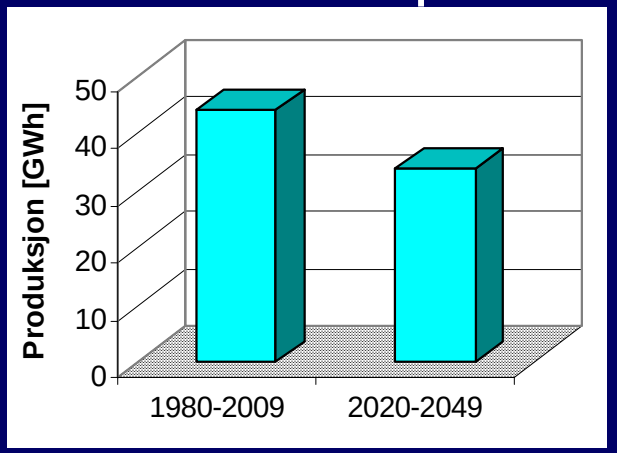
# Results: Power production

## Power production

9.5 %



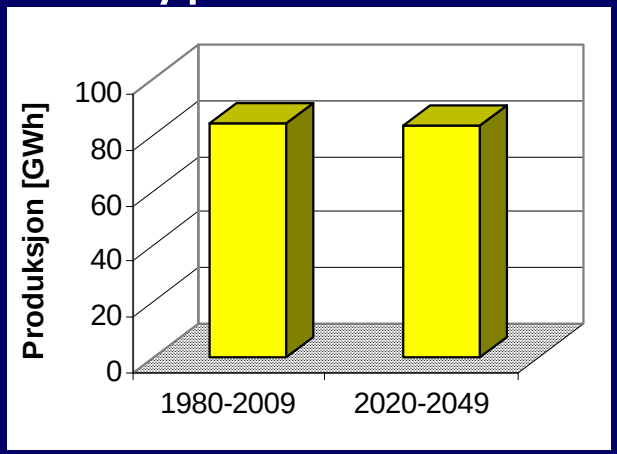

## Flood spill



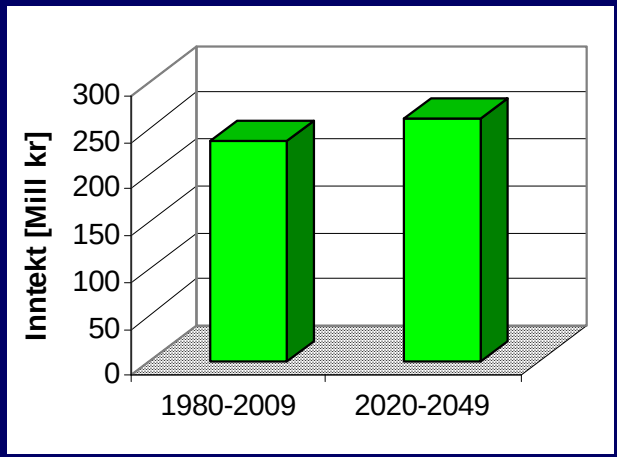

-23%

## Bypassed water

-0.4%




## Income

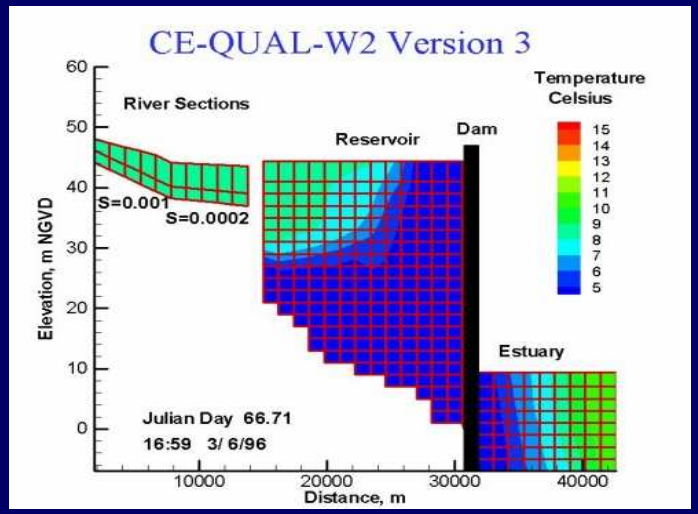


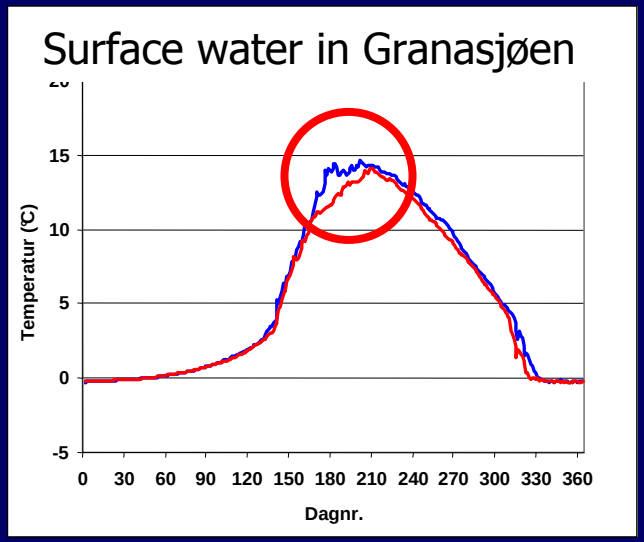

9.9 %

SINTEF NIVA NINA Norsk institutt for naturforskning NTNU

VAKLE

# Water temperature and ice



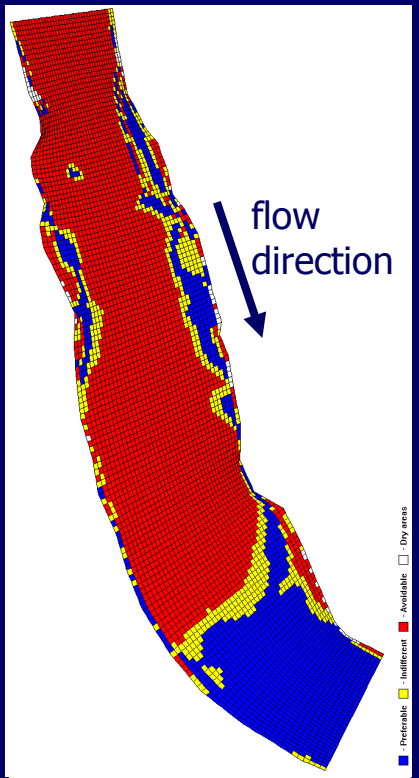




General effects:
Days with ice production in a future climate reduced from 130 to 80 (Bjørset)
Higher water temperatures, especially in early summer

Local effects:
- Reduced growth of surface ice due to increased velocities
- Increased growth of frazil ice and anchor ice due to more open areas
- Possibly more ice drift during winter due to more intense precipitation

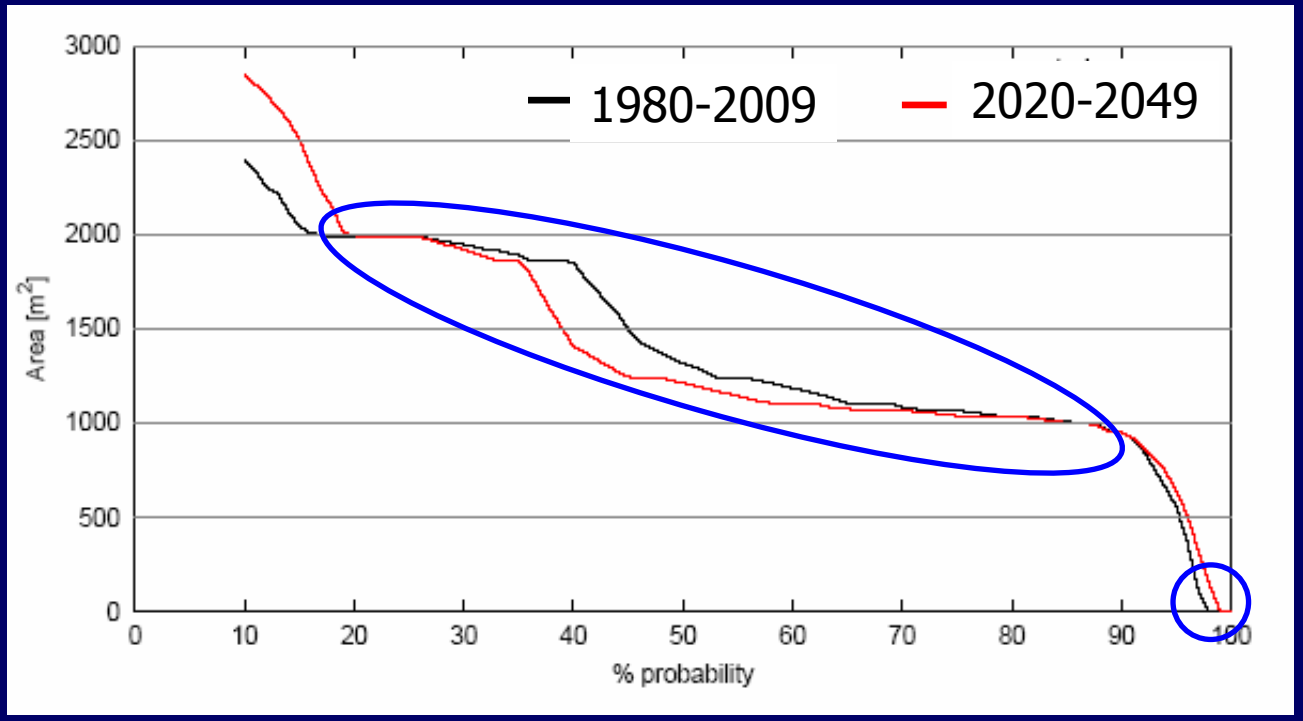
SINTEF NIVA NINA Norsk institutt for naturforskning NTNU VAKLE

