# Current and future riverine nutrient input to the Baltic Sea

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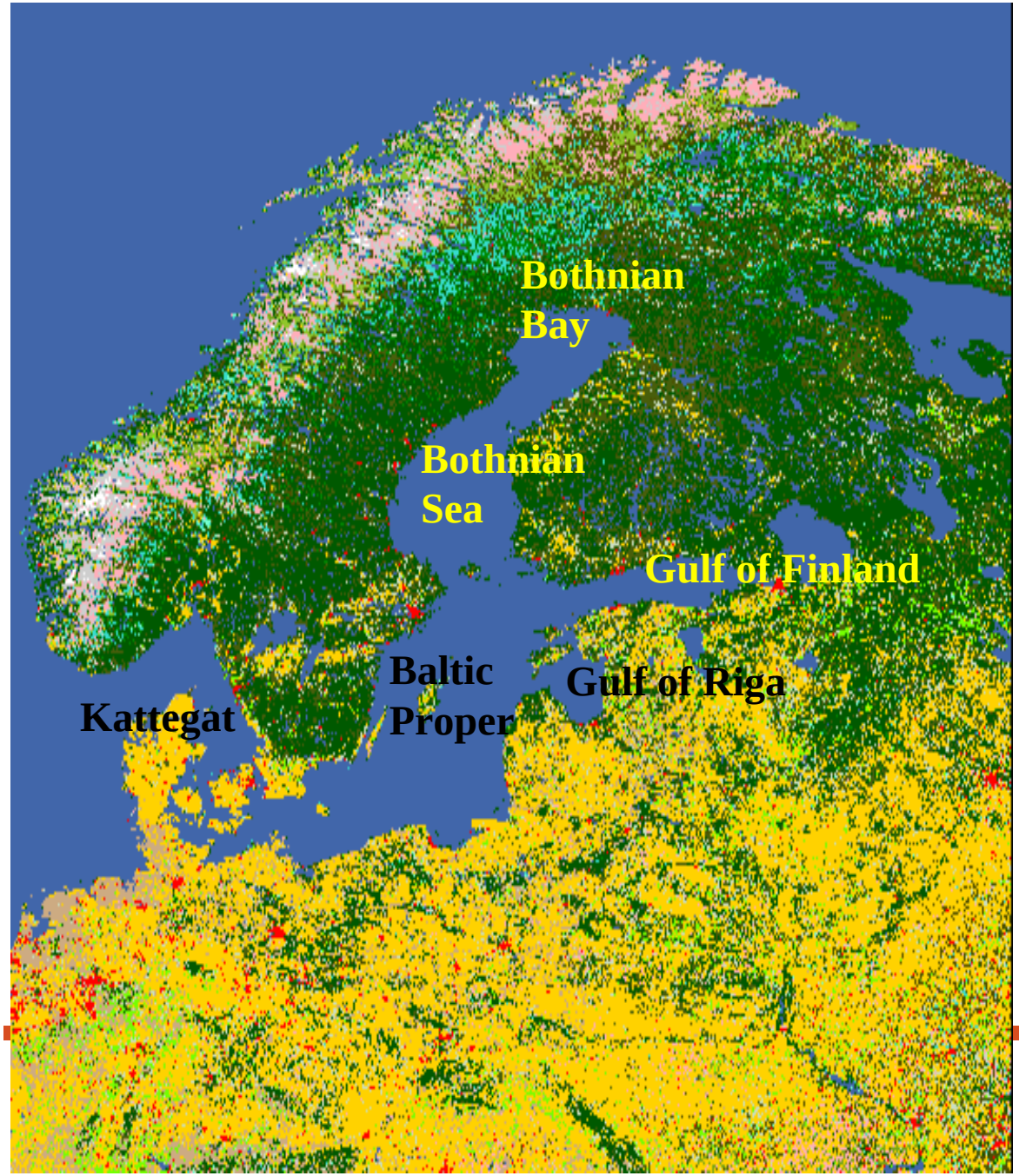
Research for Governance of Social-Ecological Systems
Stockholm University
Baltic Nest Institute

# Outline

- Baltic Sea Catchment
- Major drivers and trends for TN loads
- N accounting based on NANI and its implementation for managment
- Scenarios




## Legend

### glc250m

**Class_Names**

- Artificial surfaces and associated areas
- Bare areas
- Cultivated and managed terrestrial areas
- Herbaceous, closed - pastures, natural grassl
- Herbaceous, open with shrubs
- Lichens and mosses
- Mosaic: crop/ tree cover
- Regularly flooded shrub and/or herbaceous
- Snow and ice
- Sparse herbaceous or sparse shrubs
- Tree cover, broadleaved, deciduous, closed
- Tree cover, broadleaved, deciduous, open
- Tree cover, mixed phrenology, closed
- Tree cover, mixed phrenology, open
- Tree cover, needleleaved, evergreen, closed
- Tree cover, needleleaved, evergreen, open
- Water

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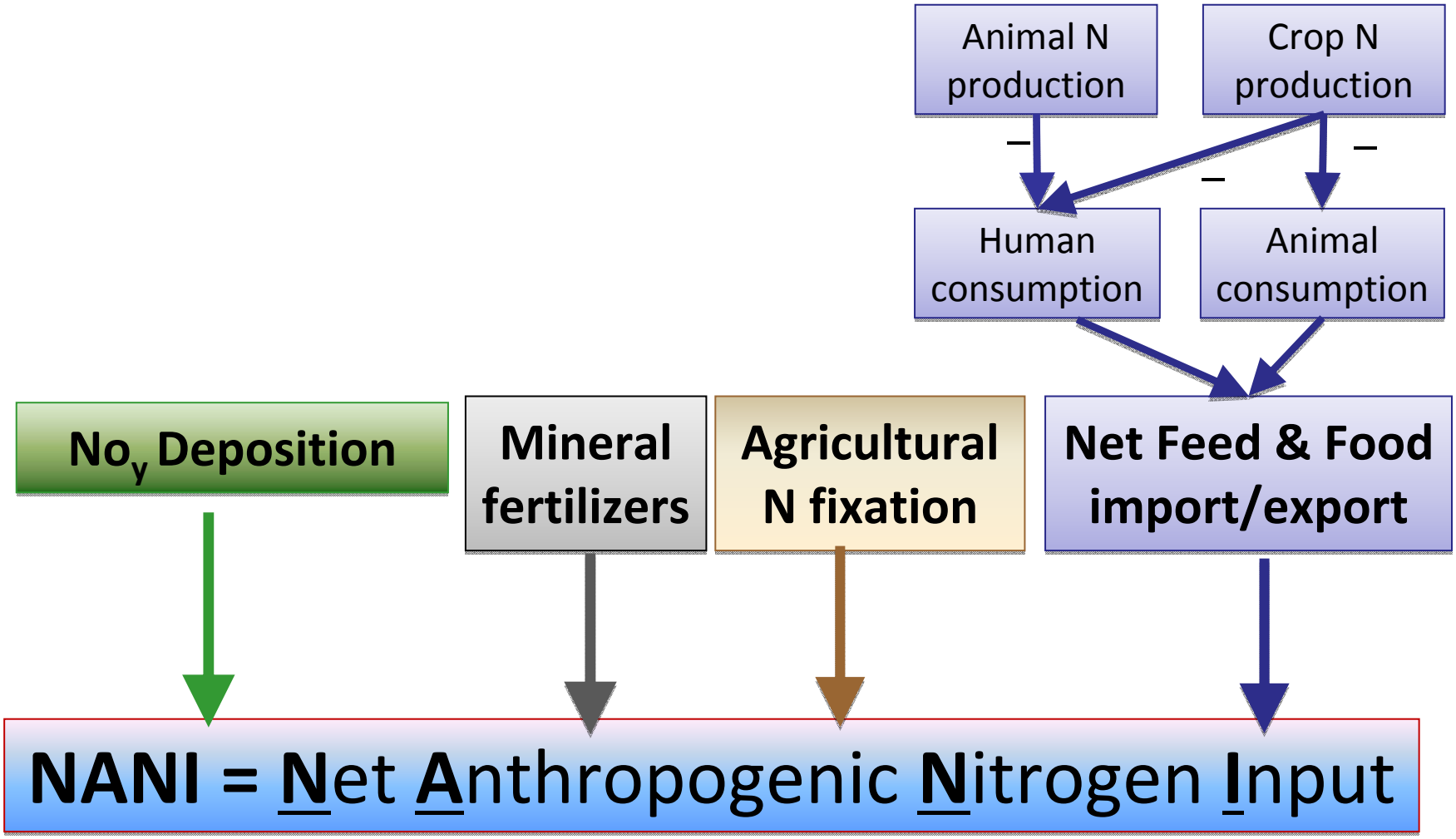
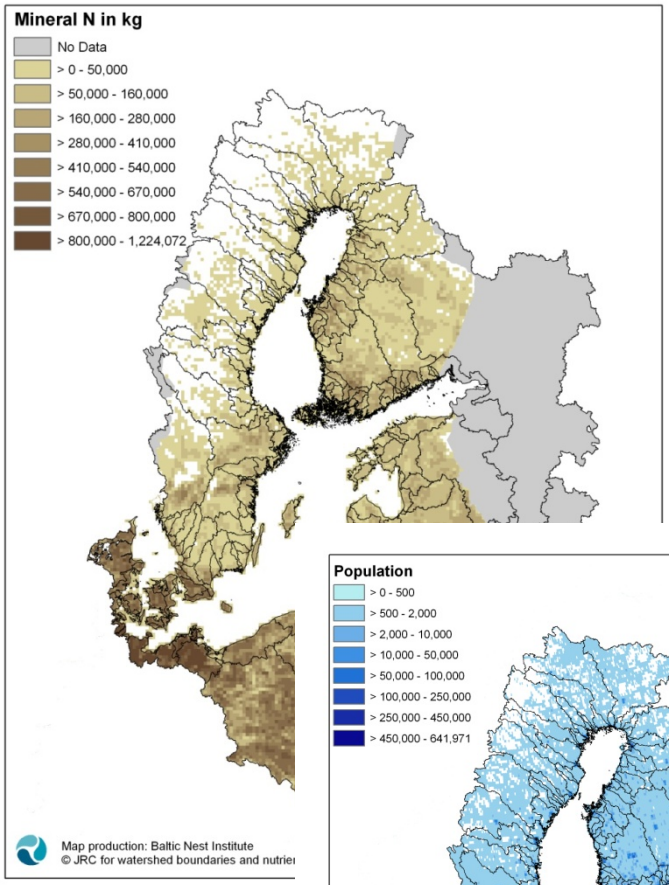
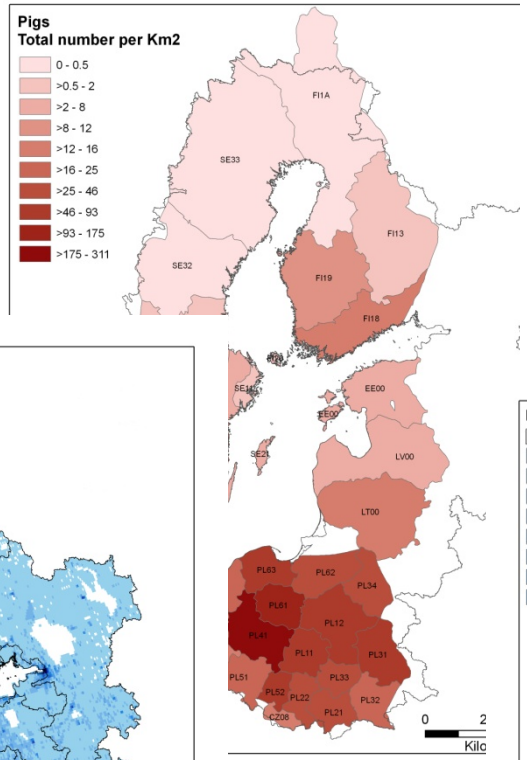
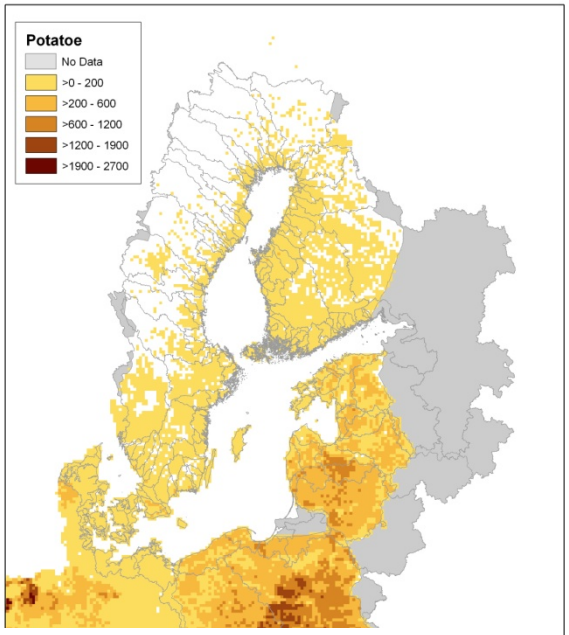
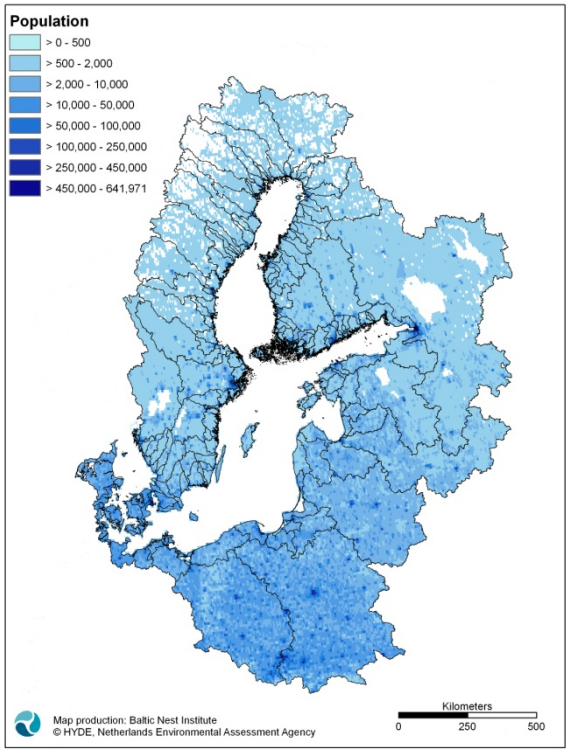

Animal N production
Crop N production
–
–
–
Human consumption
Animal consumption
$No_y$ Deposition
Mineral fertilizers
Agricultural N fixation
Net Feed & Food import/export
NANI = Net Anthropogenic Nitrogen Input

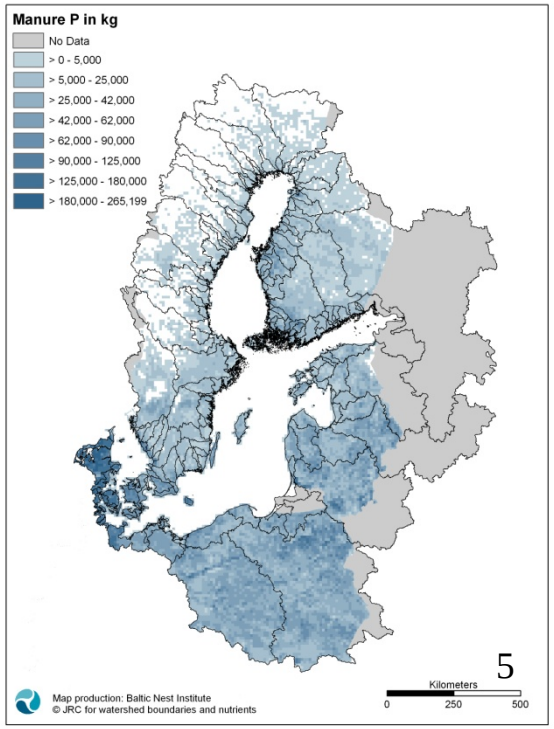
# Input Data: EUROSTAT, FAO JRC

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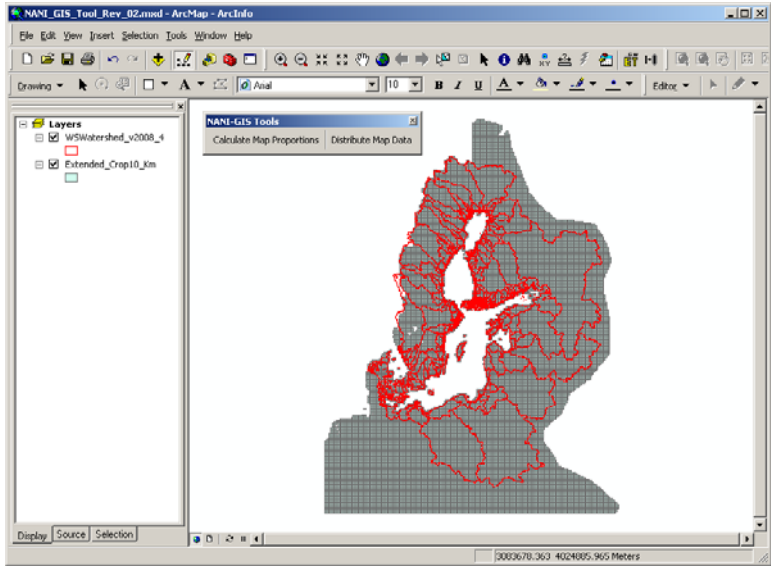
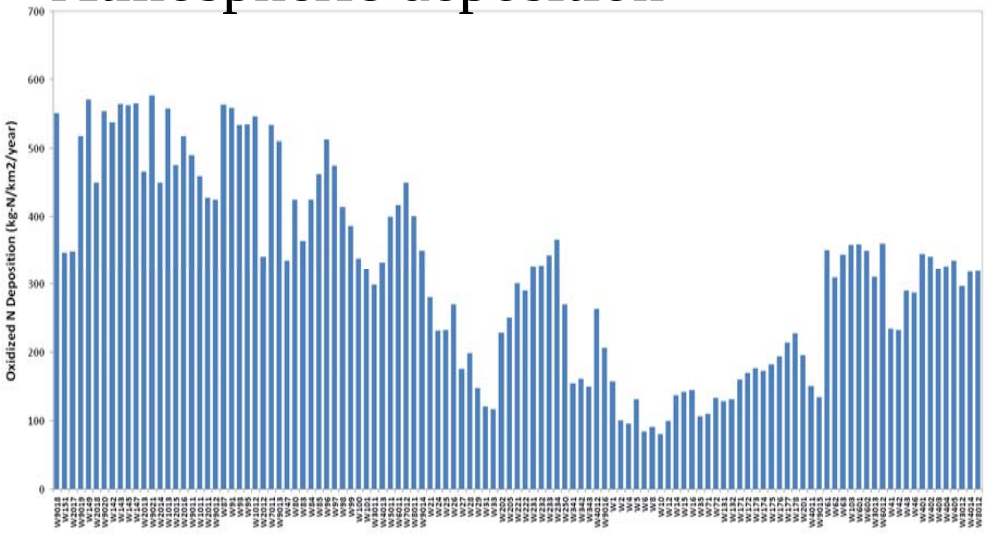
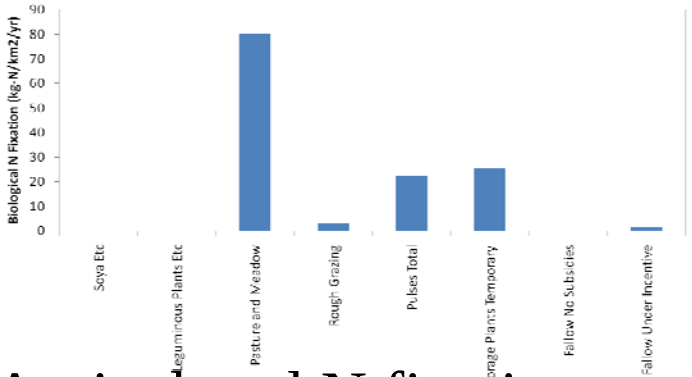
# NANI TOOLBOX