# Fish habitat conditions




Habitat model

- Preferred
- Indifferent
- Avoided



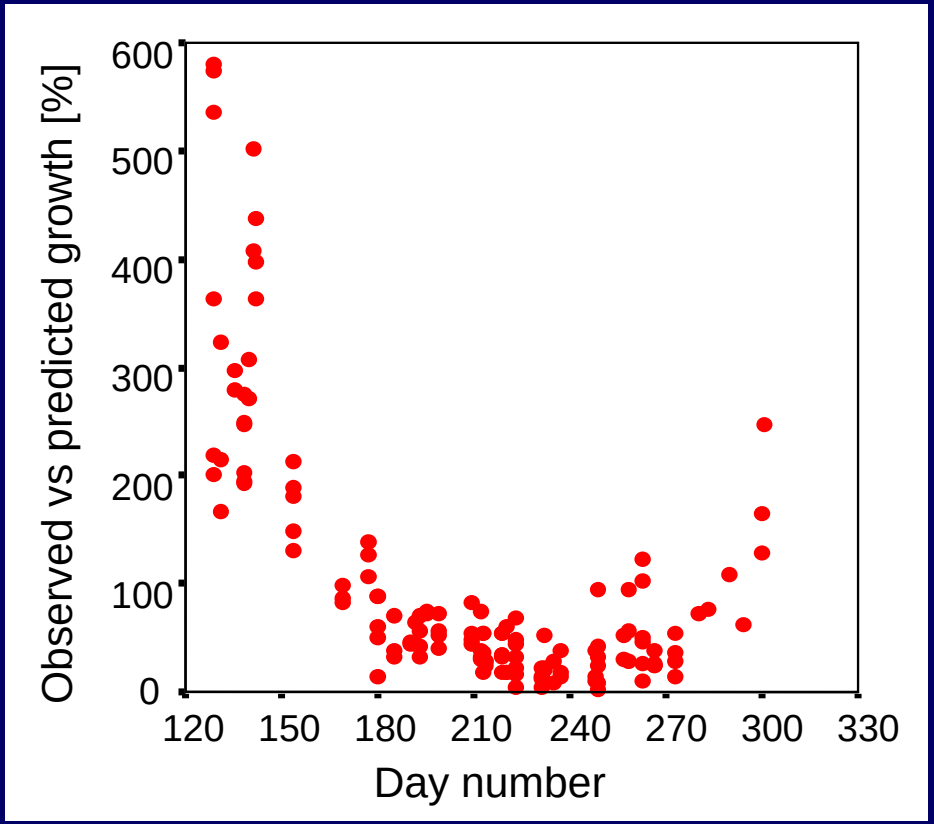

Slightly decreased habitat quality most of the time
Period without preferred habitat reduced from 3 to 1.5 percent of the time

SINTEF NIVA NINA Norsk institutt for naturforskning NTNU

VAKLE

# Fish growth models

- Water temperature relation to growth
- Existing models have poor performance early and late in growing season
- Field and experimental data used to improve models
- Validated in several rivers

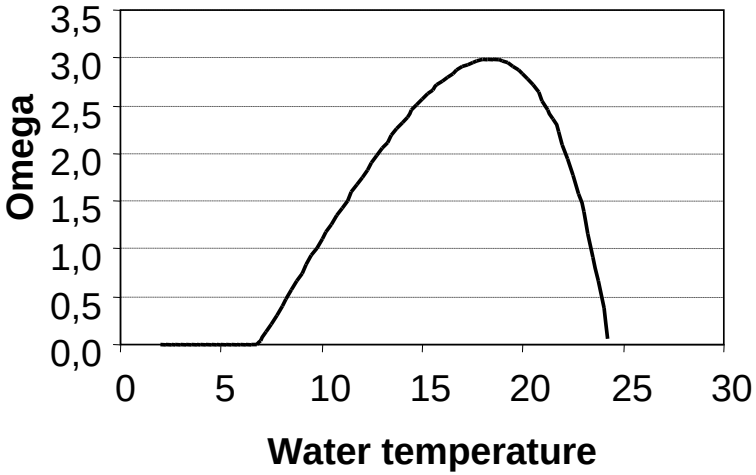



SINTEF NIVA NINA Norsk institutt for naturforskning NTNU

VAKLE

# Improved fish growth models

- Laboratory-based models poor performance
- In total 7 174 fish samples, 4-8 times pr year in 17 years
- Changes:
  - Lower limit for growth
  - Seasonal moderator
  - Start time for seasonal moderator




$$\Omega = d(T - T_L) \cdot (1 - e^{g(T - T_U)})$$

$$\ln(1 + g(T_M - T_L)) = -g(T_M - T_U)$$

$\Omega$ Specific standardised growth rate

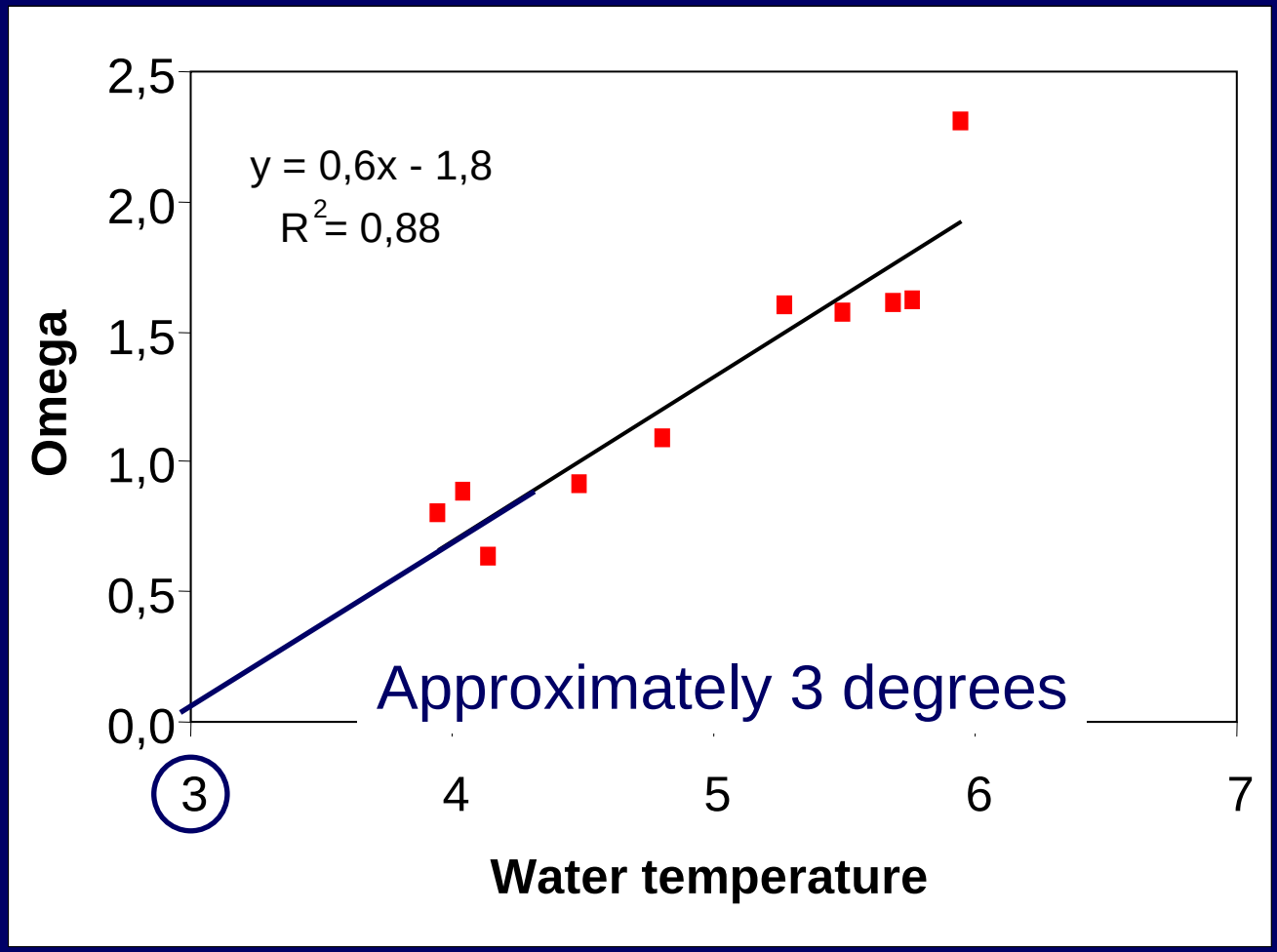
$T_L$ lower temp. $T_M$ max growth temp.

$T_U$ upper temp. d, g parameters

SINTEF NIVA NINA Norsk institutt for naturforskning NTNU

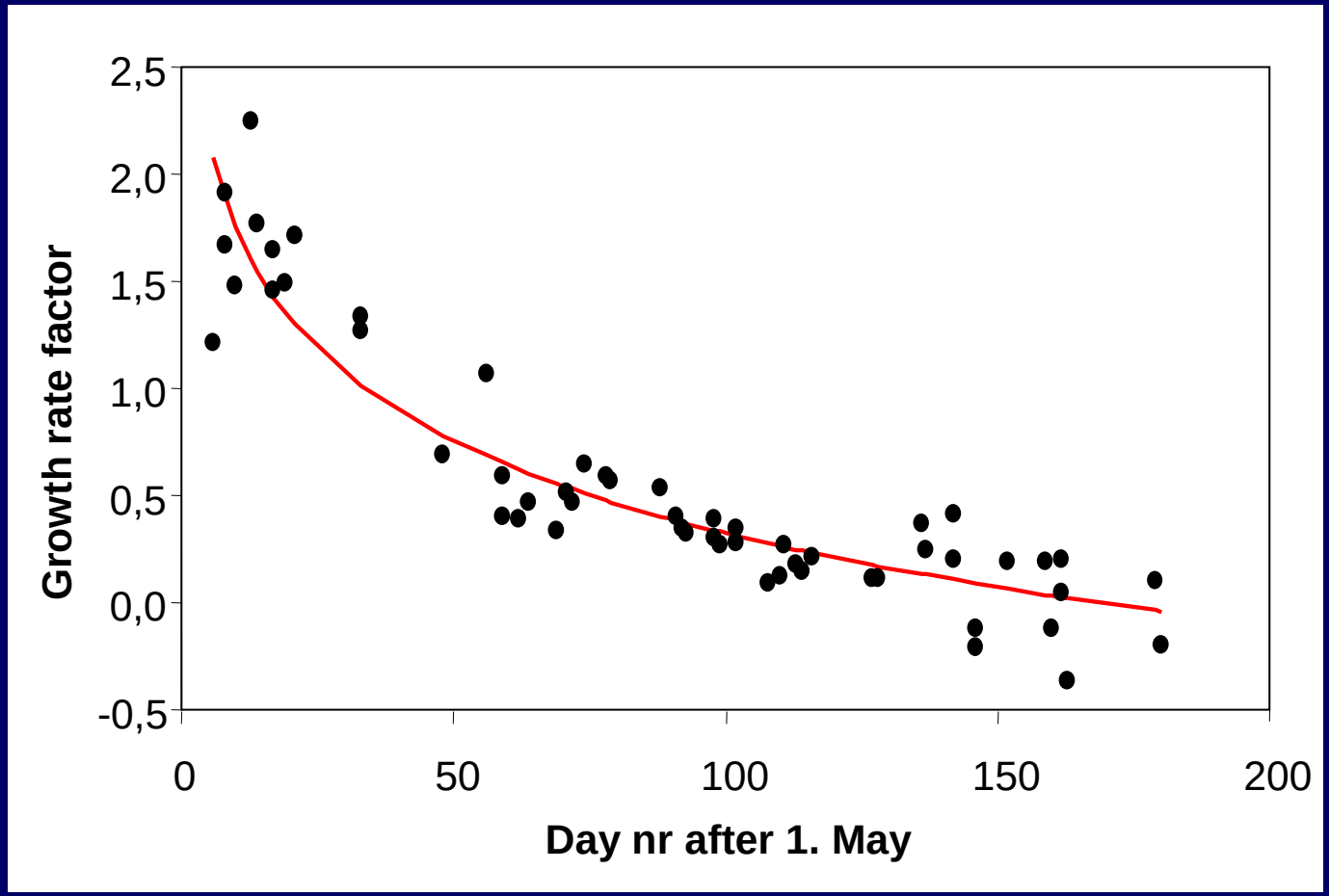
VAKLE

# Lower limit for fish growth



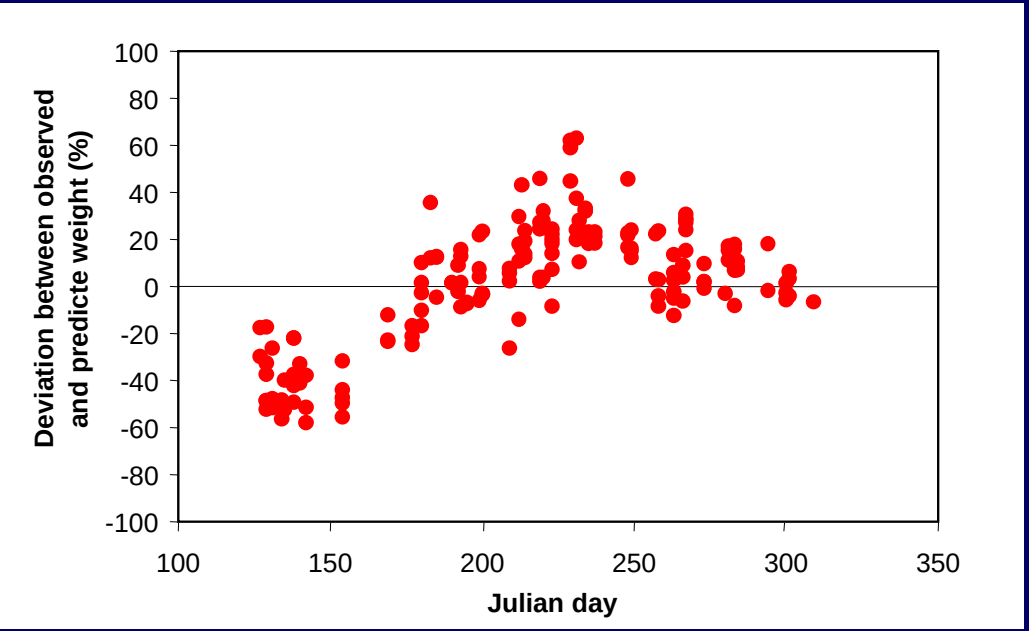

SINTEF NIVA NINA Norsk institutt for naturforskning NTNU VAKLE

# Seasonal moderator for fish growth

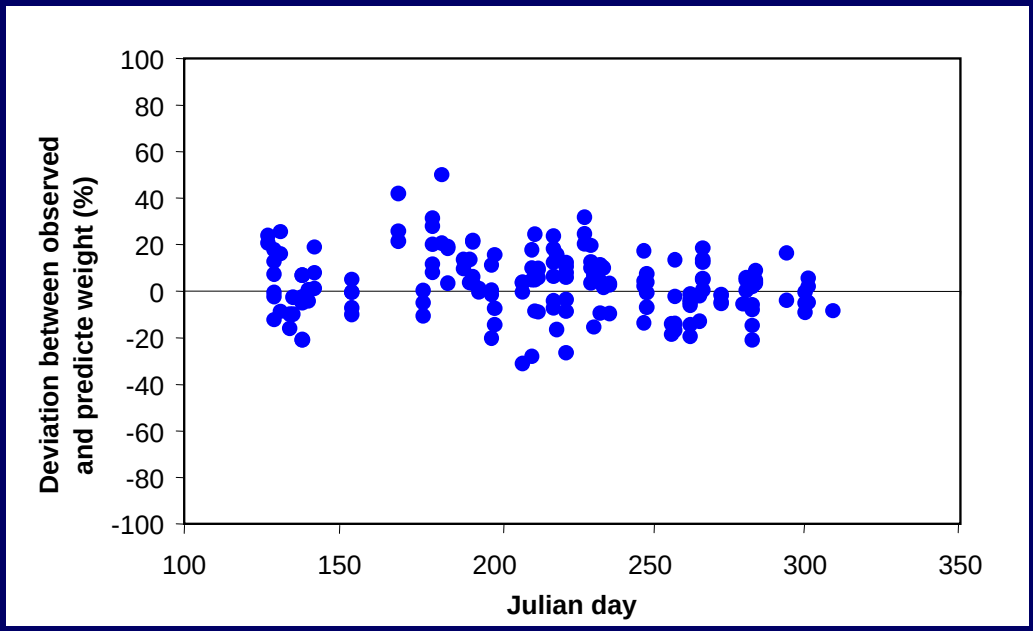



SINTEF NIVA NINA Norsk institutt for naturforskning NTNU VAKLE

# Predictions without changes



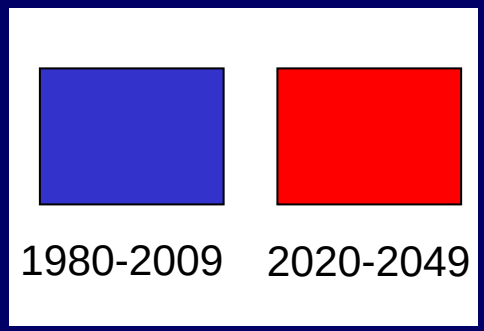