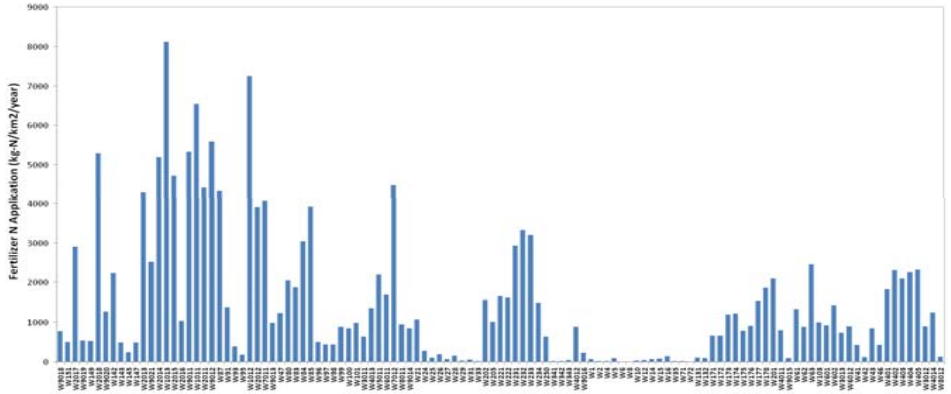

## Atmospheric deposition

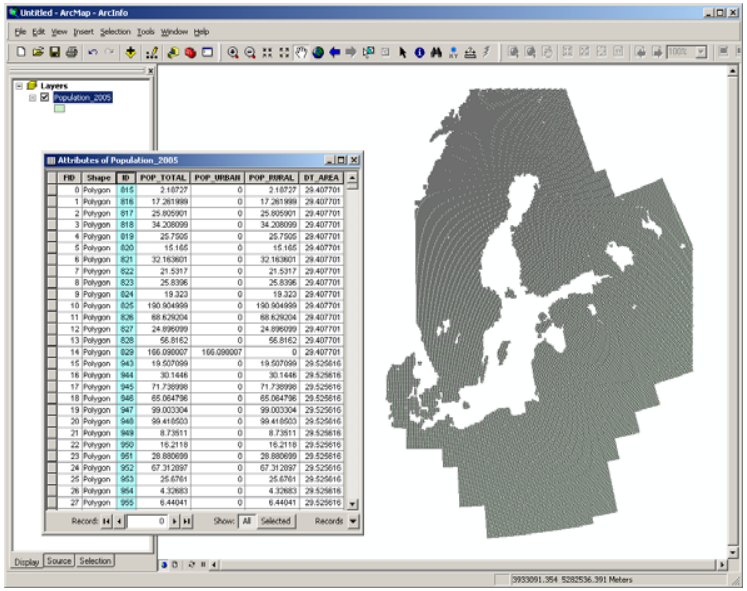


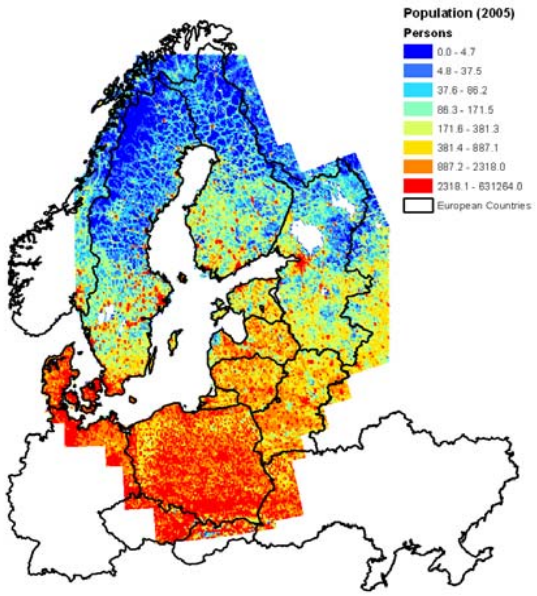

## Agricultural N fixation



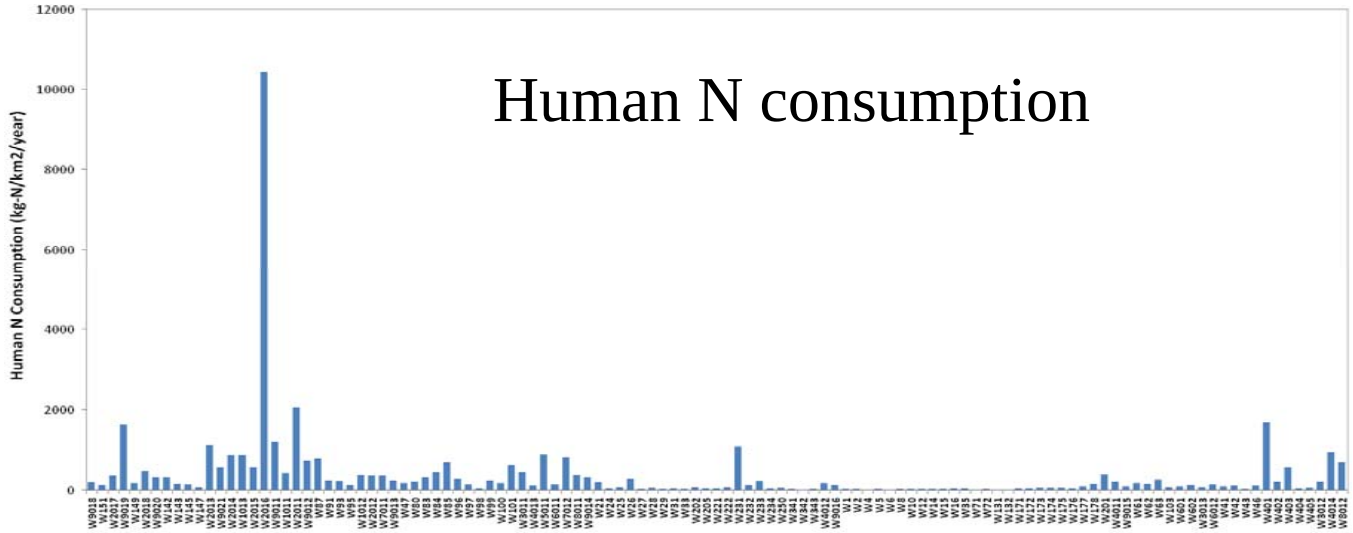

## Fertilizer use



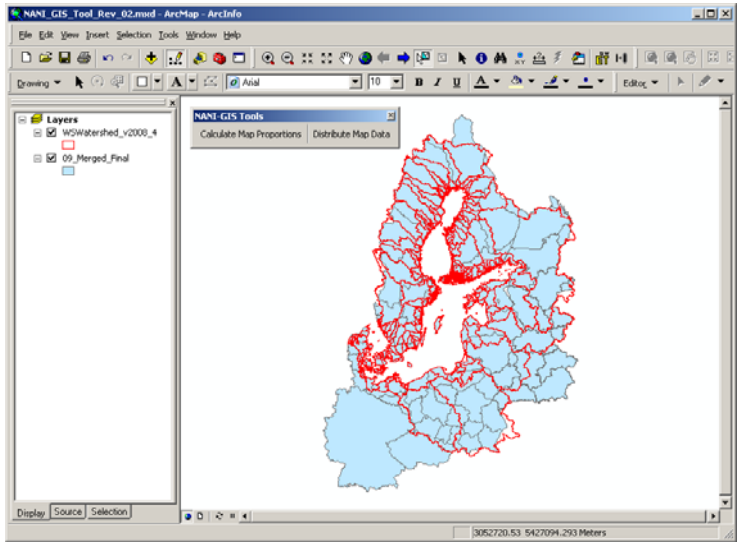


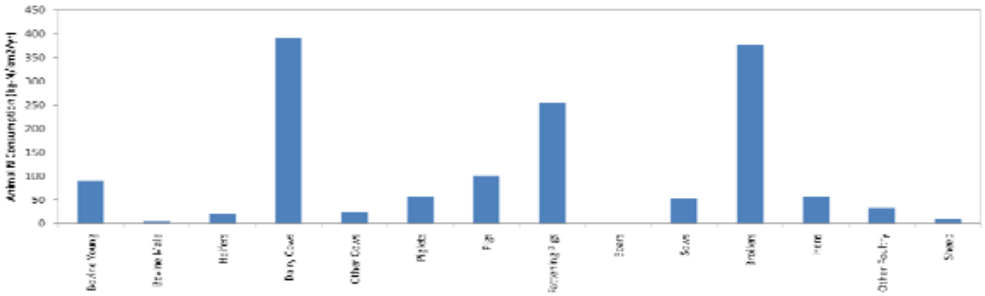




# Human N consumption



| Country Code | Bovine Young | | Bovine Male | | Heifers | | Dairy Cows | | Other Cows | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Intake | Excretion | Intake | Excretion | Intake | Excretion | Intake | Excretion | Intake | Excretion |
| BL | 25.11 | 22 | 49.41 | 42 | 47.06 | 40 | 93.92 | 75 | 67.42 | 60 |
| DE | 41.18 | 35 | 69.41 | 59 | 51.76 | 44 | 137.82 | 101 | 94.38 | 84 |
| DK | 49.19 | 41.81 | 64.59 | 54.9 | 72.71 | 61.8 | 154.57 | 110 | 82.36 | 73.3 |
| EE | 25.11 | 22 | 49.41 | 42 | 47.06 | 40 | 124.14 | 93 | 67.42 | 60 |
| FI | 29.41 | 25 | 47.06 | 40 | 47.06 | 40 | 146.88 | 105 | 61.80 | 55 |
| LT | 25.11 | 22 | 49.41 | 42 | 47.06 | 40 | 104.60 | 82 | 67.42 | 60 |
| LV | 25.11 | 22 | 49.41 | 42 | 47.06 | 40 | 108.91 | 86 | 67.42 | 60 |
| PL | 37.94 | 32.25 | 49.41 | 42 | 70.59 | 60 | 109.13 | 86 | 67.42 | 60 |
| RU | 25.11 | 22 | 49.41 | 42 | 51.80 | 40 | 92.00 | 76 | 67.42 | 60 |
| SE | 25.11 | 22 | 68.24 | 58 | 50.69 | 47 | 156.75 | 112 | 70.79 | 63 |
| CZ | 50.43 | 42.867 | 92.47 | 78.6 | 68.82 | 58.5 | 133.07 | 98 | 88.31 | 78.6 |
| NO | 35.43 | 29.3 | 47.06 | 40 | 52.9 | 40 | 121.13 | 93 | 74.6 | 66.6 |
| SK | 25.11 | 22 | 49.41 | 42 | 47.06 | 40 | 83.39 | 70 | 67.42 | 60 |
| UA | 25.11 | 22 | 49.41 | 42 | 47.06 | 40 | 89.50 | 74 | 67.42 | 60 |

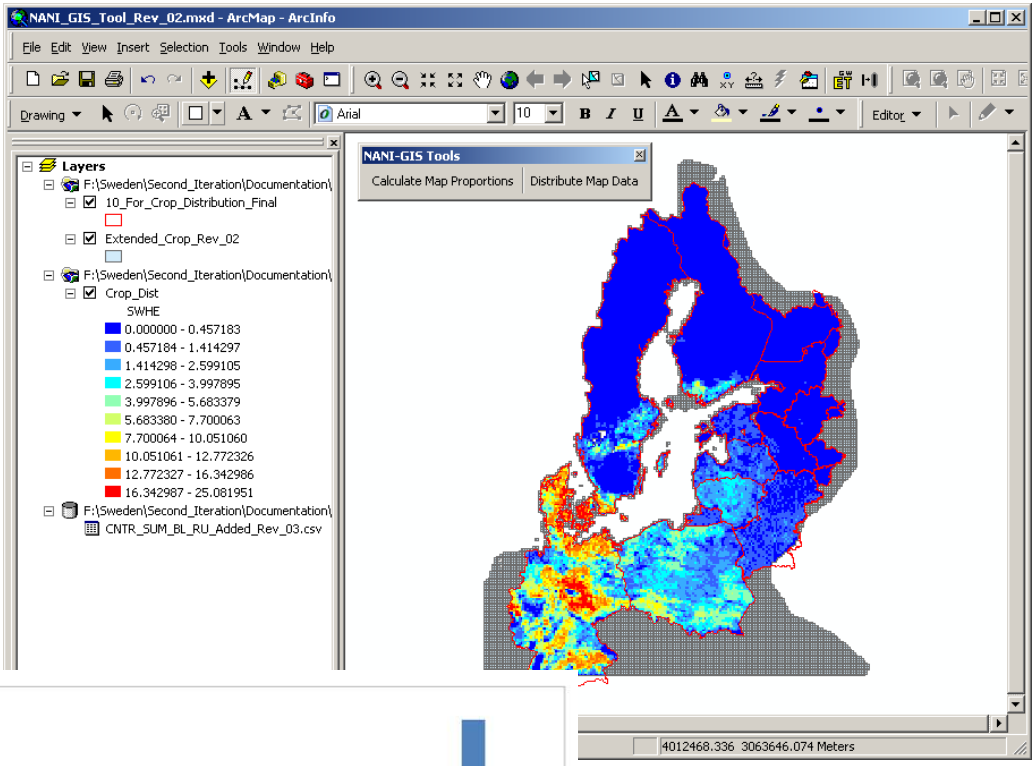


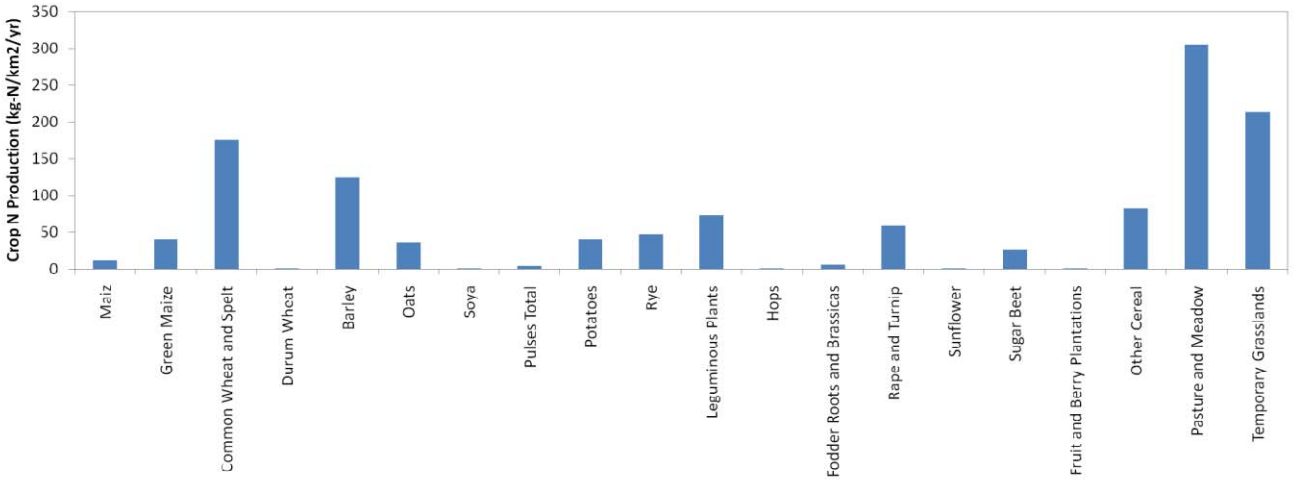



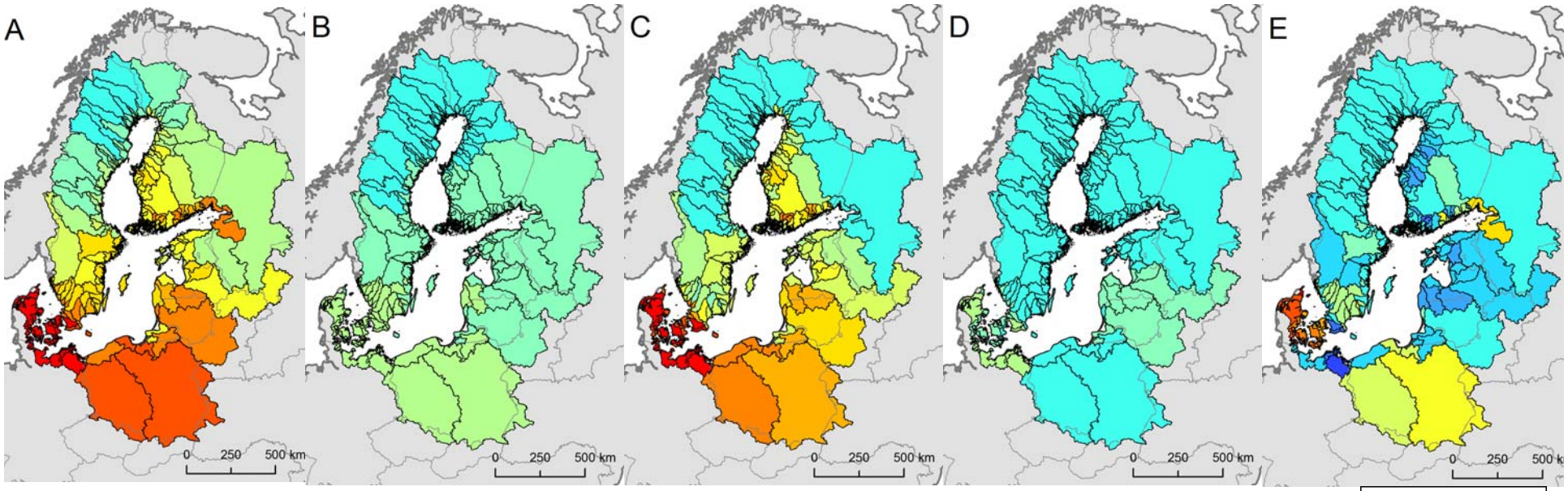

# Animal consumption

| Country Code | Piglets | | Pigs | | Fattening Pigs | | Boars | | Sows | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Intake | Excretion | Intake | Excretion | Intake | Excretion | Intake | Excretion | Intake | Excretion |
| BL | 7.31 | 2 | 21.43 | 9 | 31.60 | 11 | 10.81 | 9 | 25.49 | 19 |
| DE | 13.89 | 3.8 | 26.19 | 11 | 31.60 | 11 | 15.62 | 13 | 34.88 | 26 |
| DK | 7.31 | 2 | 14.76 | 6.2 | 46.83 | 16.3 | 27.63 | 23 | 34.48 | 25.7 |
| EE | 7.31 | 2 | 21.43 | 9 | 31.60 | 11 | 10.81 | 9 | 25.49 | 19 |
| FI | 20.46 | 5.6 | 21.43 | 9 | 31.60 | 11 | 10.81 | 9 | 25.49 | 19 |
| LT | 7.31 | 2 | 21.43 | 9 | 31.60 | 11 | 10.81 | 9 | 25.49 | 19 |
| LV | 7.31 | 2 | 21.43 | 9 | 31.60 | 11 | 10.81 | 9 | 25.49 | 19 |
| PL | 9.14 | 2.5 | 21.43 | 9 | 43.10 | 15 | 24.03 | 20 | 21.47 | 16 |
| RU | 7.31 | 2 | 21.43 | 9 | 31.60 | 11 | 10.81 | 9 | 25.49 | 19 |
| SE | 8.40 | 2.3 | 21.43 | 9 | 25.86 | 9 | 10.81 | 9 | 25.49 | 19 |
| CZ | 12.79 | 3.5 | 22.14 | 9.3 | 43.10 | 15 | 25.11 | 20.9 | 28.04 | 20.9 |
| NO | 7.31 | 2 | 21.43 | 9 | 31.60 | 11 | 16.70 | 13.9 | 29.65 | 22.1 |
| SK | 7.31 | 2 | 21.43 | 9 | 31.60 | 11 | 10.81 | 9 | 25.49 | 19 |
| UA | 7.31 | 2 | 21.45 | 9 | 31.60 | 11 | 10.81 | 9 | 25.49 | 19 |