# Predictions with new start temperature and seasonal moderator

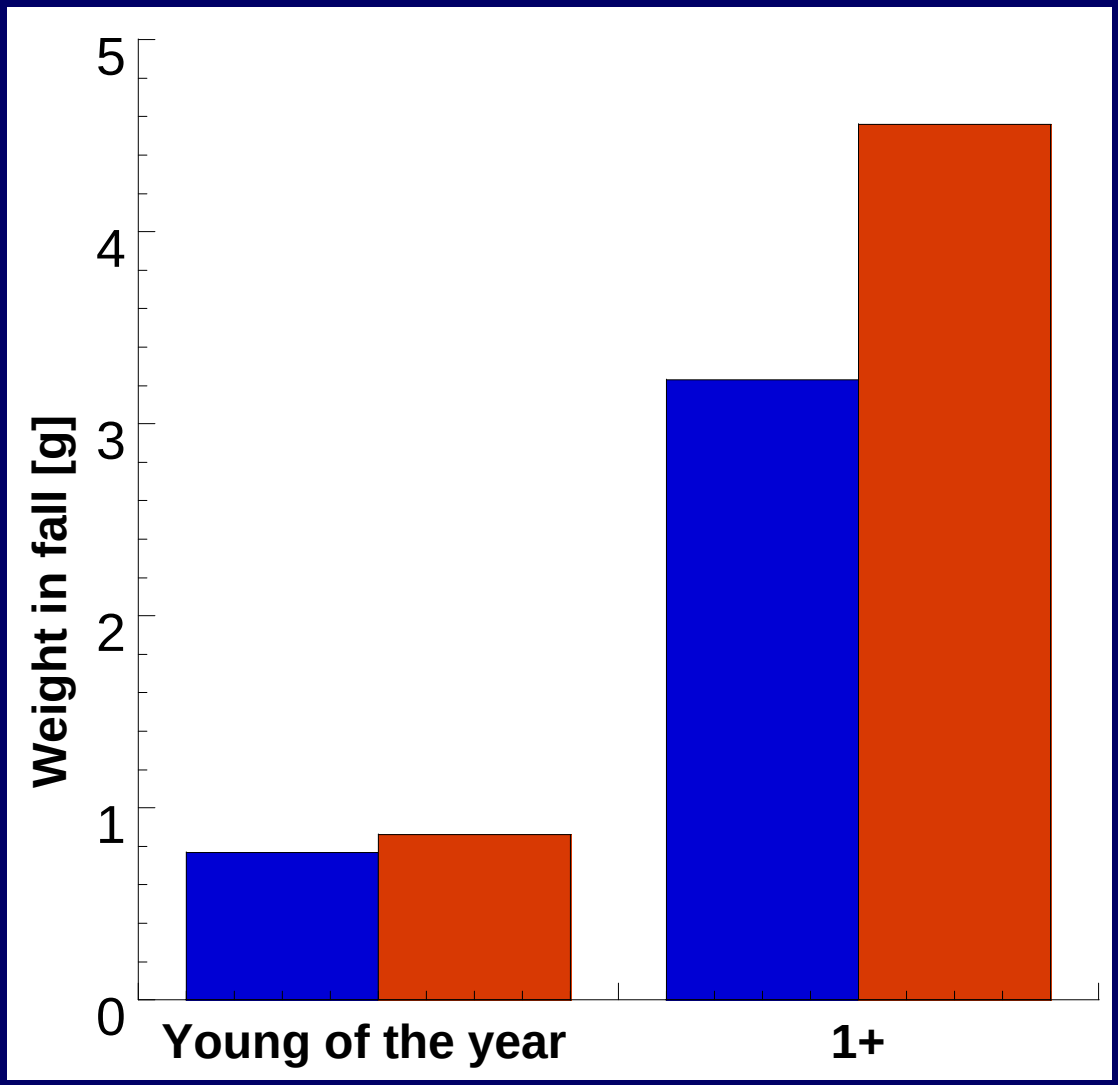



SINTEF NIVA NINA Norsk institutt for naturforskning NTNU

VAKLE

# Fish growth in Orkla

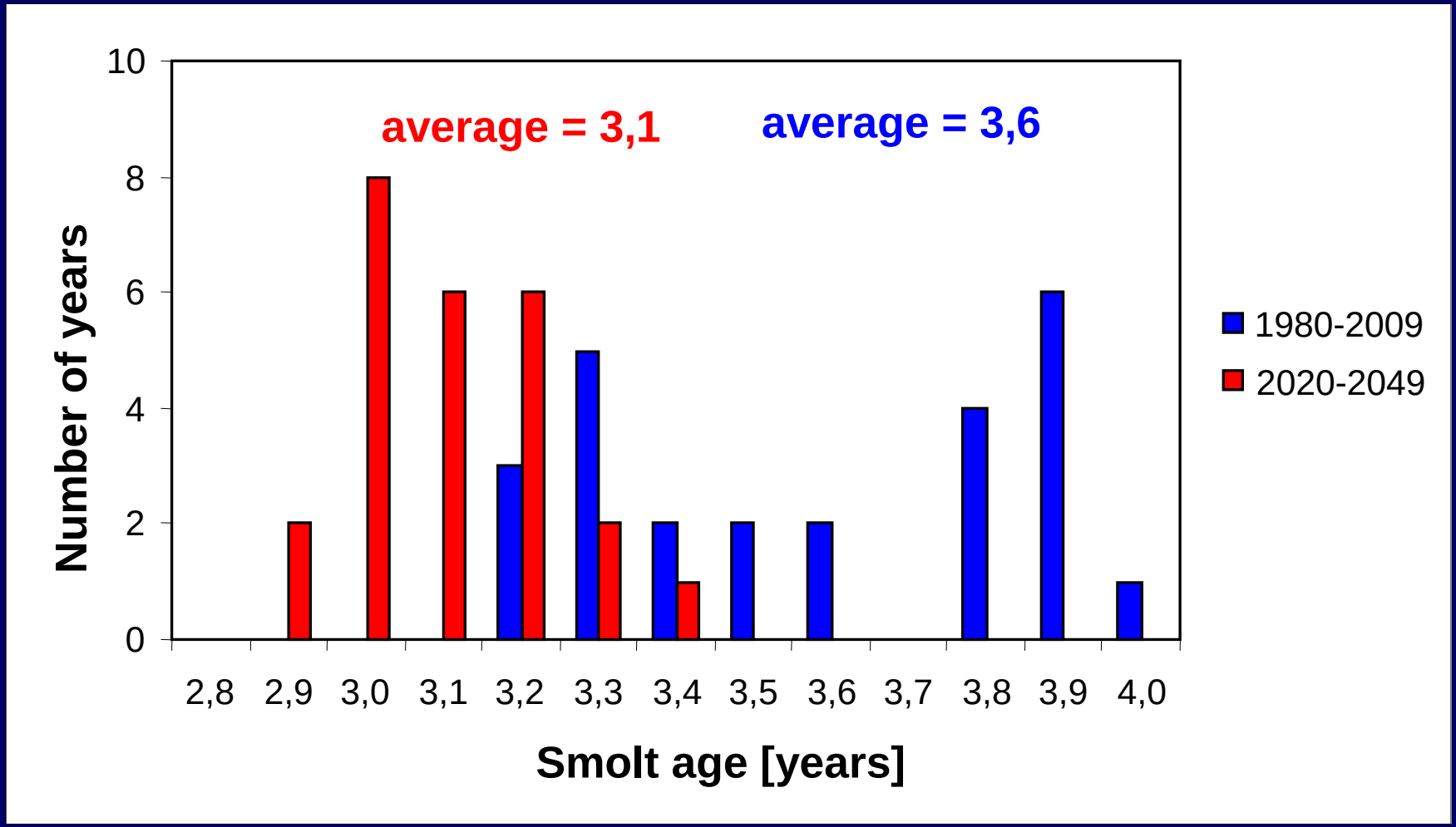



SINTEF NIVA NINA Norsk institutt for naturforskning NTNU

VAKLE

# Smolt age




SINTEF NIVA NINA Norsk institutt for naturforskning NTNU

VAKLE

# Fish growth from fry to smolt

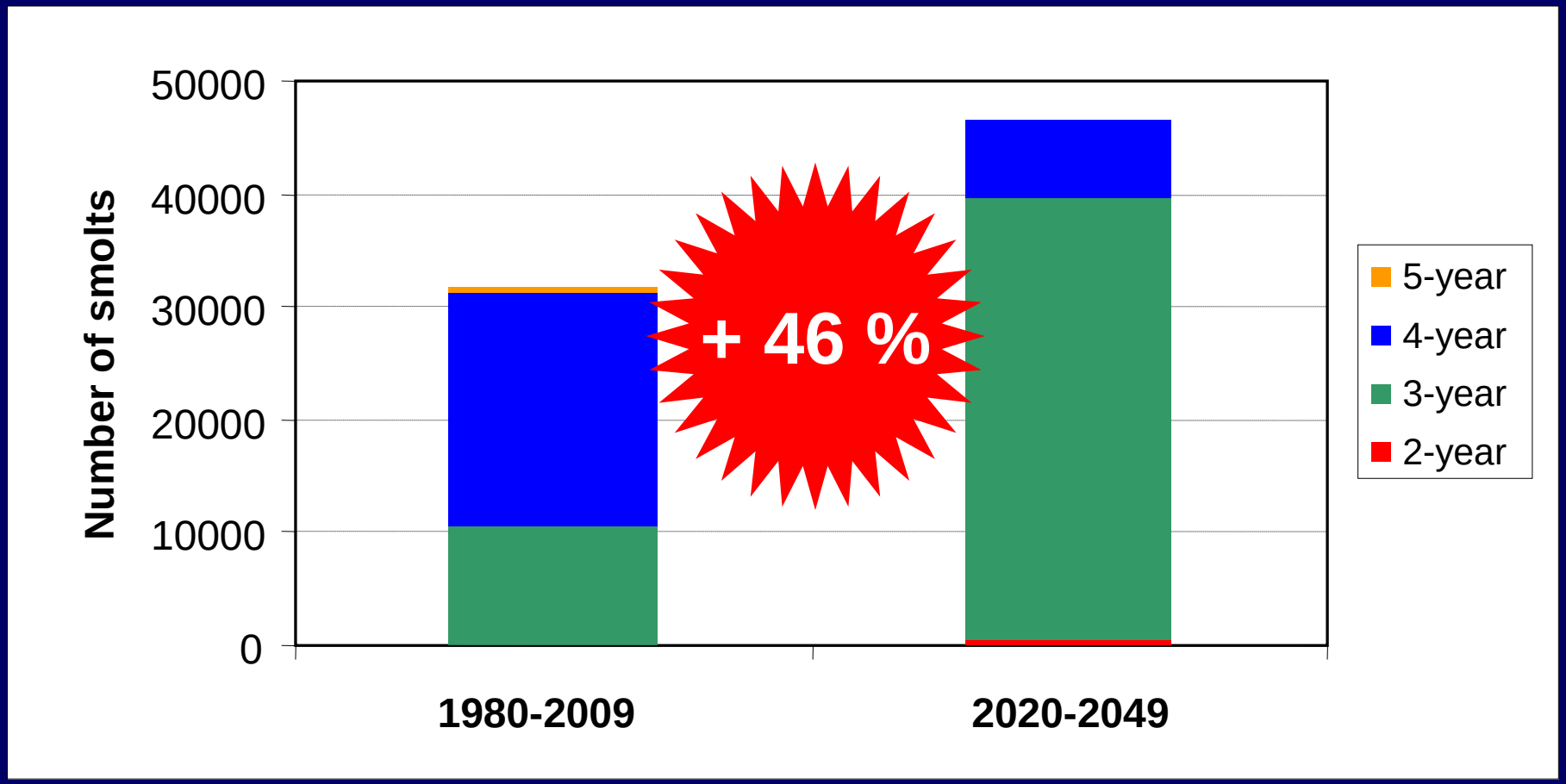





SINTEF NIVA NINA Norsk institutt for naturforskning NTNU

VAKLE

# Total smolt production



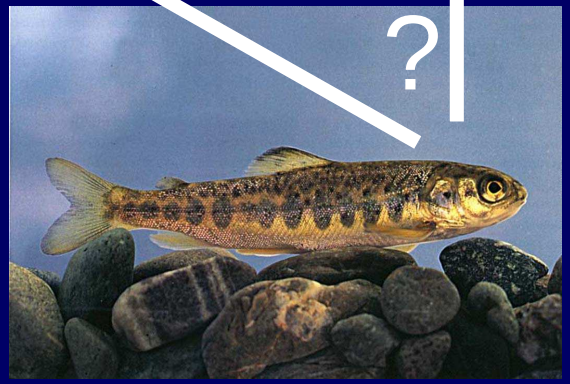

SINTEF NIVA NINA Norsk institutt for naturforskning NTNU

VAKLE

# Fish survival and winter energetics







?

Die from hunger

or

More food

More activity

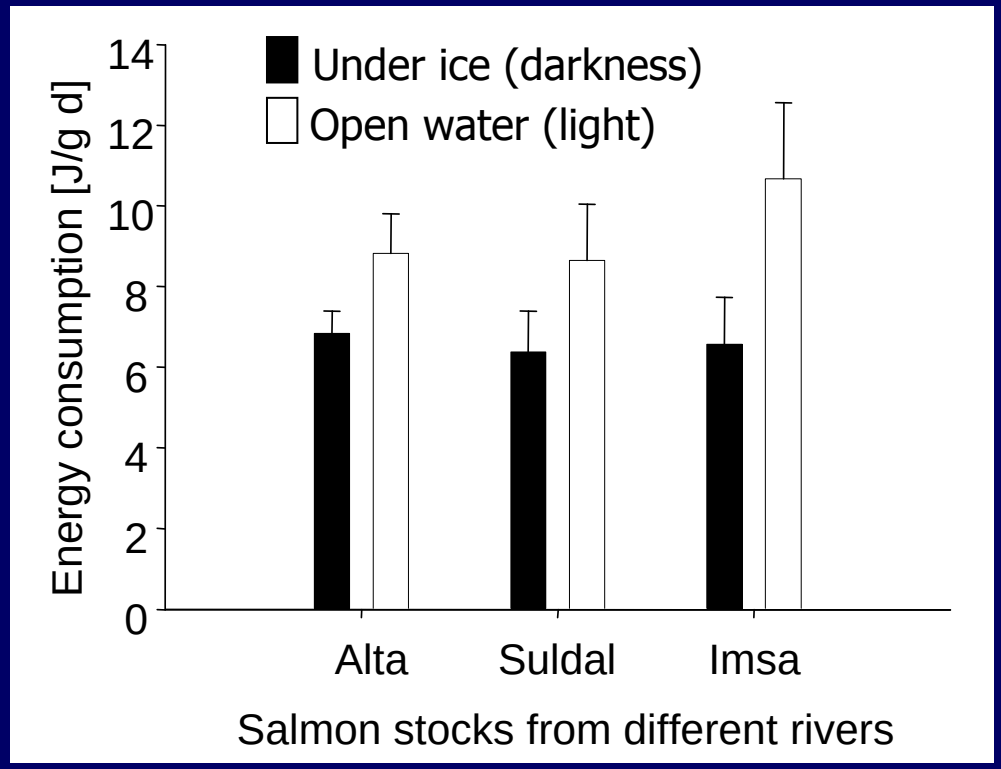
Predation risk

Trade-off

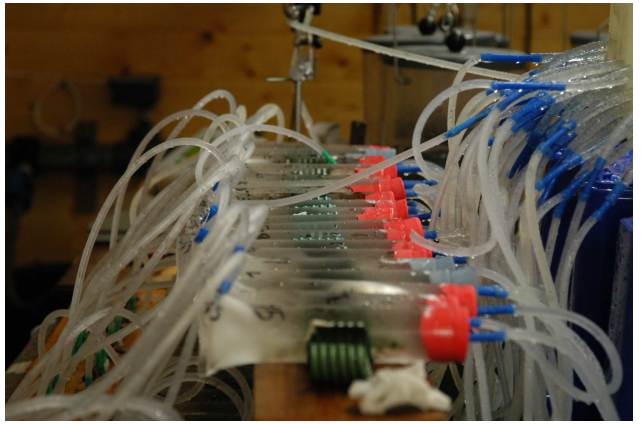
SINTEF NIVA NINA Norsk institutt for naturforskning NTNU

VAKLE

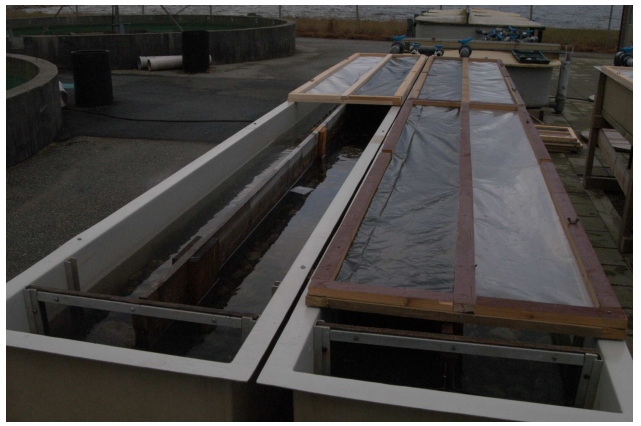
# Experimental studies of ice cover impacts