# Crop production






NANI (A) in Baltic Sea catchments and its components, oxidized N deposition (B), fertilizer N application (C), agricultural N fixation (D), and N in net food and feed imports (E), calculated by NANI Calculator Toolbox.

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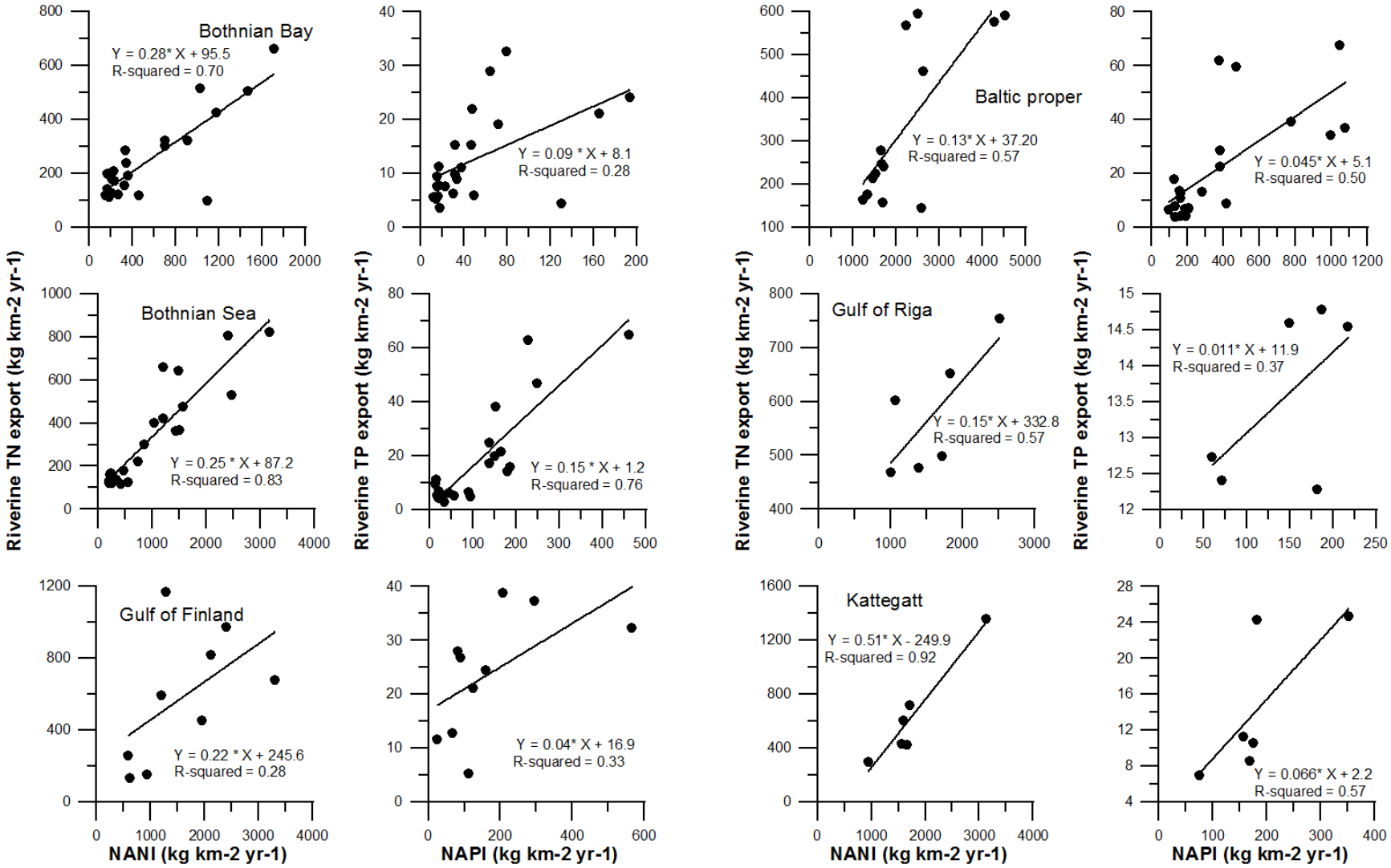
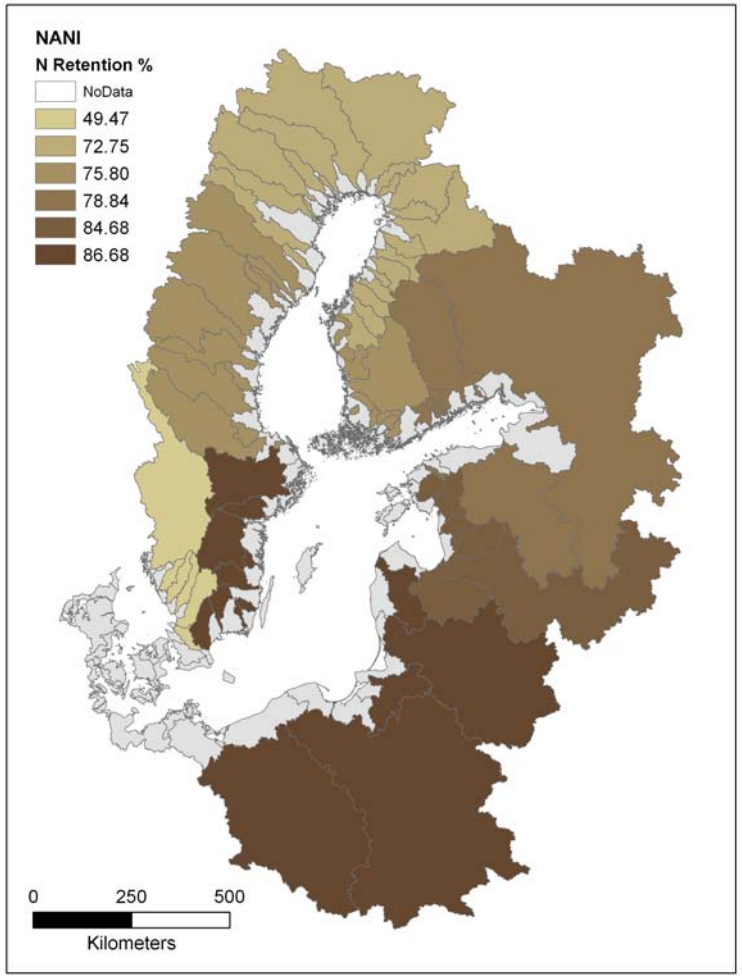
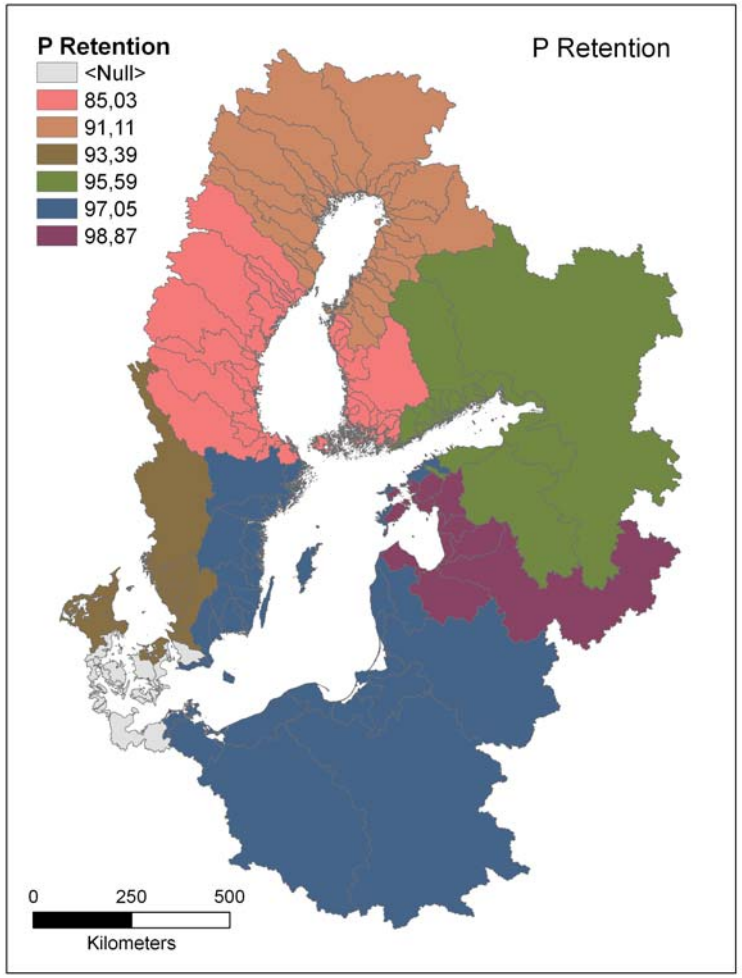



**Background TN loads 100-300 kg km$^{-2}$ yr$^{-1}$**
**60-90% TN retention**

| Variable | Bothnian Bay | Bothnian Sea | Baltic Proper |
|---|---|---|---|
| NANI (kg-N/km$^2$/yr) | 373 | 567 | 3555 |
| TN Export (kg-N/km$^2$/yr) | 174 | 215 | 544 |
| % Export | 47 | 38 | 15 |
| NAPI (kg-P/km$^2$/yr) | 38 | 62 | 732 |
| TP Export (kg-P/km$^2$/yr) | 8.9 | 9.1 | 28.5 |
| % Export | 23 | 15 | 3.9 |

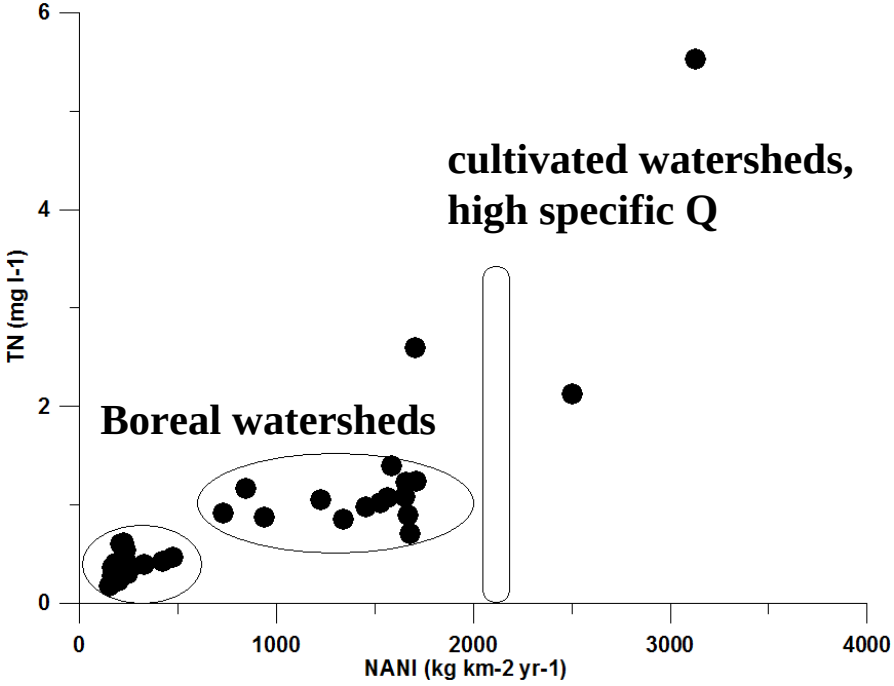


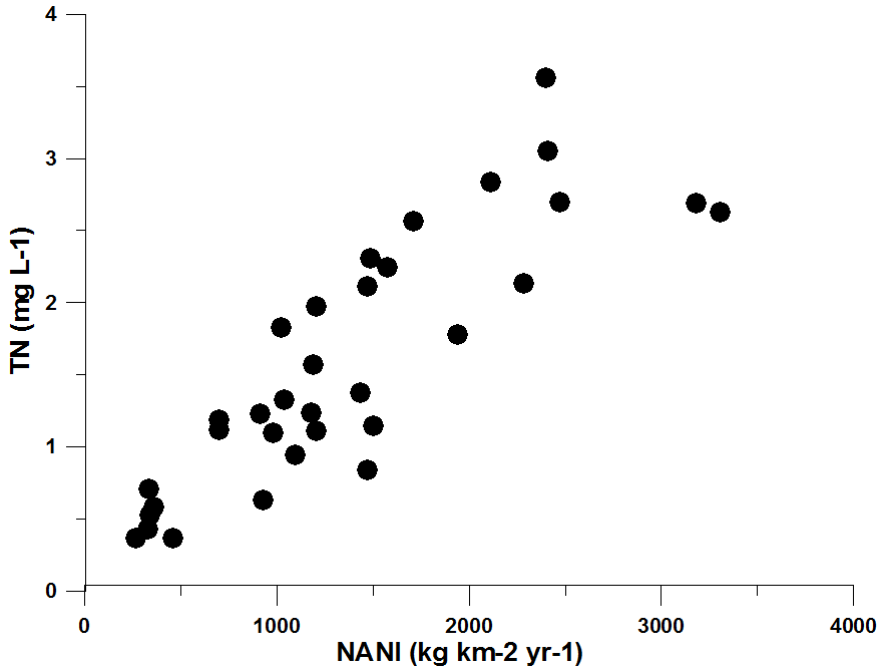

**NW -> SE gradient in TN retention**
**following hydrological and landscape patterns**

# Tipping points or critical loading?

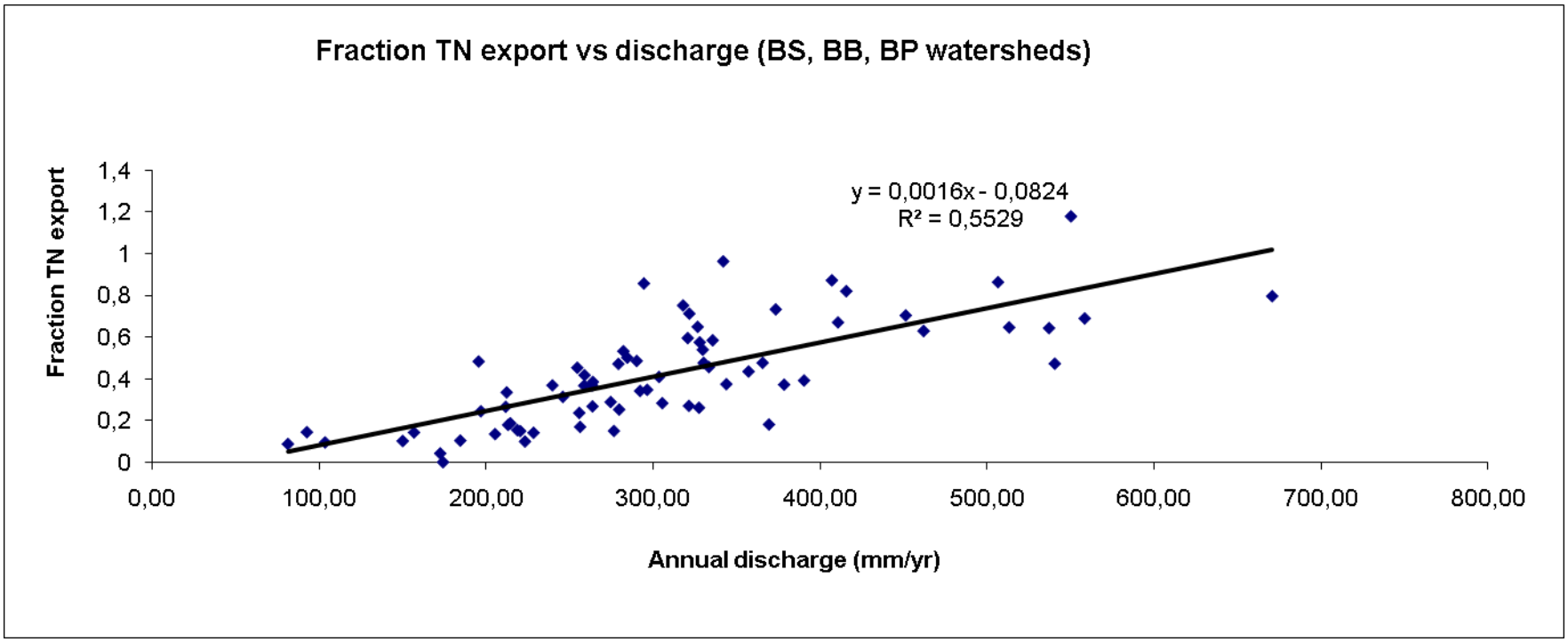
Swedish watersheds




Finnish watersheds

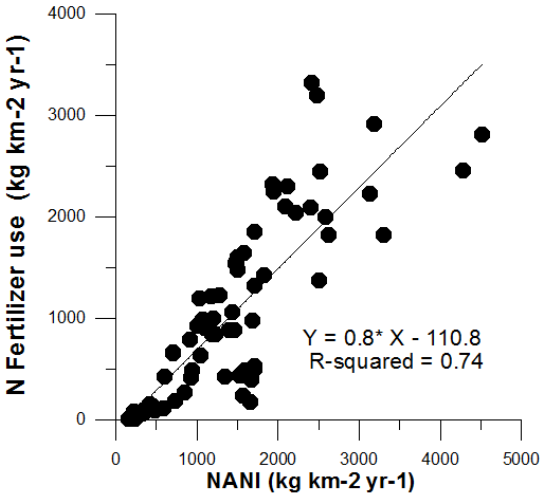


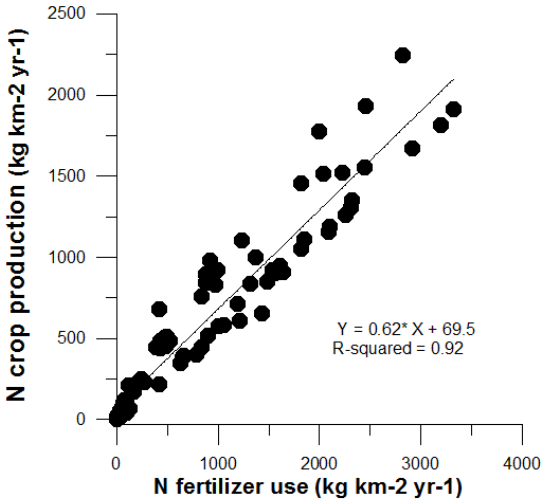
# Specific discharge explains a fare deal in retention patterns