30 % less energy consumption under ice cover



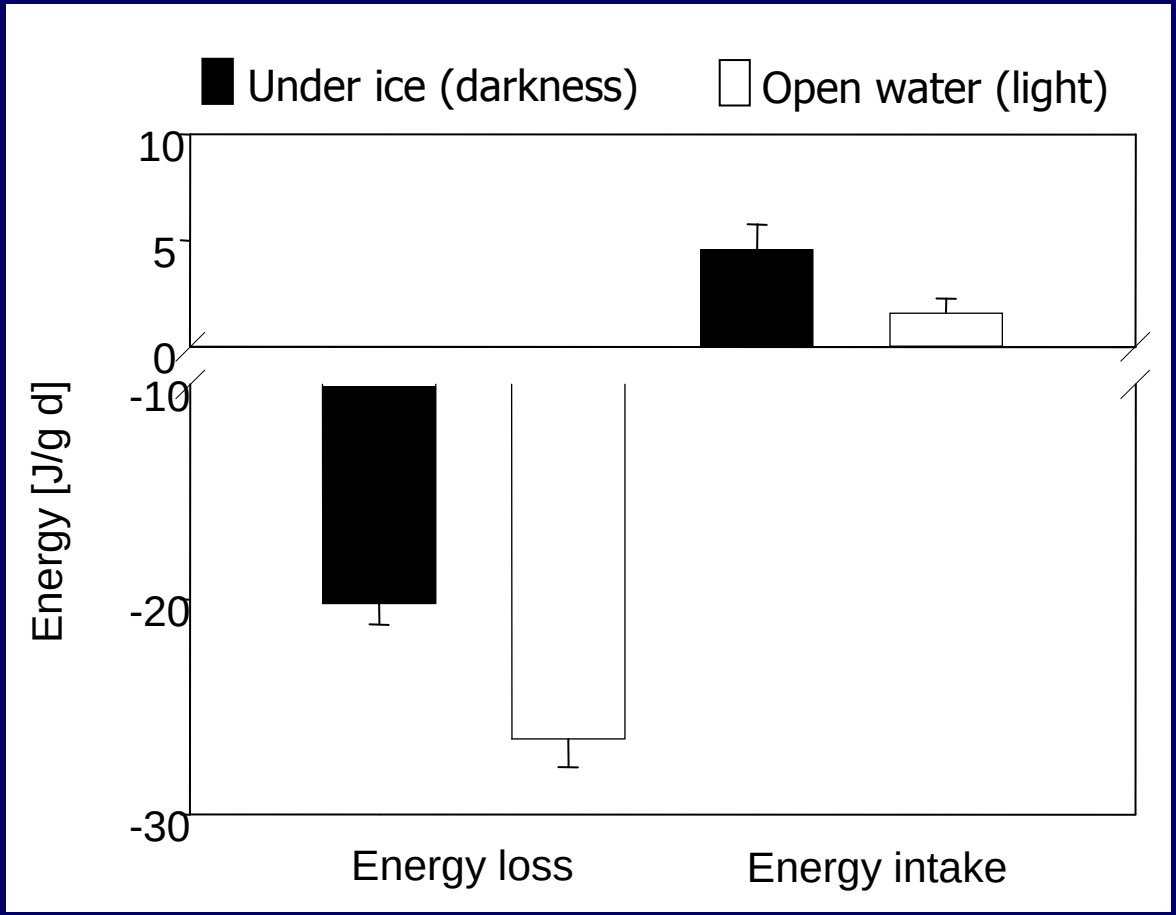




SINTEF NIVA NINA Norsk institutt for naturforskning NTNU

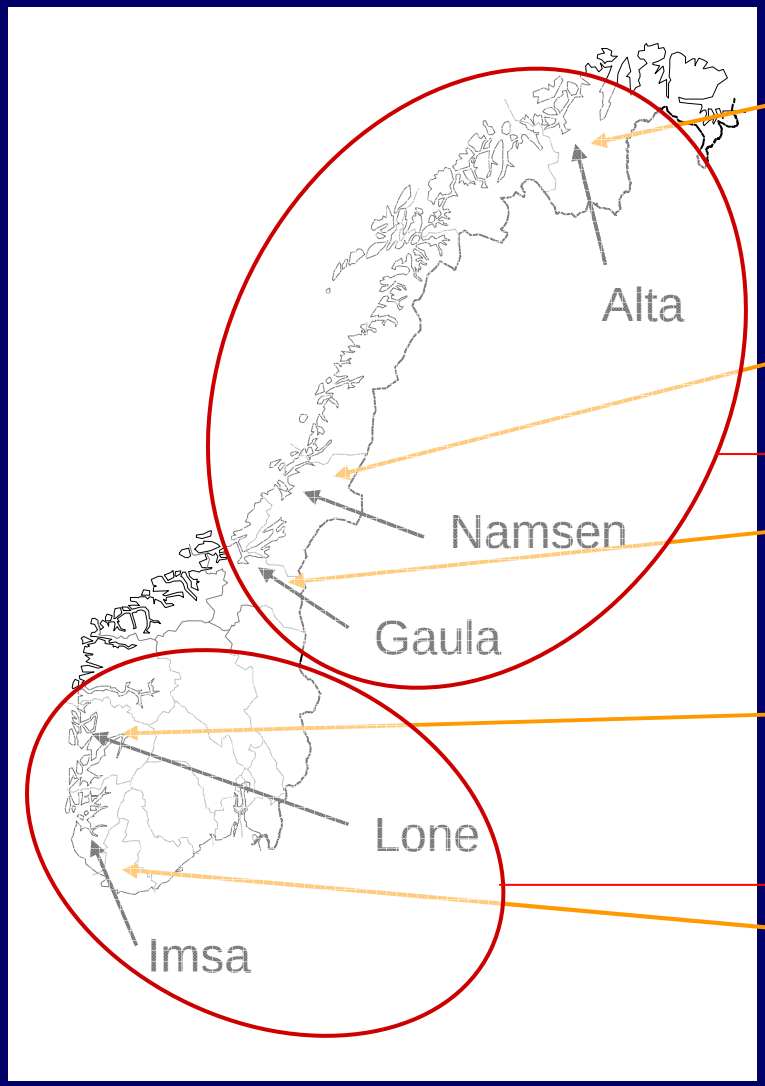
VAKLE

# Energy loss and gain



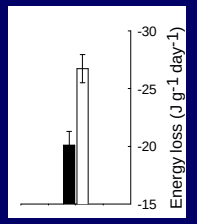

SINTEF NIVA NINA Norsk institutt for naturforskning NTNU

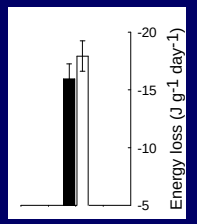
VAKLE

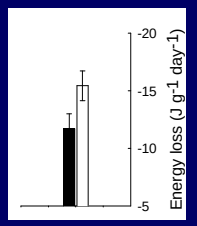


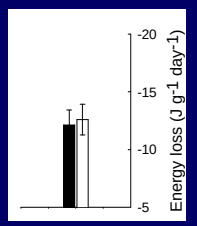

Natural ice cover

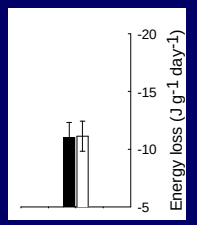
No permanent ice cover



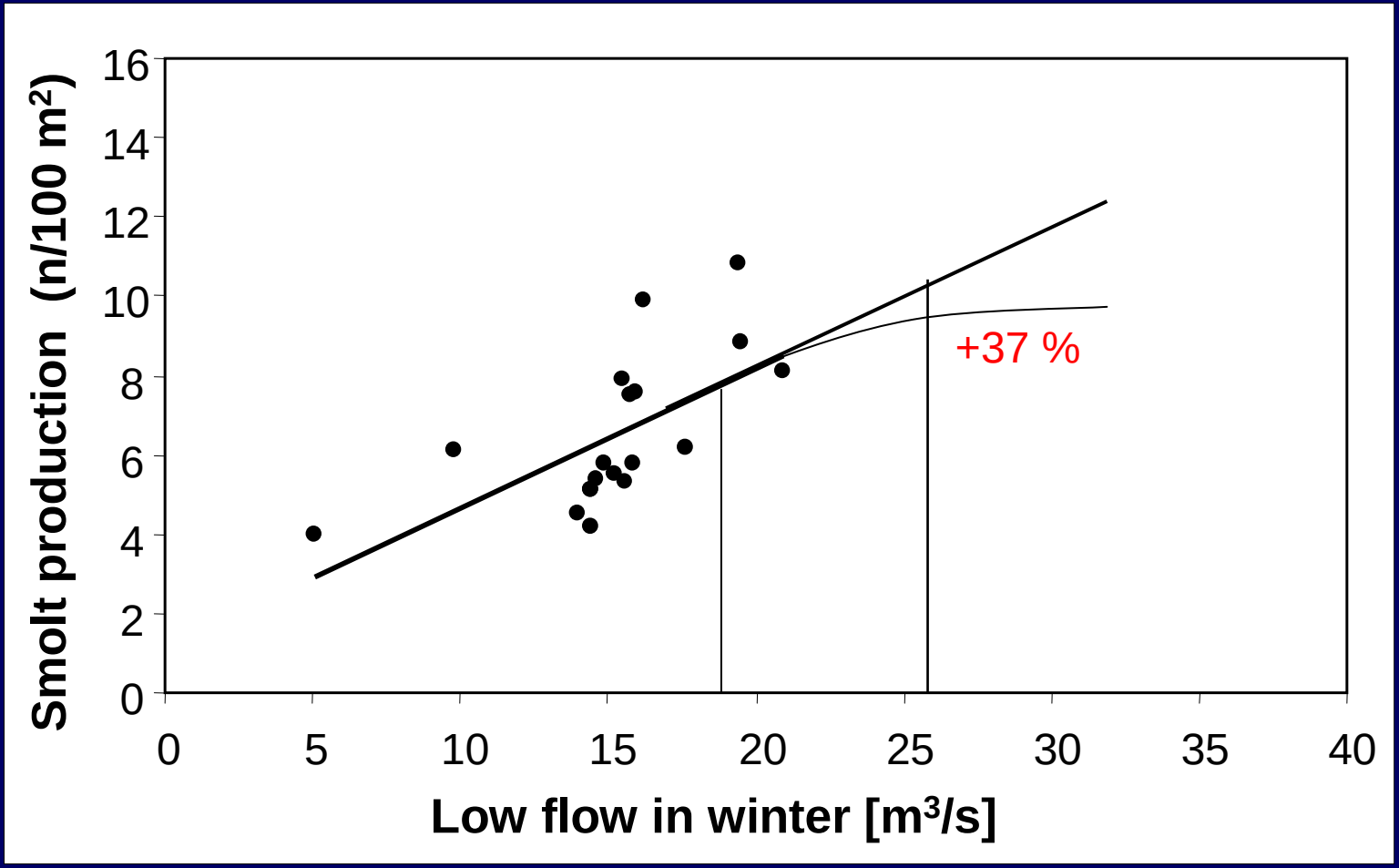




Increased importance of ice cover

SINTEF NIVA NINA Norsk institutt for naturforskning NTNU

VAKLE

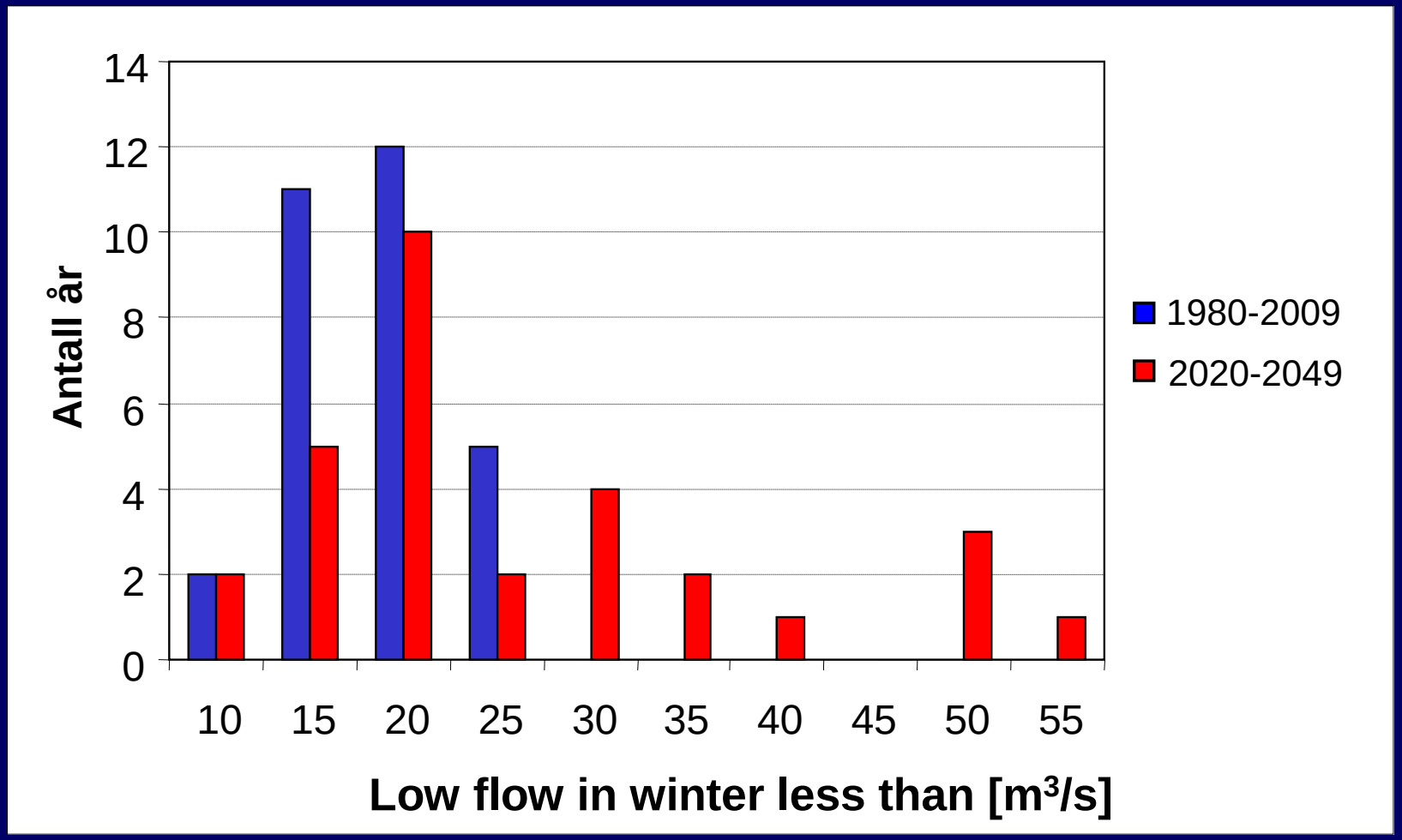
# Winter survival




SINTEF NIVA NINA Norsk institutt for naturforskning NTNU

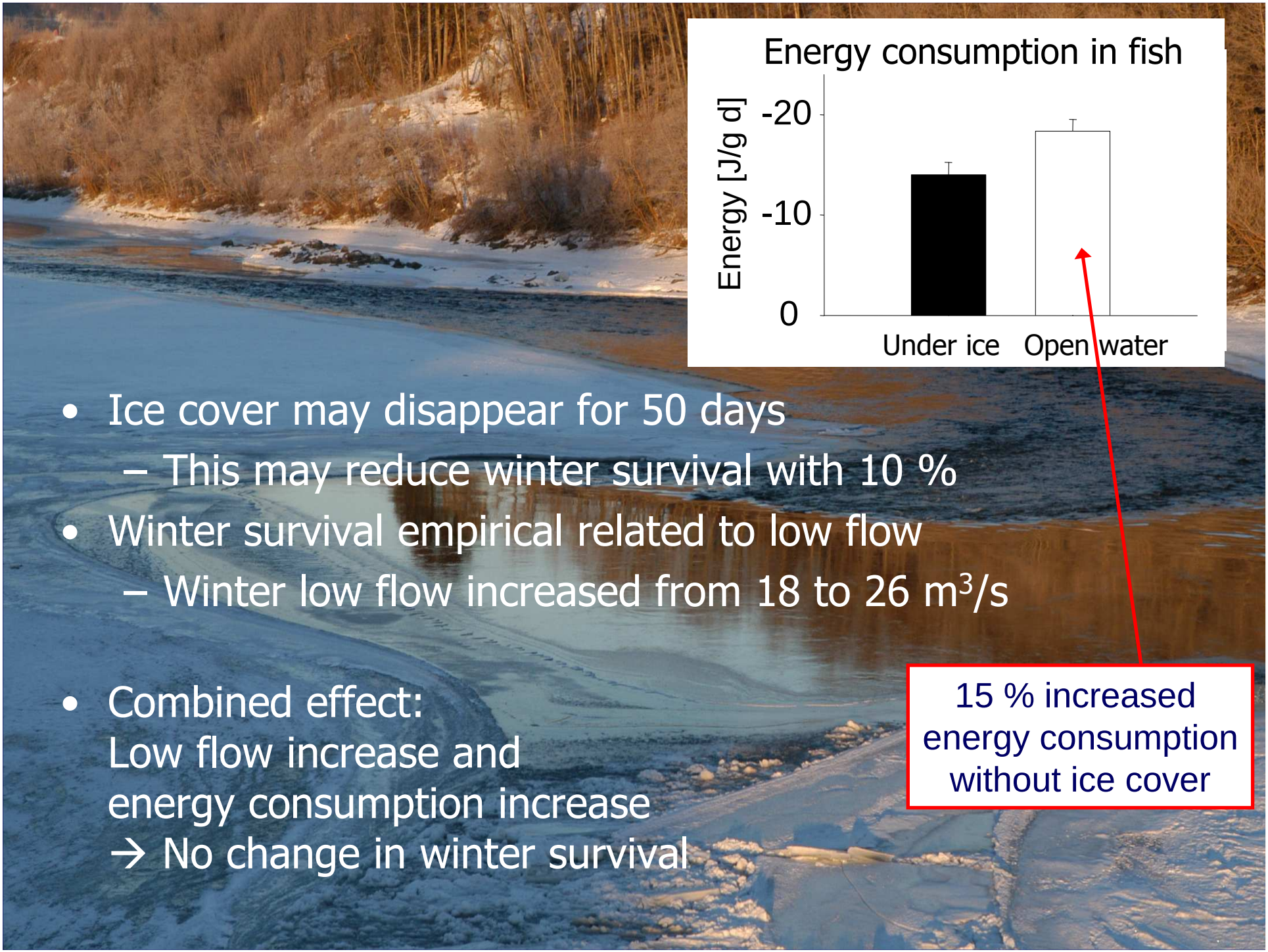
VAKLE

# Low flow in winter




SINTEF NIVA NINA Norsk institutt for naturforskning NTNU

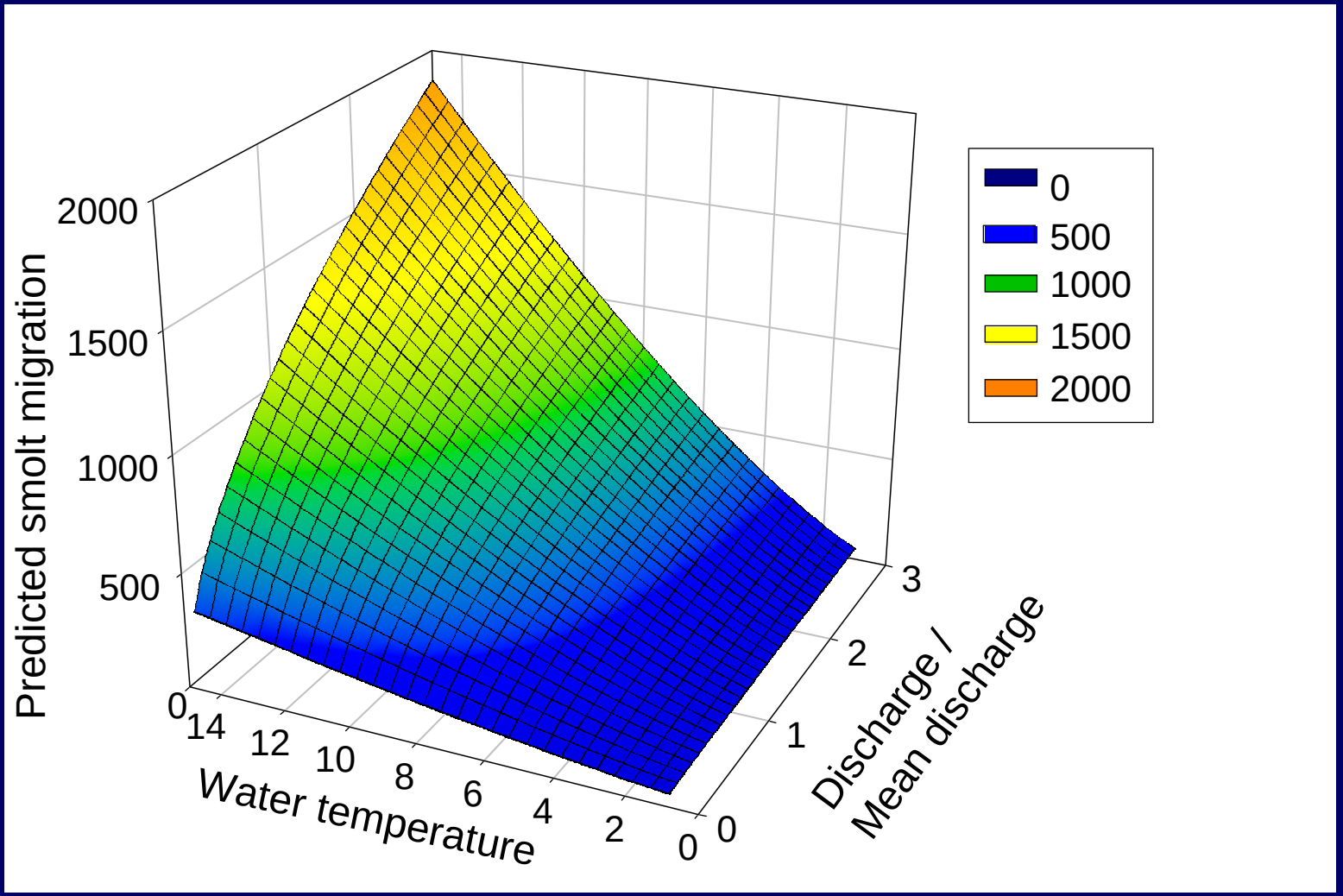
VAKLE




- Ice cover may disappear for 50 days
  - This may reduce winter survival with 10 %
- Winter survival empirical related to low flow
  - Winter low flow increased from 18 to 26 $m^3/s$

- Combined effect:
  Low flow increase and
  energy consumption increase
  → No change in winter survival

# Smolt migration



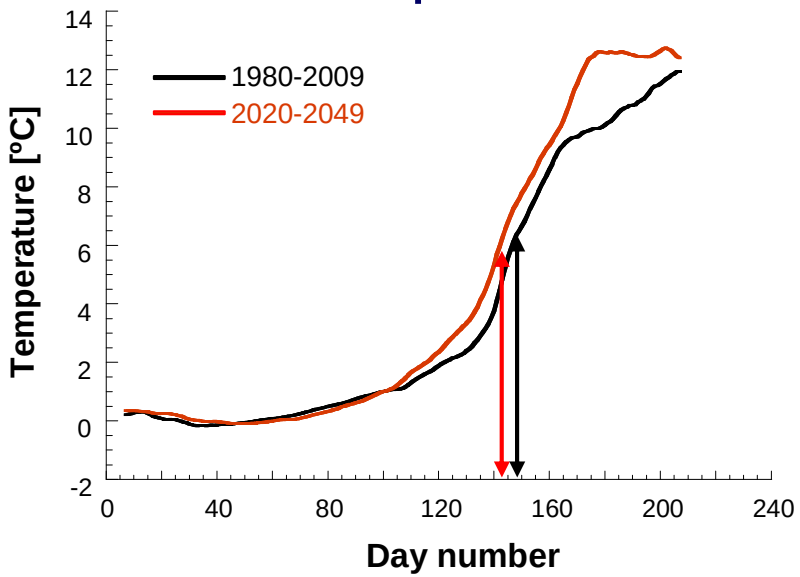

SINTEF NIVA NINA Norsk institutt for naturforskning NTNU

VAKLE

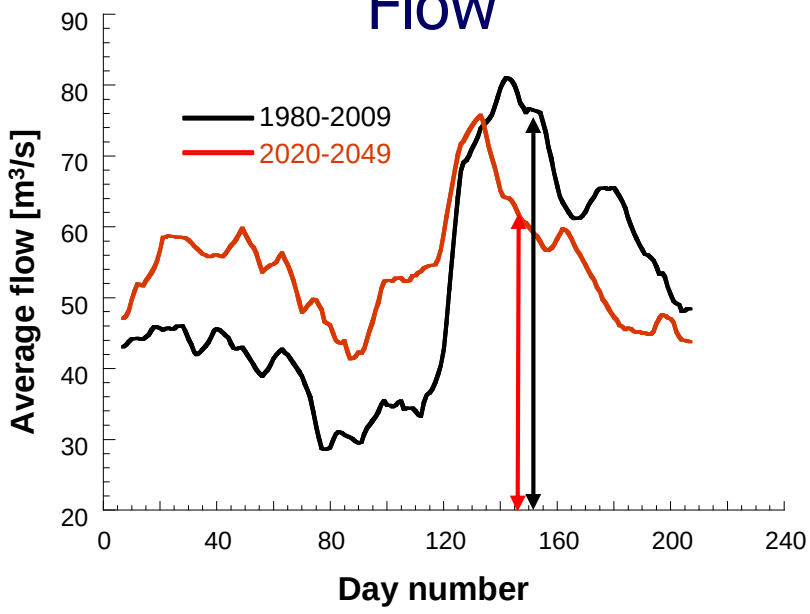
# Smolt migration

1980-2009
2020-2049

## Water temperature




## Flow




3 days earlier migration
(20 May)
At + 0.7 °C

Migration at 11 $m^3/s$
lower flow

SINTEF NIVA NINA Norsk institutt for naturforskning NTNU

VAKLE

# Conclusions – the future in Orkla

- More inflow and more hydro power production
- Seasonal pattern changes in inflow and power production
- Higher water temperature
- Less surface ice and more anchor and frazil ice
- Increased salmon production due to increased growth rate and younger smolt
- Slight decrease in fish habitat quality most of the time, but fewer days with no suitable habitat
- Increased energy consumption in winter, but higher minimum flow in winter →No change in winter survival
- No change in smolt survival during migration

SINTEF NIVA NINA Norsk institutt for naturforskning NTNU VAKLE

# Utfordringer for forvaltningen

- Tør vi bruke scenarier til konsesjoner og forvaltning?
- Mer vann å fordele til alle brukergrupper
- Endret vannføringsmønster – sesongvariasjoner
- Økt vanntemperatur og vannføring om vinteren
  - Flere vinterflommer
  - Isgang
  - Økt sarrproduksjon
- Økt vanntemperatur i vekstsesongen
  - Hurtigere vekst hos stedegne arter
  - Bedre forhold for fremmede arter?
  - Skadelig høy vanntemperatur for stedegne arter?
- Se klimaendringer i sammenheng med nye konsesjoner, implementering av Vanndirektivet og andre forvaltningsoppgaver!

SINTEF NIVA NINA Norsk institutt for naturforskning NTNU VAKLE


BÅDE mer kraft OG
mer laks i Orkla
Vi jobber nå for å etablere et prosjekt i EU's 7. rammeprogram
Takk for oppmerksomheten!