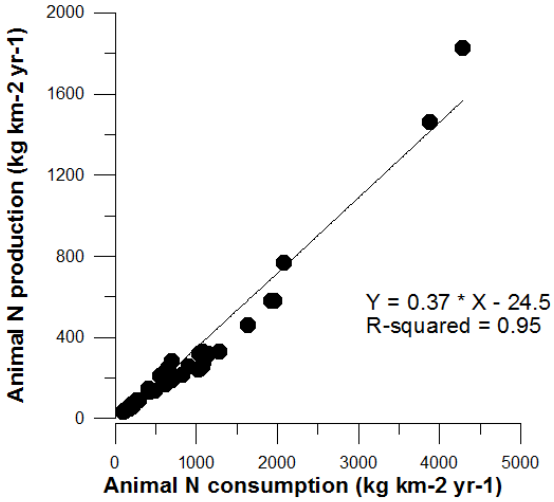


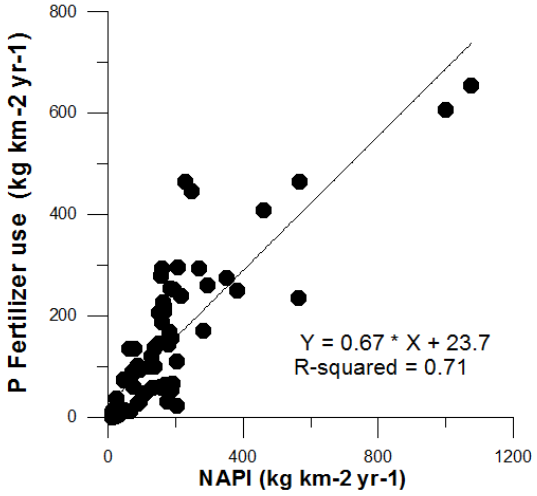
# Various NANI compounds can be used for Scenario analyses

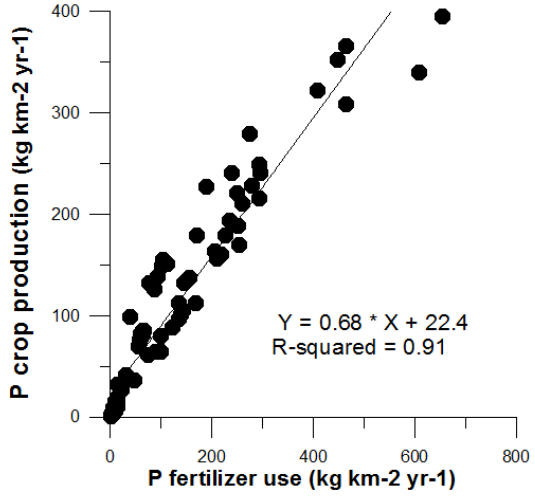
**NANI is dominated by fertilizer use → Fertilizer use translates to crops → Crops translates to animals**

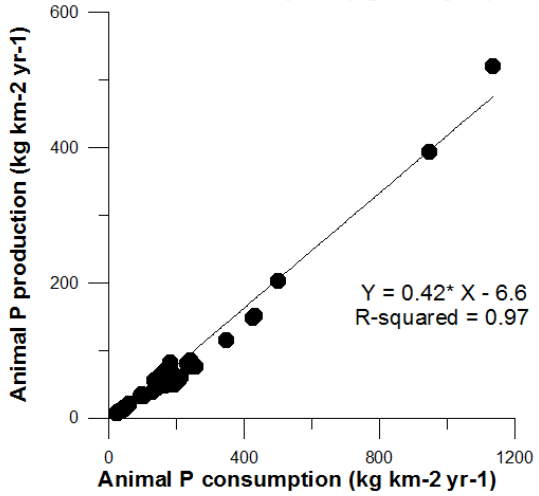


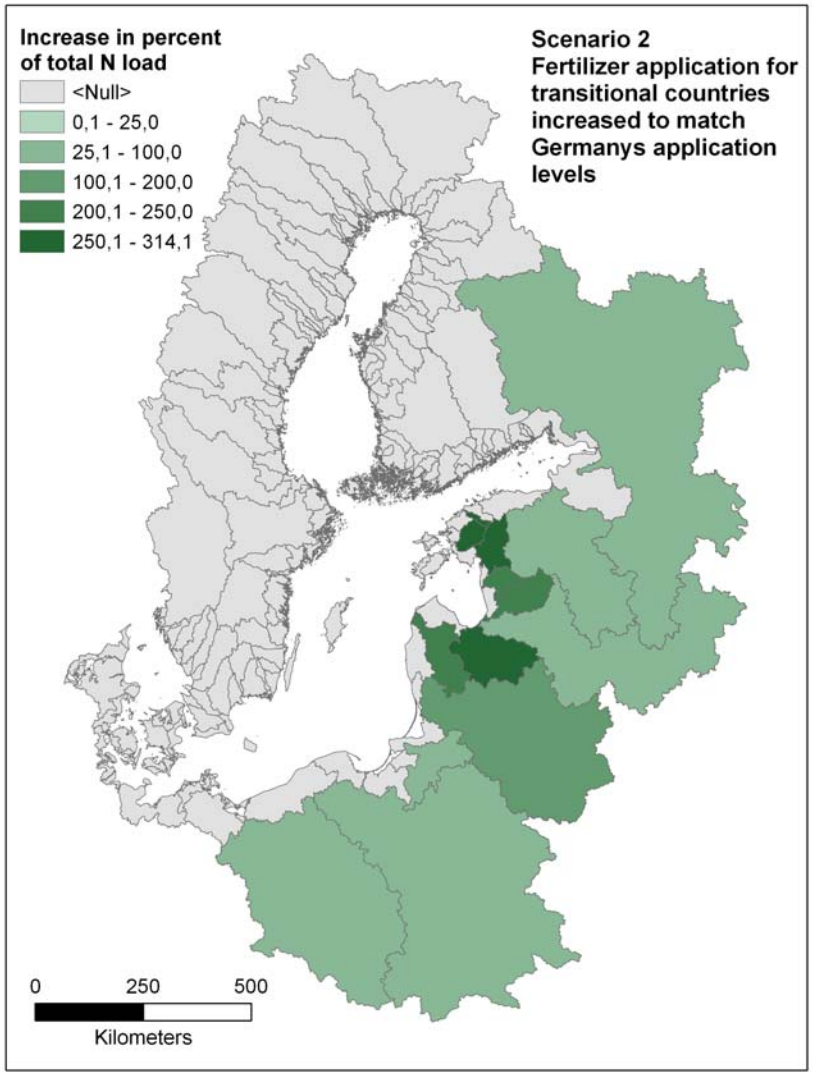



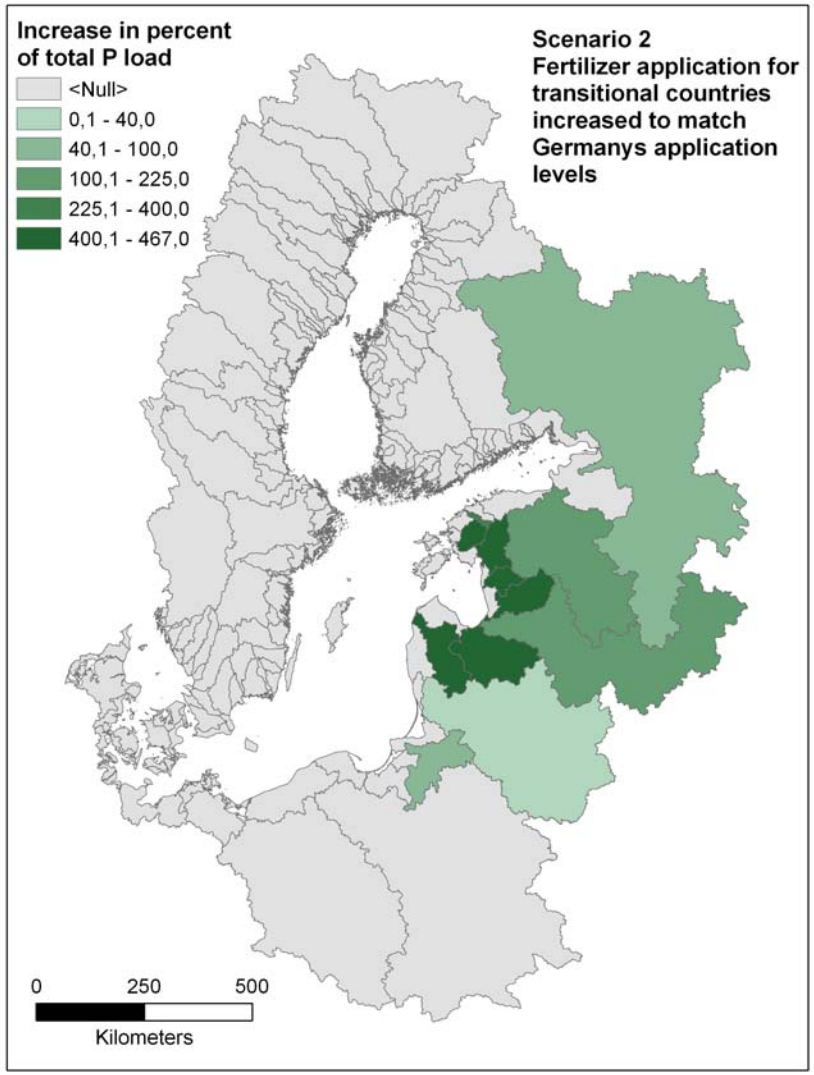



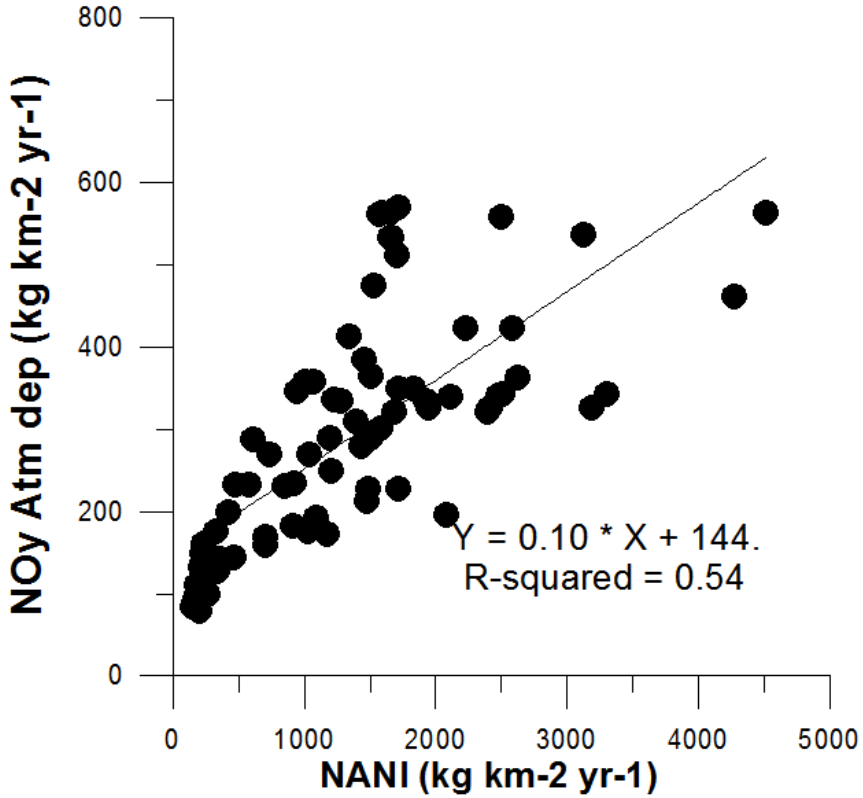
# Some Managemet Implications

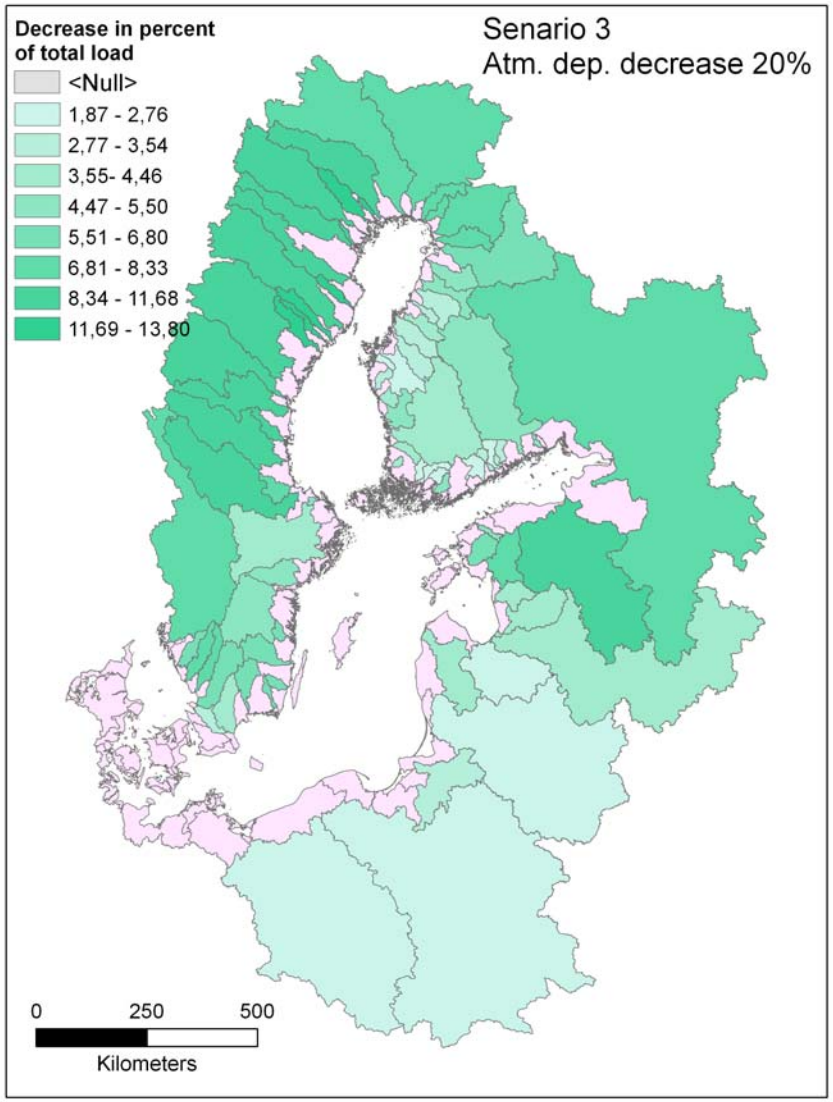
- **Sweden has to reduce annual TN loads by 20 000 tons (BSAP)**
- **NANI tells us that 85% of TN inputs is retained and that 80% of NANI is fertilizer**
- **This implies that Sweden has to reduce the TN inputs by some 120 000 tons and some 100 000 tons of this must be fertilizer (or its equvalents = manure, sewage; ~50% of the annual fertilizer use )**


Increase in percent of total N load
<Null>
0,1 - 25,0
25,1 - 100,0
100,1 - 200,0
200,1 - 250,0
250,1 - 314,1
Scenario 2
Fertilizer application for transitional countries increased to match Germanys application levels
0
250
500
Kilometers


Increase in percent of total P load
<Null>
0,1 - 40,0
40,1 - 100,0
100,1 - 225,0
225,1 - 400,0
400,1 - 467,0
Scenario 2
Fertilizer application for transitional countries increased to match Germanys application levels
0
250
500
Kilometers

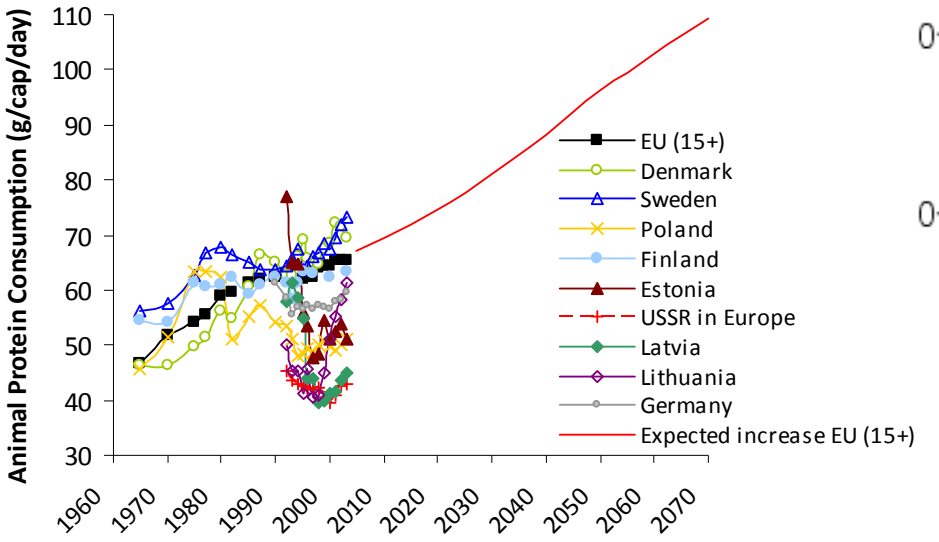
# EU NEC Directive



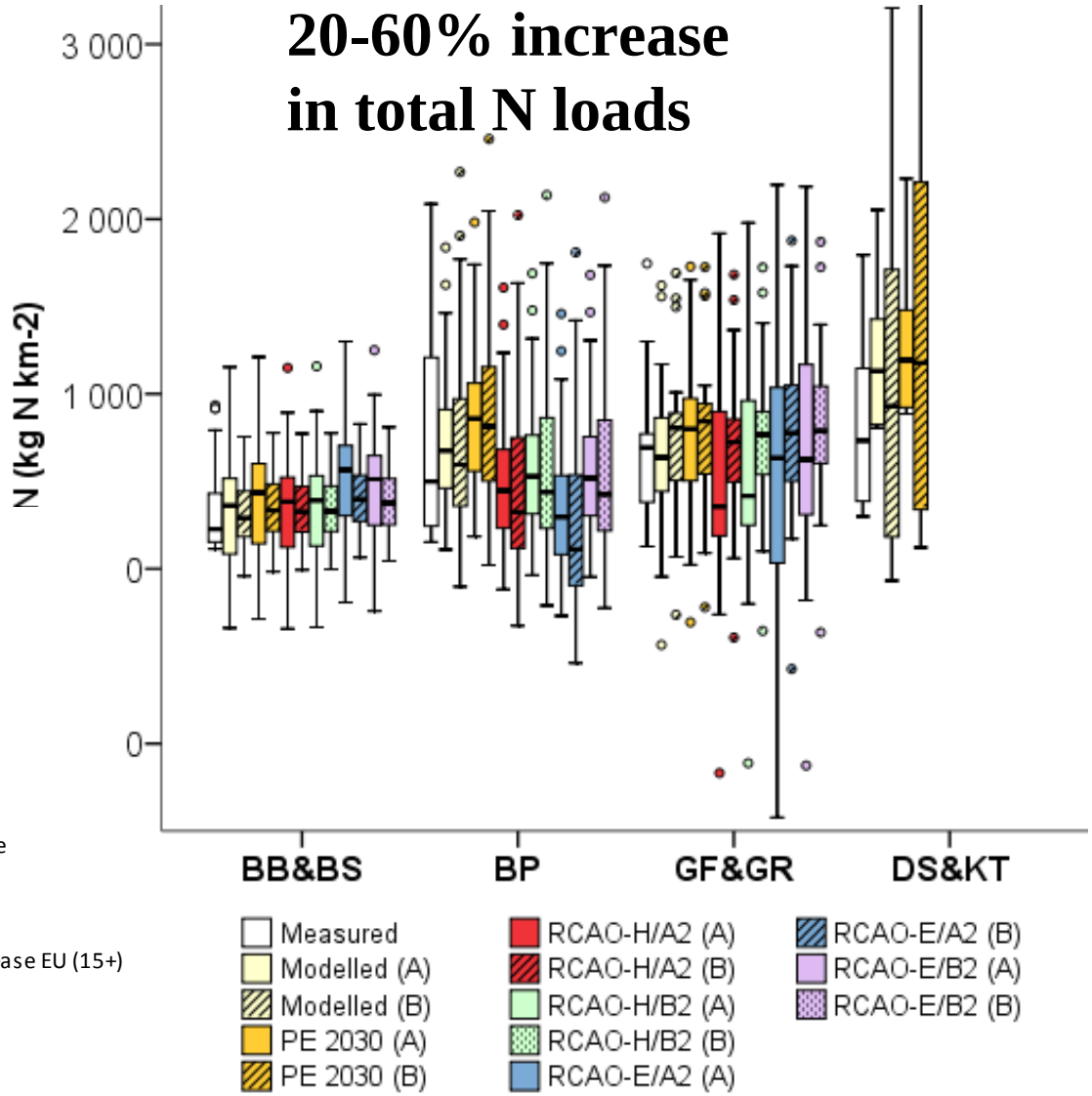



# Scenarios on combined climate and lifestyle effects

## Eriksson et al. ES&T 2010




## 20-60% increase in total N loads

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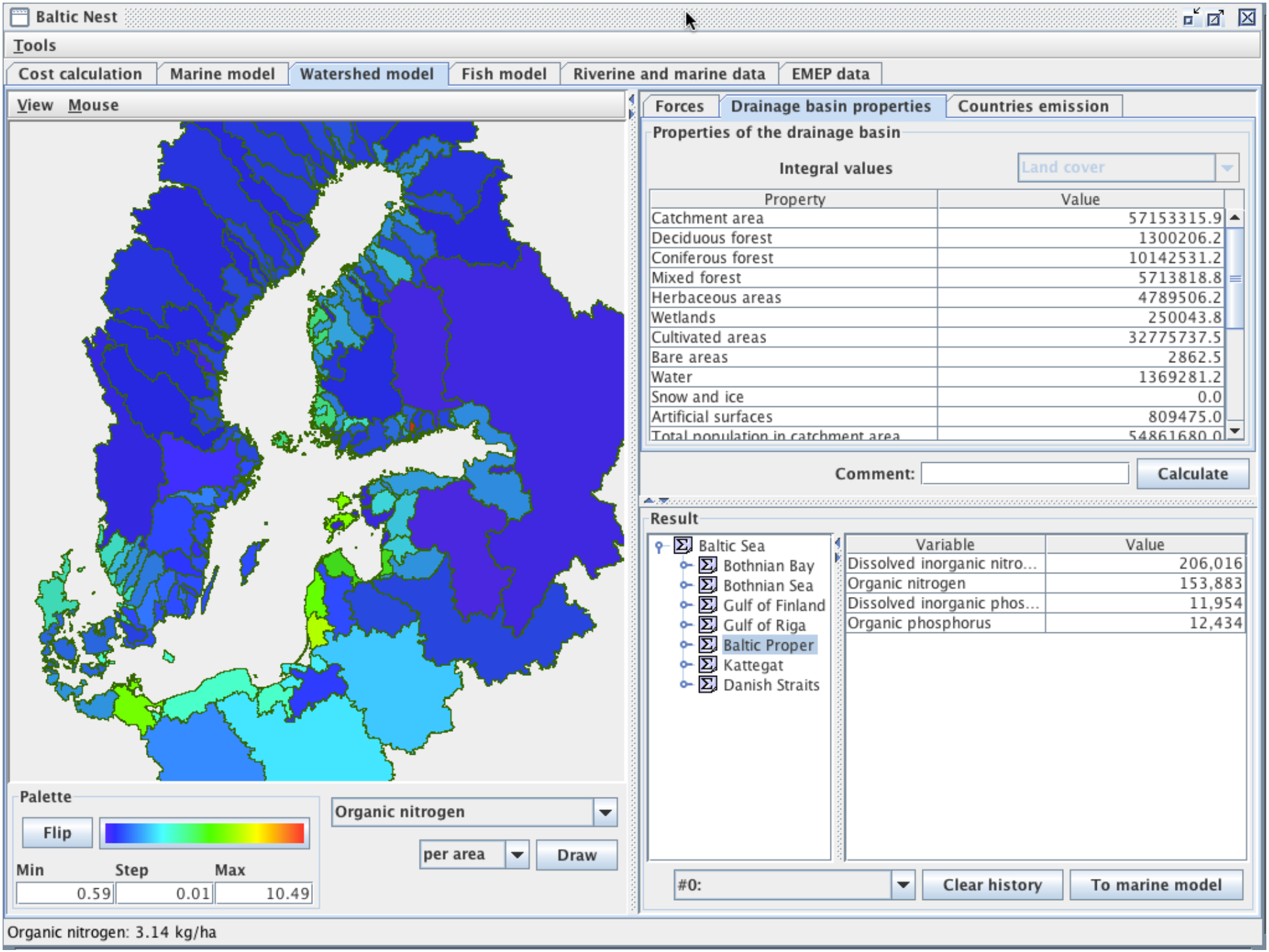
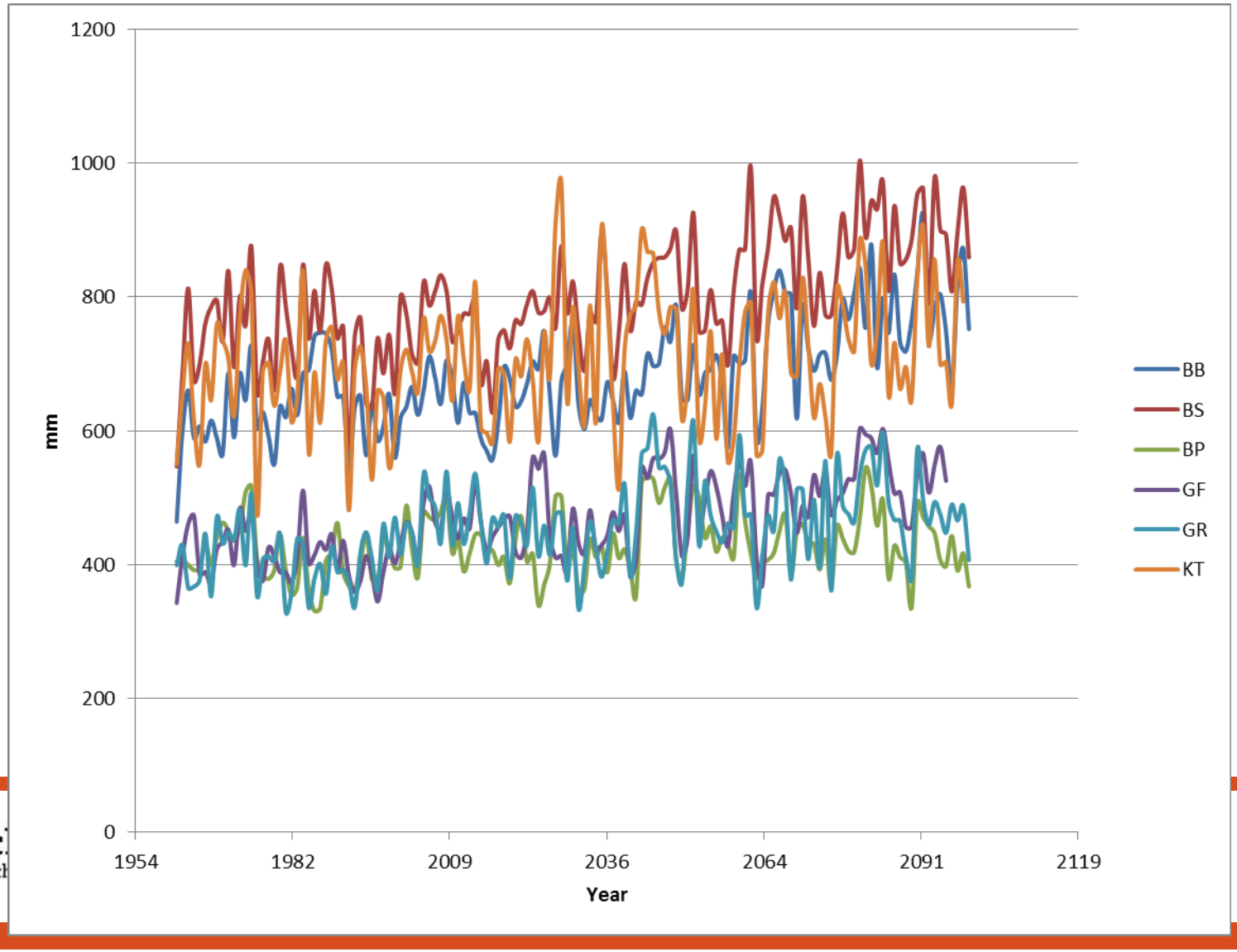
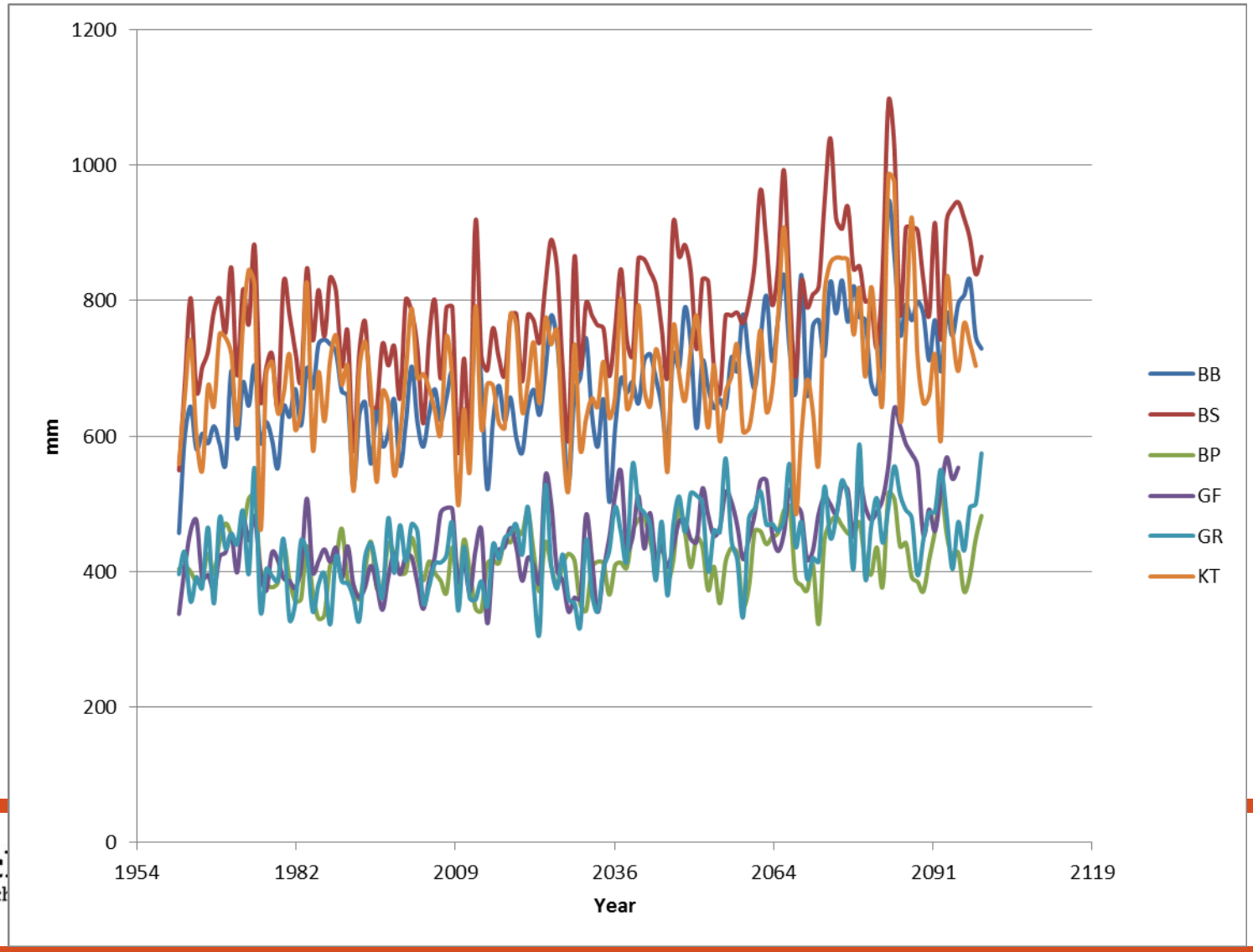

Baltic Nest
Tools
Cost calculation
Marine model
Watershed model
Fish model
Riverine and marine data
EMEP data
View
Mouse
Forces
Drainage basin properties
Countries emission
Properties of the drainage basin
Integral values
Land cover
Property
Value
Catchment area 57153315.9
Deciduous forest 1300206.2
Coniferous forest 10142531.2
Mixed forest 5713818.8
Herbaceous areas 4789506.2
Wetlands 250043.8
Cultivated areas 32775737.5
Bare areas 2862.5
Water 1369281.2
Snow and ice 0.0
Artificial surfaces 809475.0
Comment:
Calculate
Result
Baltic Sea
Bothnian Bay
Bothnian Sea
Gulf of Finland
Gulf of Riga
Baltic Proper
Kattegat
Danish Straits
Variable
Value
Dissolved inorganic nitro... 206,016
Organic nitrogen 153,883
Dissolved inorganic phos... 11,954
Organic phosphorus 12,434
Palette
Flip
Min
Step
Max
0.59
0.01
10.49
Organic nitrogen
per area
Draw
#0:
Clear history
To marine model
Organic nitrogen: 3.14 kg/ha

| | Description | AMBER | ECOSUPPORT |
|---|---|---|---|
| 1 | Re – analyzed true weather 1961-2009 | RCA-ERA40, 50 km | RCA-ERA40, 25 km |
| 2 | IPCC Scenario A1B, ECHAM global model | RCA-ECHAM5 A1B_1, 50 km | RCAO-ECHAM5 A1B_1, 25 km |
| 3 | IPCC Scenario A1B, ECHAM global model | RCA-ECHAM5 A1B_2, 50 km | N/A |
| 4 | IPCC Scenario A1B, ECHAM global model | RCA-ECHAM5 A1B_3, 50 km | RCAO-ECHAM5 A1B_3, 25 km |
| 5 | IPCC Scenario A1B, HadCM global model | RCA-HadCM3 A1B, 50 km | RCAO-HadCM3 A1B, 25 km |
| 6 | IPCC Scenario A2, ECHAM global model | RCA-ECHAM5 A2, 50 km | RCAO-ECHAM5 A2, 25 km |
| 7 | IPCC Scenario B1, ECHAM global model | RCA-ECHAM5 B1, 50 km | N/A |
| 8 | IPCC Scenario A1B, CCSM3 global model | RCA-CCSM3 A1B, 50 km | N/A |

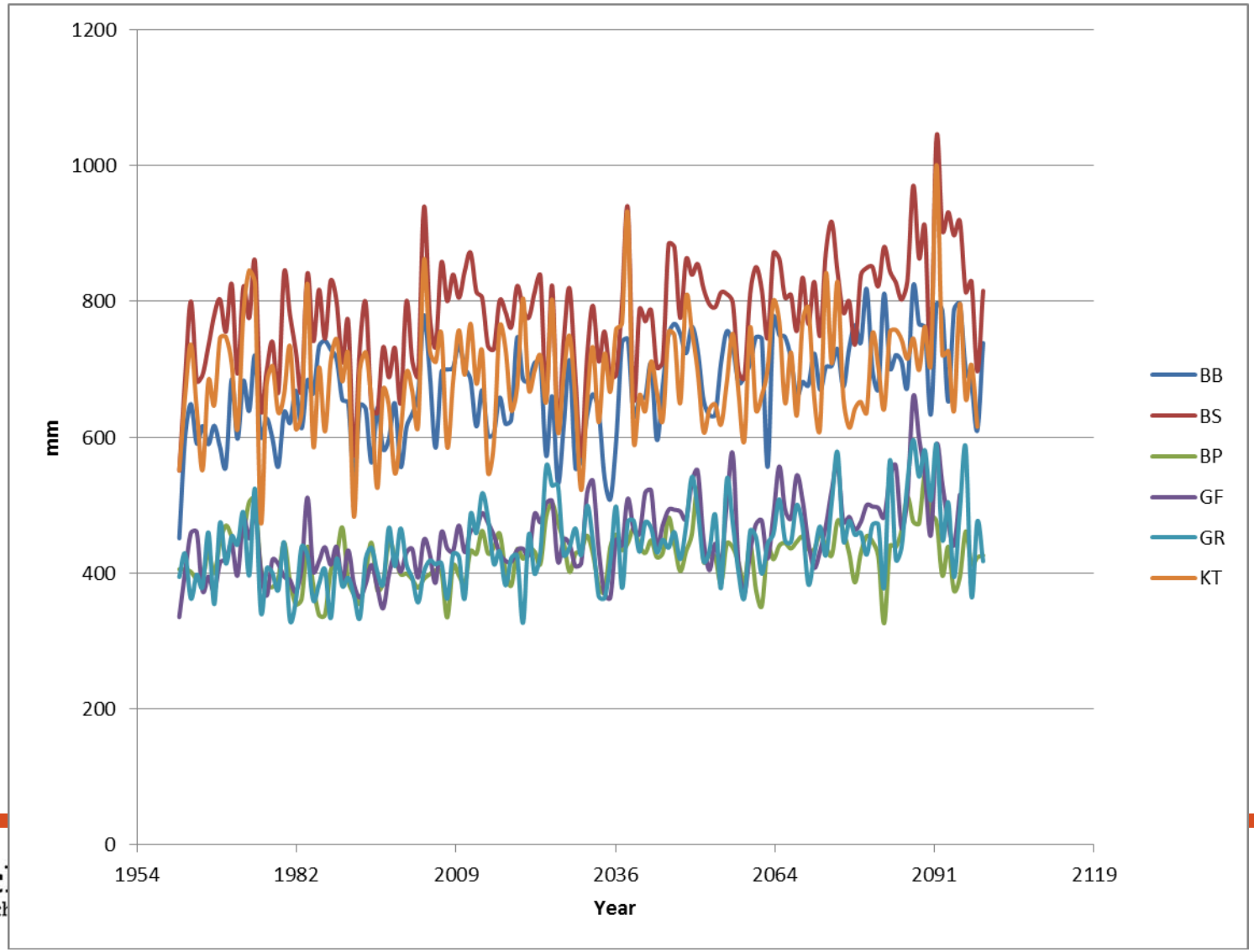
# Echam5_a1b


1200
1000
800
600
400
200
0
mm
1954
1982
2009
2036
2064
2091
2119
Year
BB
BS
BP
GF
GR
KT

# Echam5_a2


1200
1000
800
600
400
200
0
mm
1954
1982
2009
2036
2064
2091
2119
Year
BB
BS
BP
GF
GR
KT

# Echam5_b1


1200
1000
800
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mm
1954
1982
2009
2036
2064
2091
2119
Year
BB
BS
BP
GF
GR
KT

*Table 2.* Regression analyses of N and P loading and yield.

| Source | log N (mol year$^{-1}$) | $R^2$ | log P (mol year$^{-1}$) | $R^2$ |
|---|---|---|---|---|
| *Loading equations* | | | | |
| Smith et al. (2003) | $-0.20 + 0.69 \times \log(\text{run}) + 0.32 \times \log(\text{pers})$ | 0.81 | $-1.15 + 0.66 \times \log(\text{run}) + 0.30 \times \log(\text{pers})$ | 0.78 |
| This paper | $0.57 + 0.61 \times \log(\text{run}) + 0.33 \times \log(\text{pers})$ | 0.76 | $-1.60 + 0.67 \times \log(\text{run}) + 0.34 \times \log(\text{pers})$ | 0.78 |
| SPARROW (Smith et al. 1997) | | 0.87 | | 0.81 |
| | log N (mol km$^{-2}$ year$^{-1}$) | $R^2$ | log P (mol km$^{-2}$ year$^{-1}$) | $R^2$ |
| *Yield equations* | | | | |
| Smith et al. (2003) | $3.99 + 0.75 \times \log(\text{run km}^{-2}) + 0.35 \times \log(\text{pers km}^{-2})$ | 0.59 | $2.72 + 0.78 \times \log(\text{run km}^{-2}) + 0.36 \times \log(\text{pers km}^{-2})$ | 0.58 |
| This paper | $4.03 + 0.69 \times \log(\text{run km}^{-2}) + 0.36 \times \log(\text{pers km}^{-2})$ | 0.44 | $2.43 + 0.63 \times \log(\text{run km}^{-2}) + 0.33 \times \log(\text{pers km}^{-2})$ | 0.38 |

In the cases of the results of Smith et al. (2003) and this paper, loading and regression are for dissolved inorganic N and P (DIN, DIP). For SPARROW, total N and P (TN, TP) loads are calculated. Correlations only are presented here for the SPARROW model loading estimates. (run = runoff (m$^3$/year); pers = number of persons).

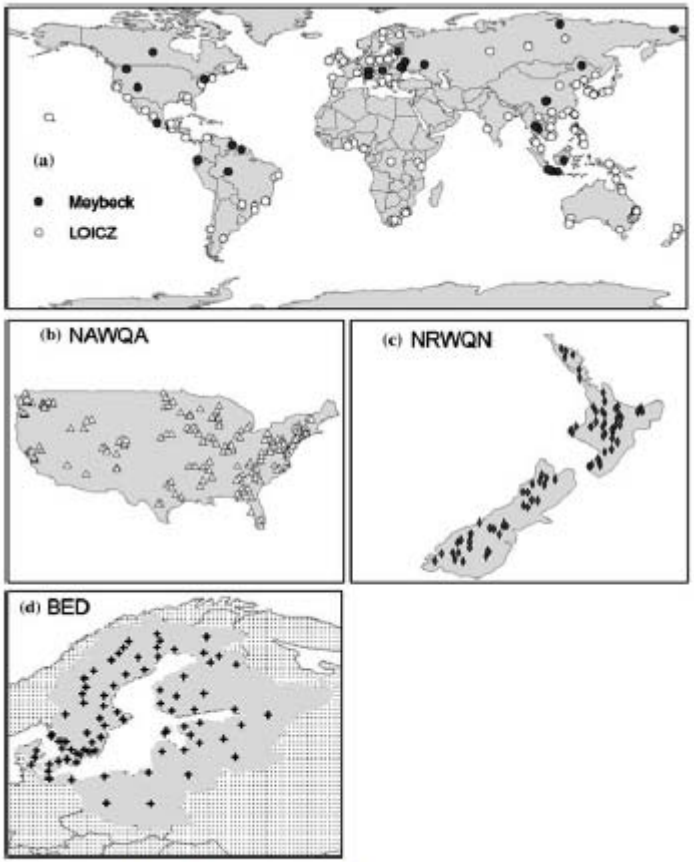
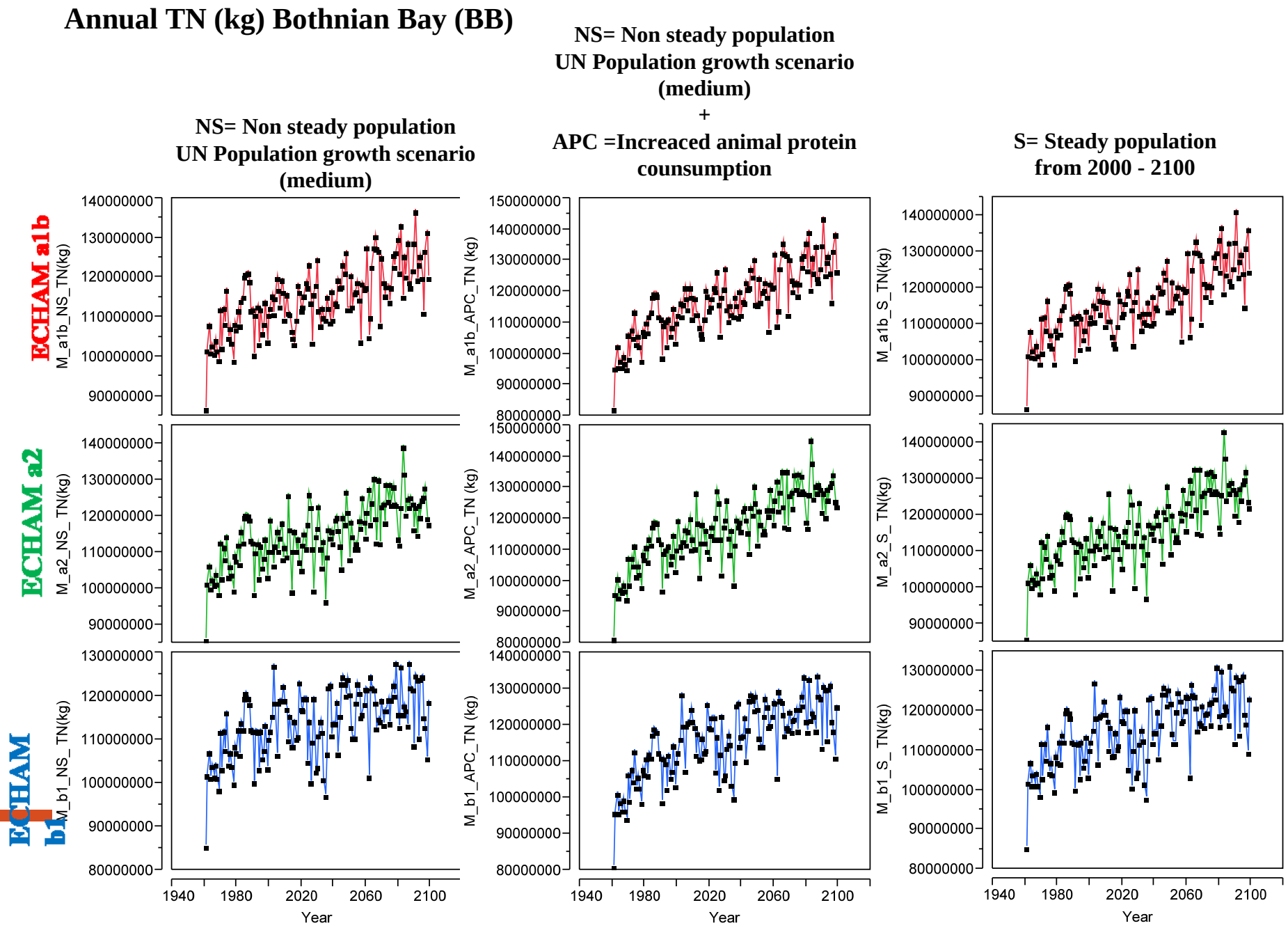
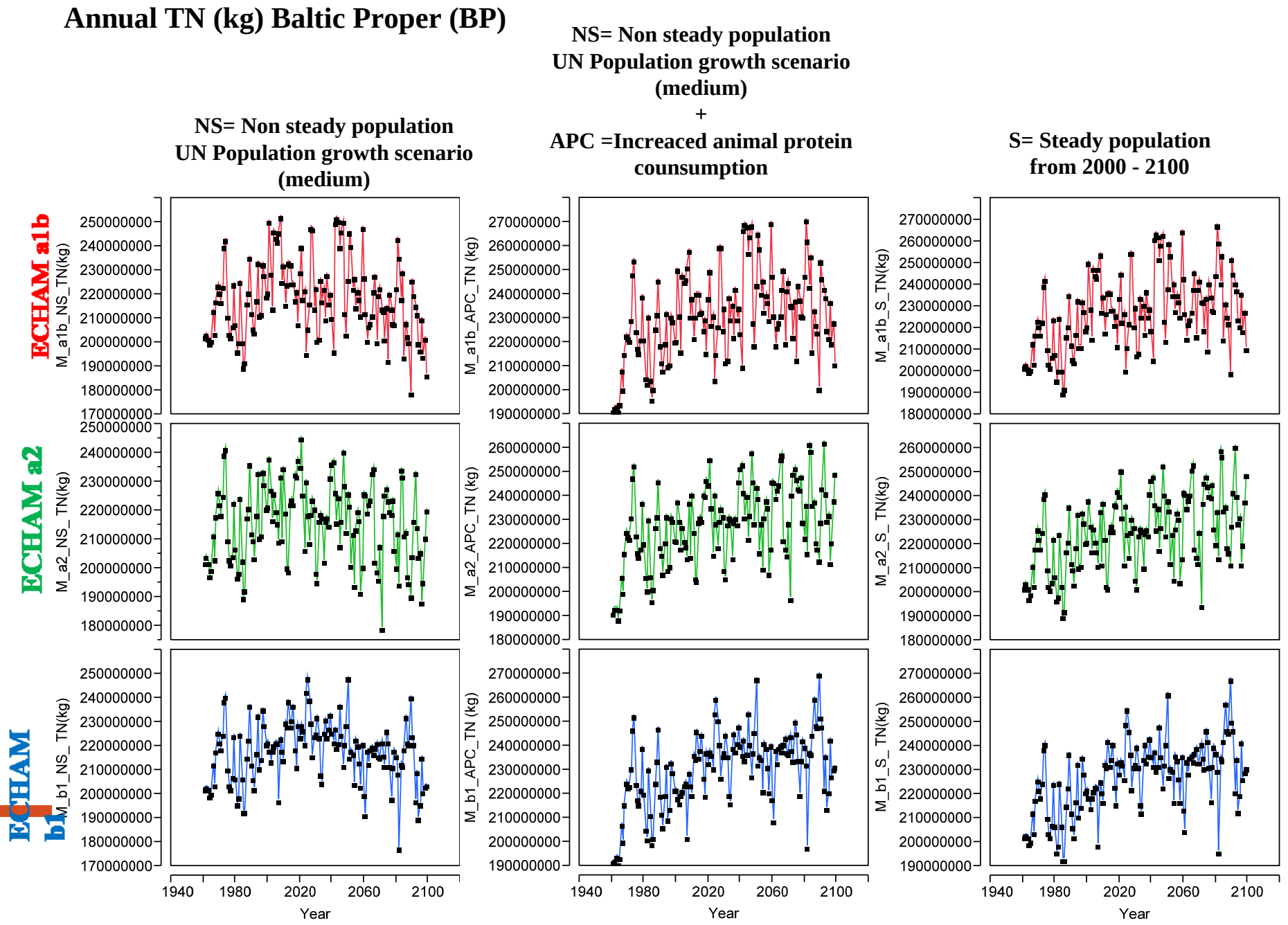



*Figure 1.* Sites used for calibrating the nutrient flux calculations. Basin geographical centers are plotted for panels (a), (c), and (d), while gauging station locations are plotted for (b).

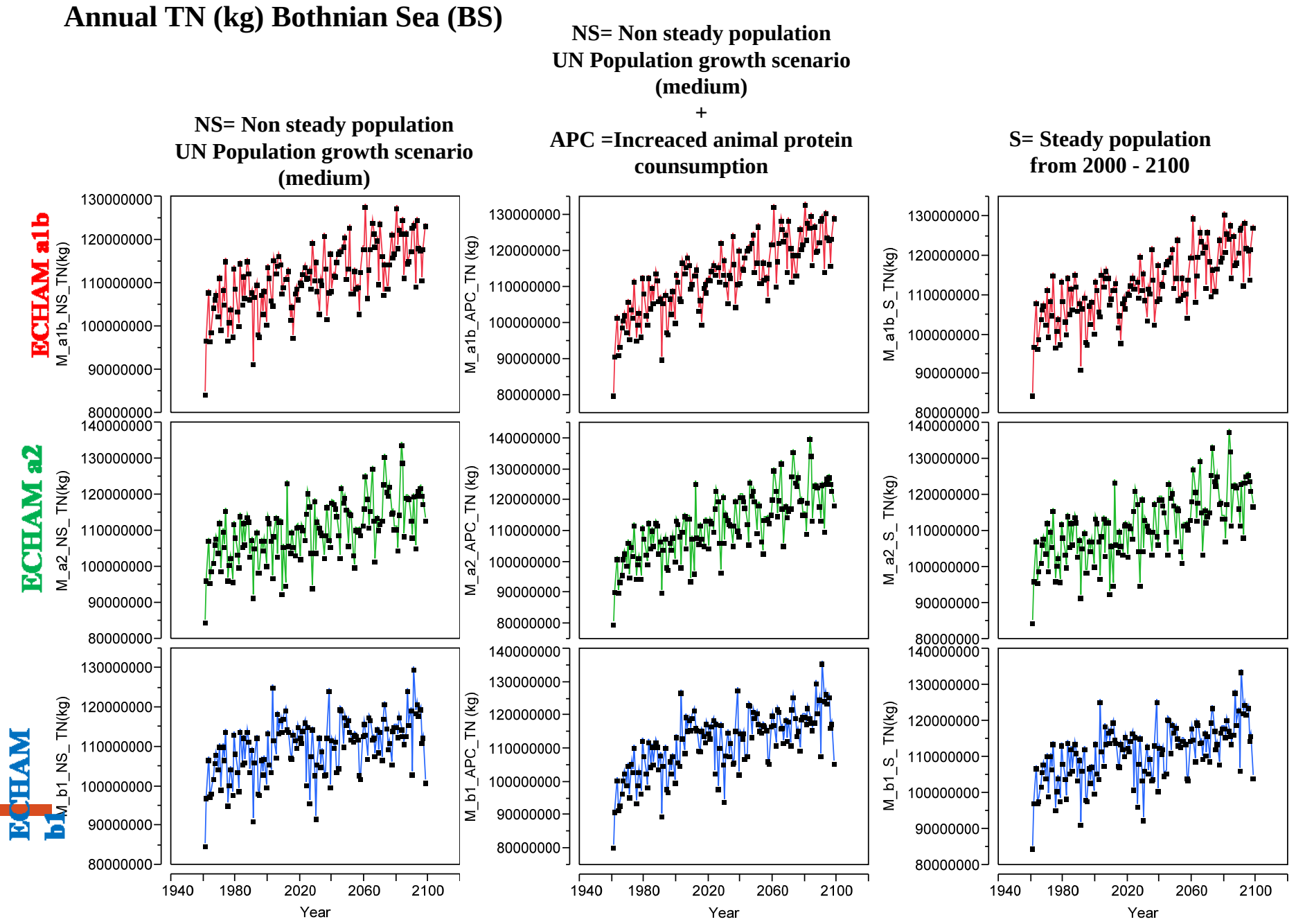
# Annual TN (kg) Bothnian Bay (BB)



# Annual TN (kg) Baltic Proper (BP)



# Annual TN (kg) Bothnian Sea (BS)



# Annual TN (kg) Gulf of Finland (GF)

**NS= Non steady population**
**UN Population growth scenario**

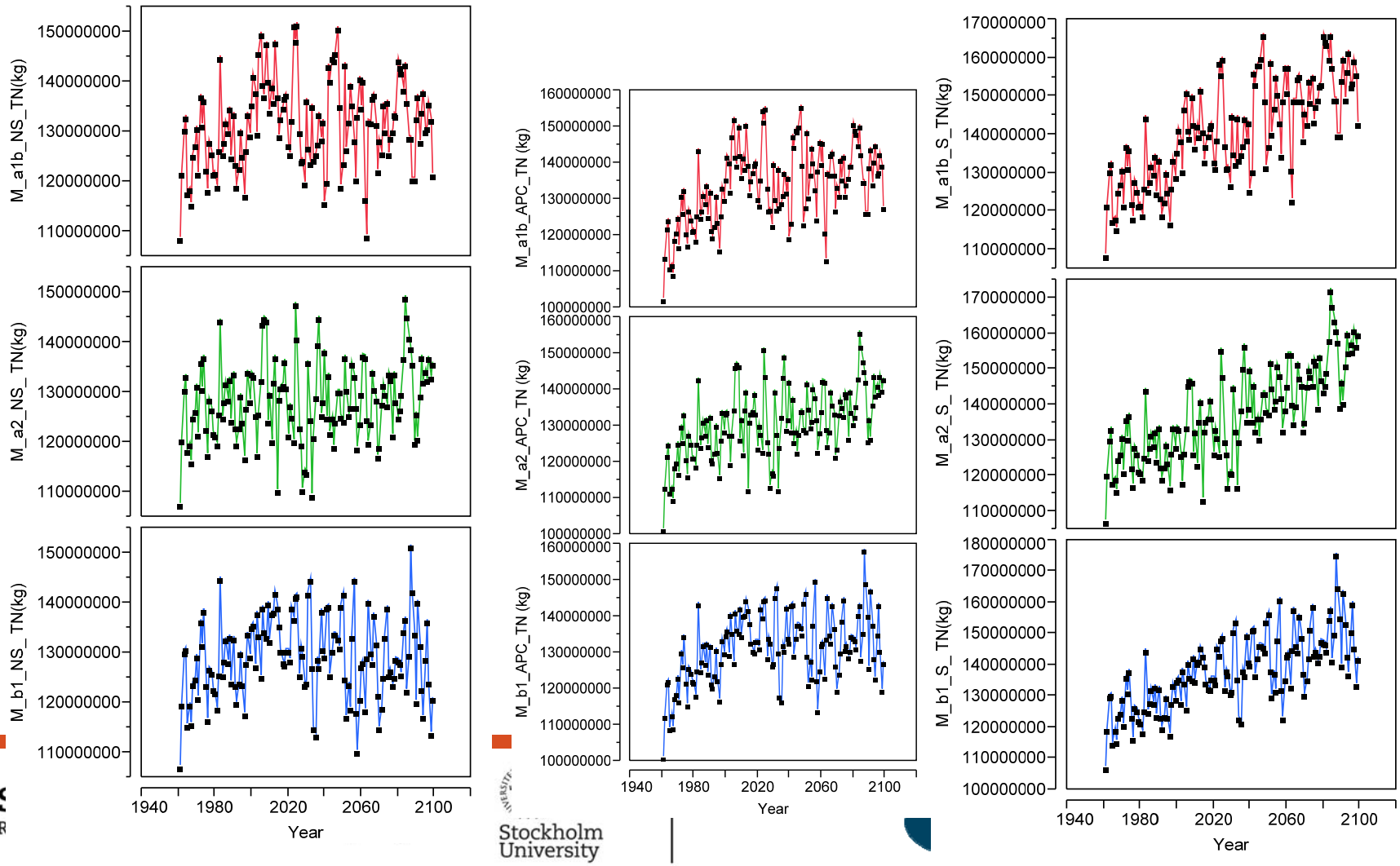
**NS= Non steady population**
**UN Population growth scenario (medium)**
**+**
**APC =Increaced animal protein counsumption**

**S= Steady population from 2000 - 2100**

ECHAM a1b

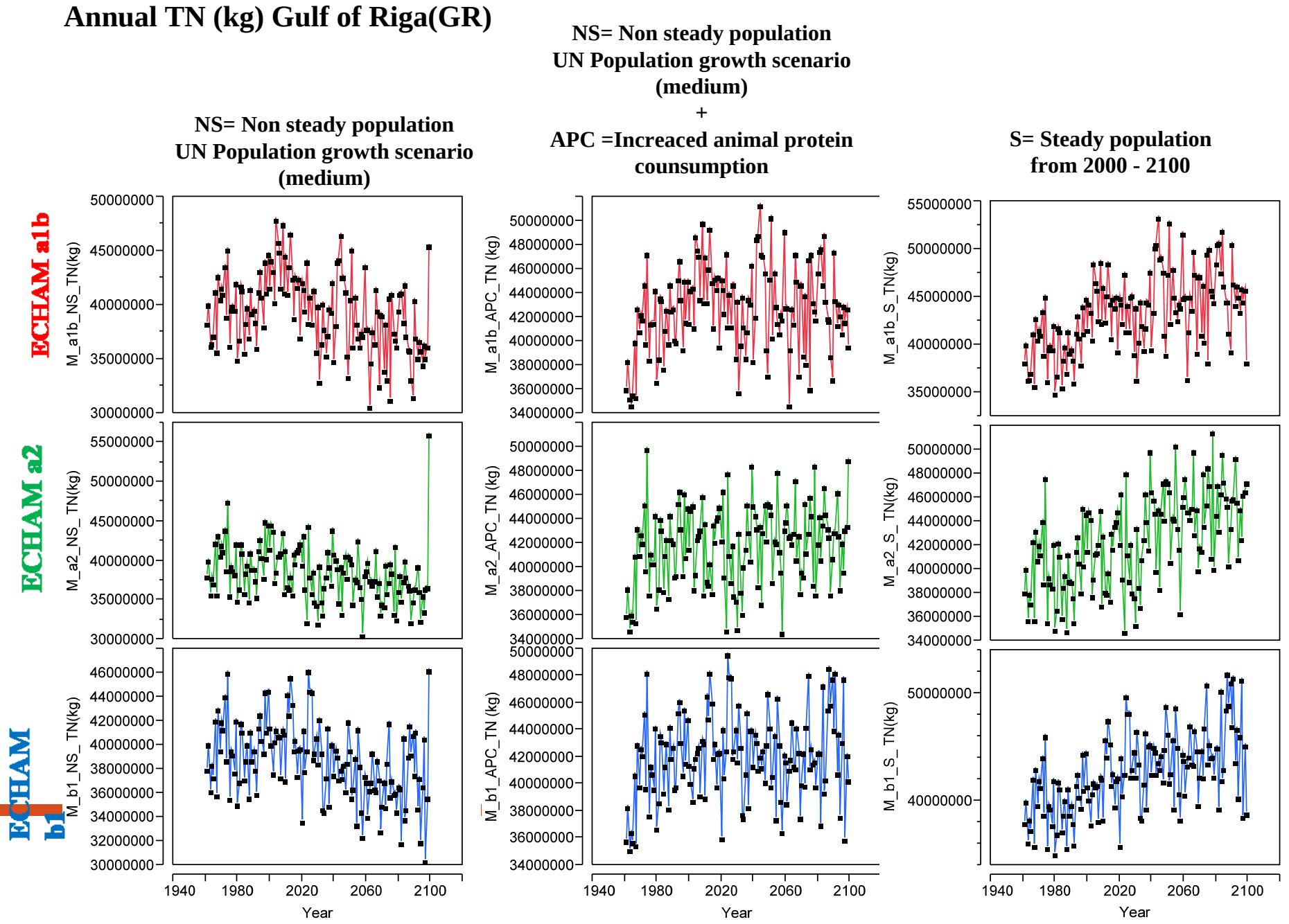
ECHAM a2

ECHAM b1




Stockholm University

# Annual TN (kg) Gulf of Riga(GR)

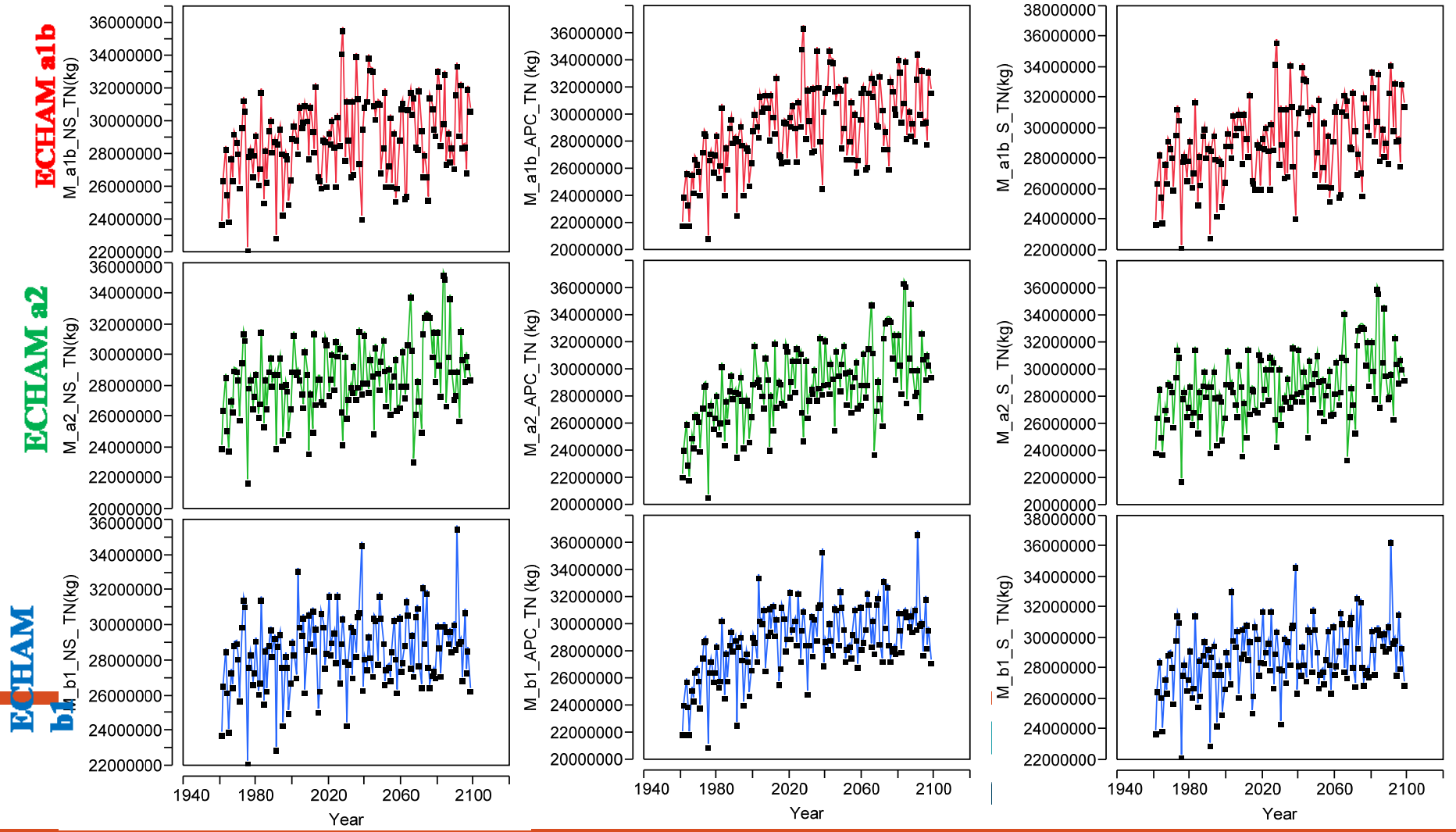


# Annual TN (kg) Kattegatt(KT)

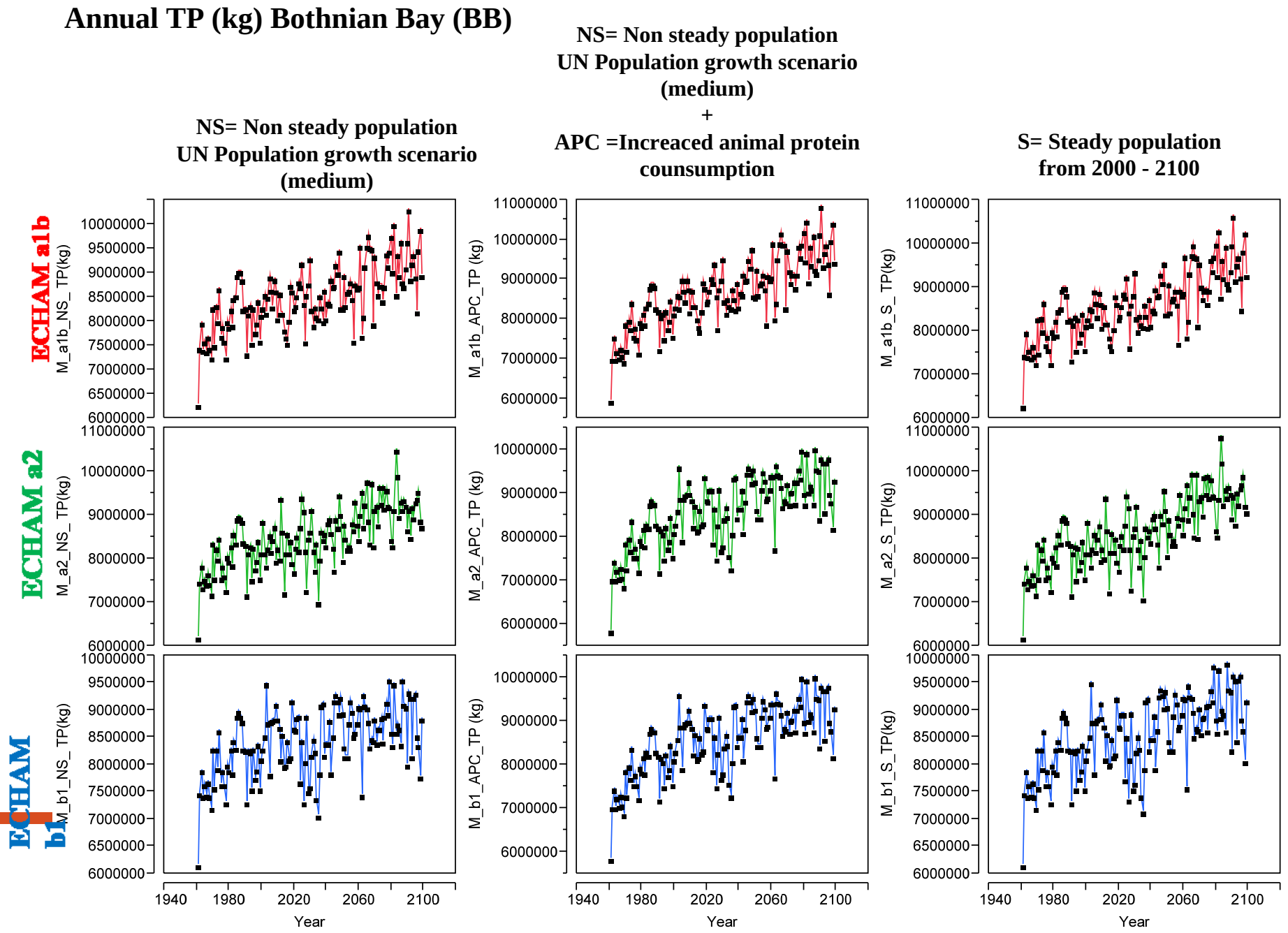
**NS= Non steady population**
**UN Population growth scenario (medium)**

**NS= Non steady population**
**UN Population growth scenario (medium)**
**+**
**APC =Increaced animal protein counsumption**

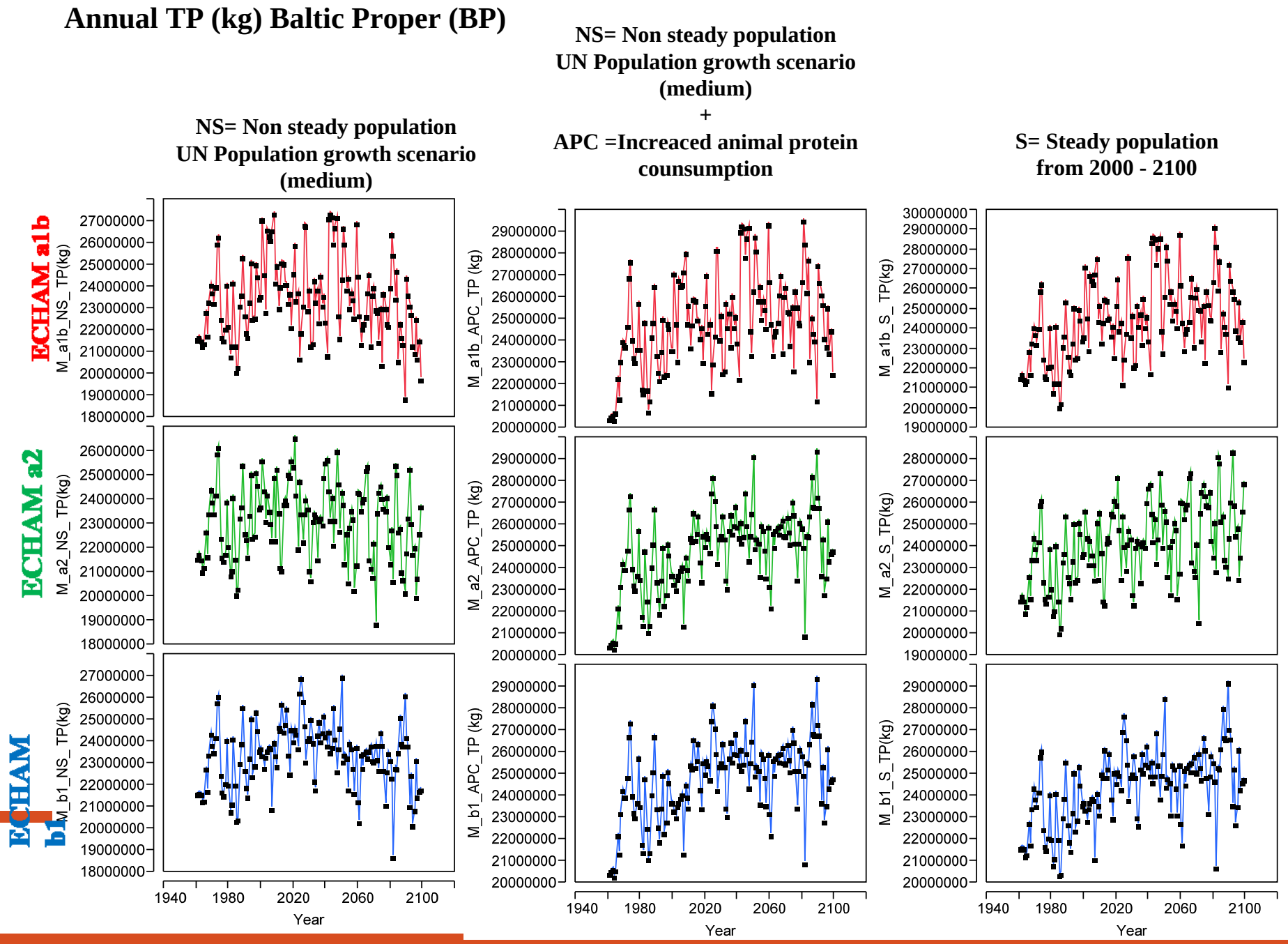
**S= Steady population from 2000 - 2100**



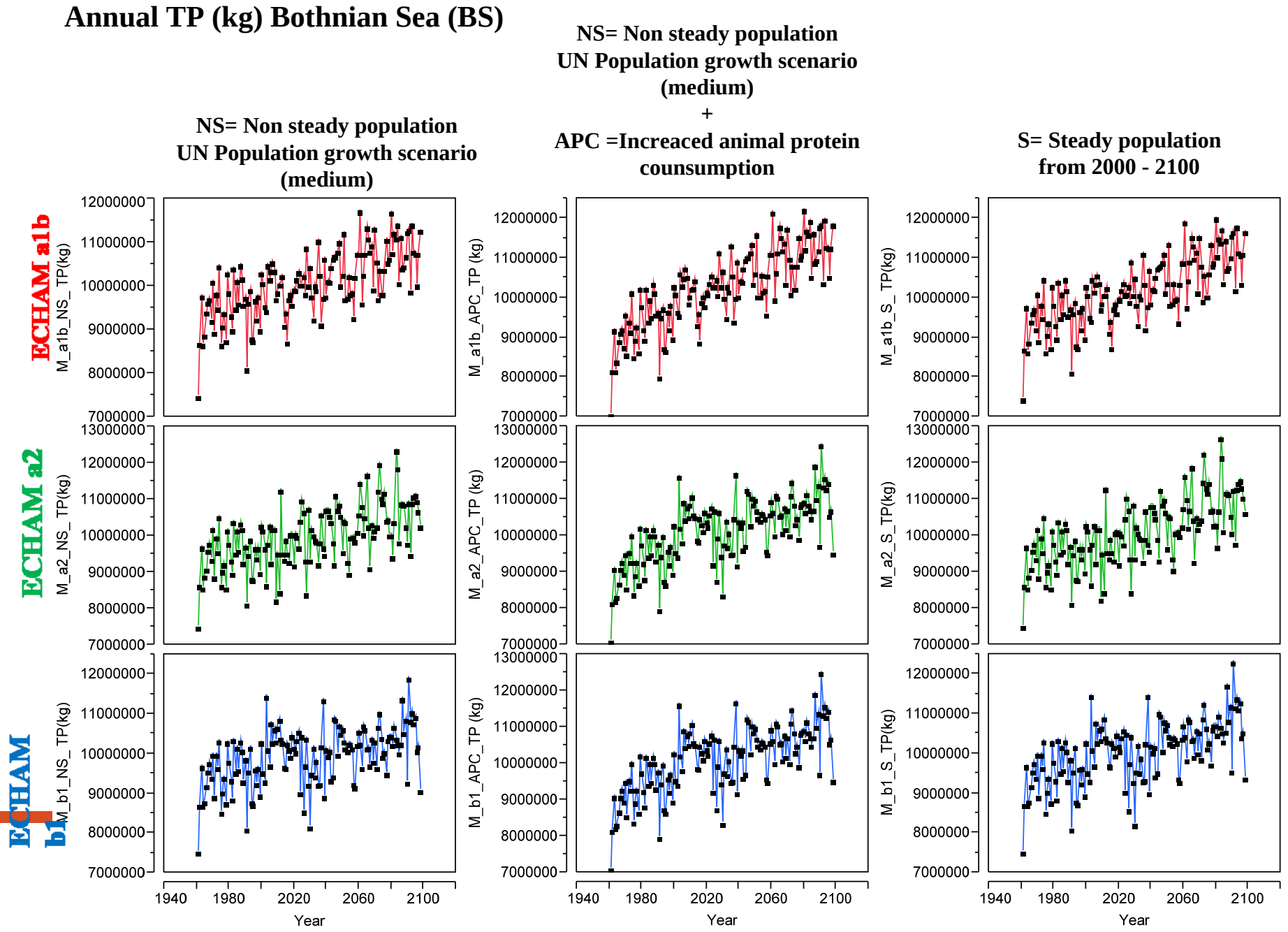
# Annual TP (kg) Bothnian Bay (BB)



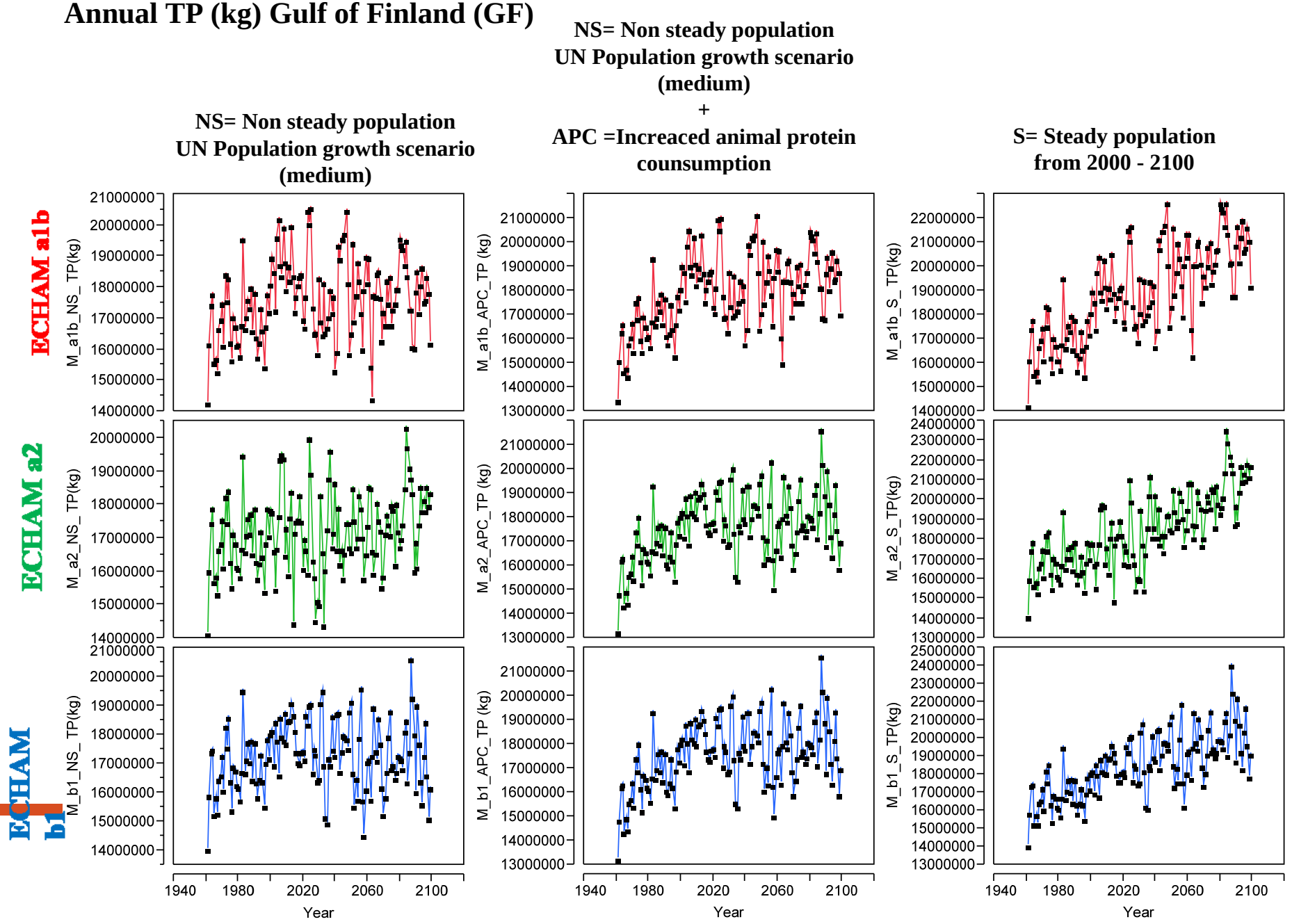
# Annual TP (kg) Baltic Proper (BP)



# Annual TP (kg) Bothnian Sea (BS)



# Annual TP (kg) Gulf of Finland (GF)

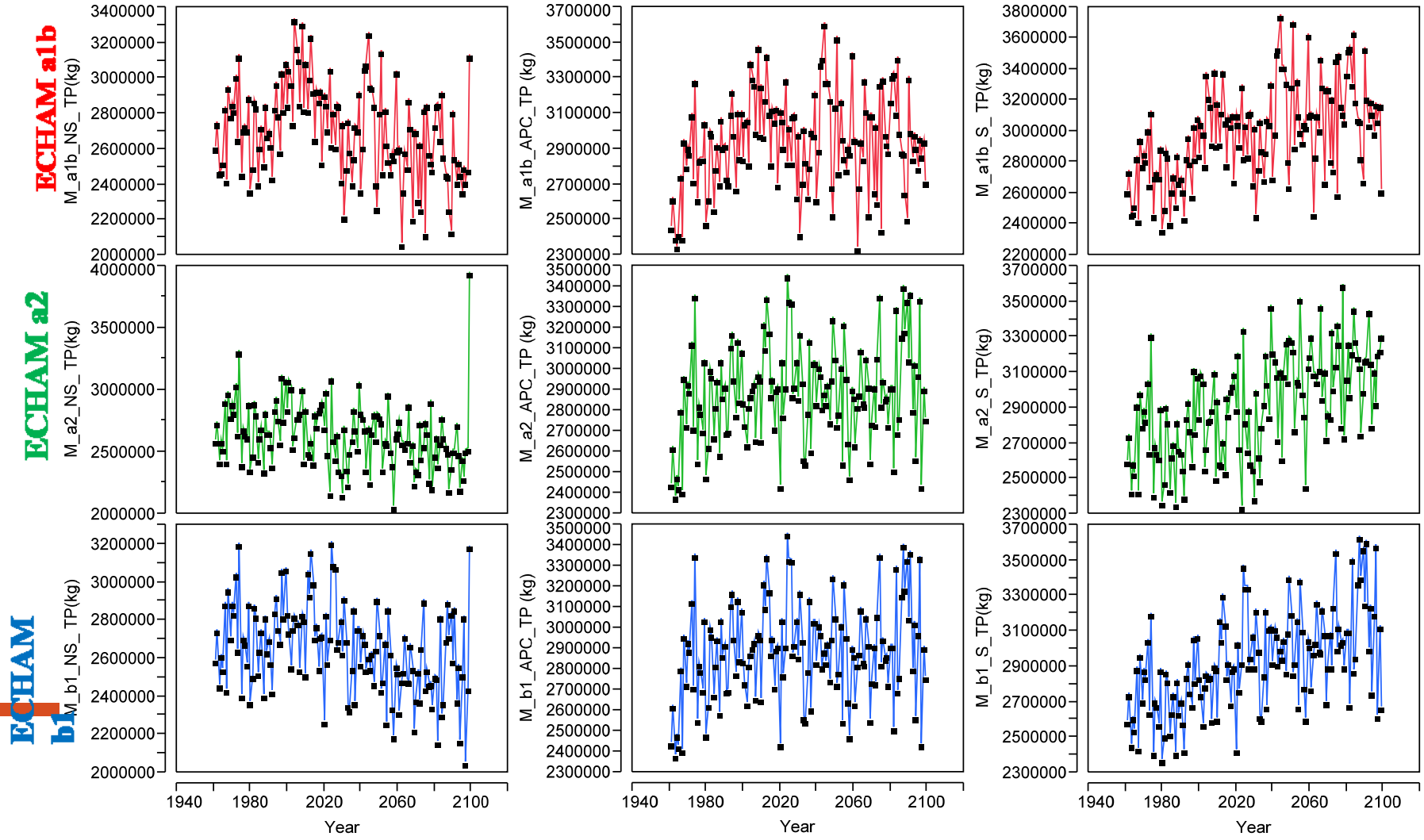


# Annual TP (kg) Gulf of Riga (GR)

**NS= Non steady population**
**UN Population growth scenario (medium)**

**NS= Non steady population**
**UN Population growth scenario (medium)**
**+**
**APC =Increaced animal protein counsumption**

**S= Steady population from 2000 - 2100**



# Annual TP (kg) Kattegatt (KT)

**NS= Non steady population**
**UN Population growth scenario (medium)**

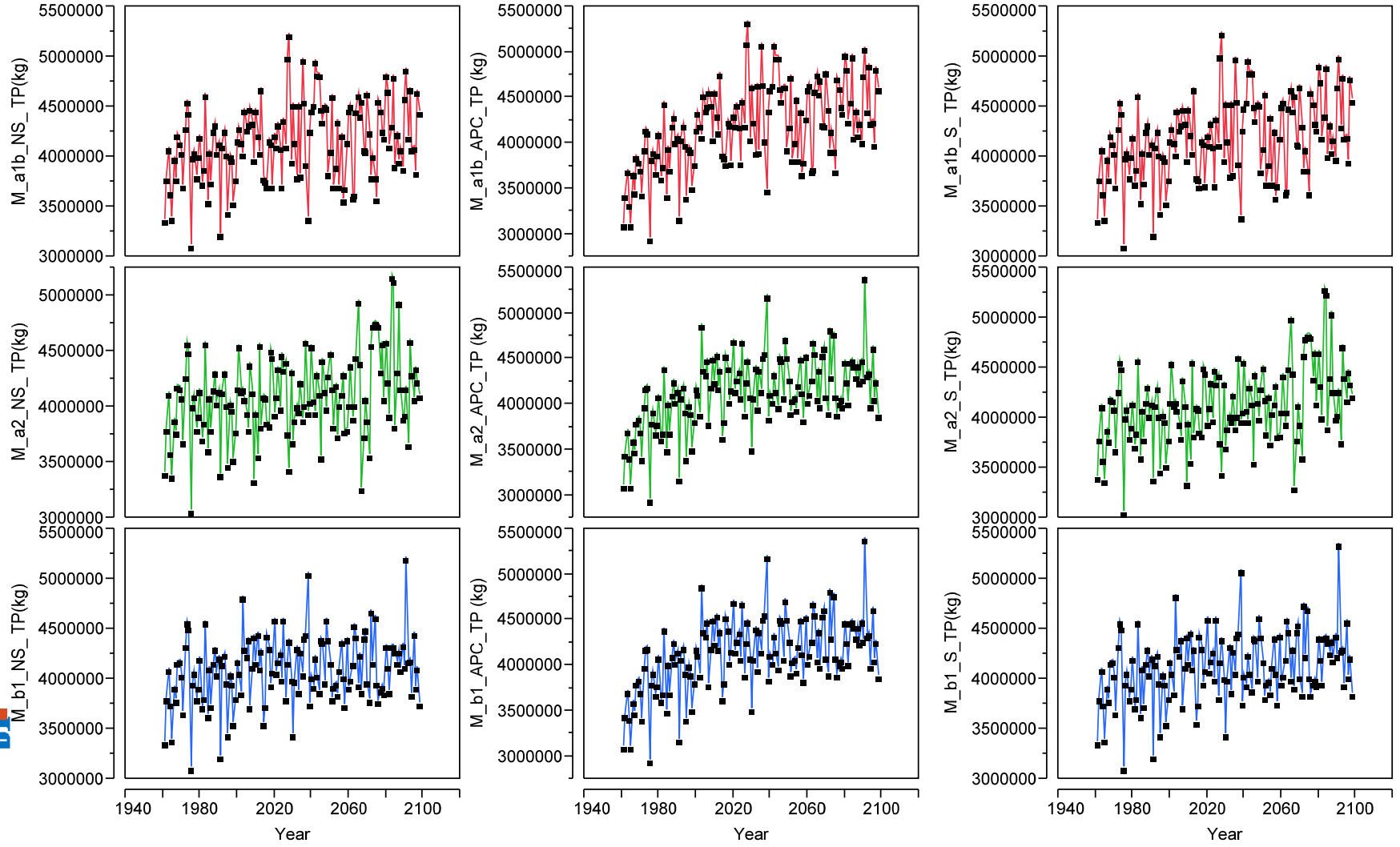
**NS= Non steady population**
**UN Population growth scenario (medium)**
**+**
**APC =Increaced animal protein counsumption**

**S= Steady population from 2000 - 2100**

**ECHAM a1b**

**ECHAM a2**

**ECHAM b1**



# Conclusions

- Lifestyle changes, climate change and EU CAP will increase TN loads to the Baltic Sea
- Baltic Sea Action Plan and Marine Strategy Directive may demand a decrease in fertilizer use > 50% in some countries!
- EU NEC Directive will have only a limited effect potentially visible only in boreal watersheds
- Changes in population, life style (protein consumption) and runoff will  significantly (10-30%) increase nutrient loads