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Scenario Analysis on Protein Consumption and Climate Change Effects on Riverine N Export to the Baltic Sea

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This paper evaluates possible future nitrogen loadings from 105 catchments surrounding the Baltic Sea. Multiple regressions are used to model total nitrogen (TN) flux as a function of specific runoff (Q), atmospheric nitrogen deposition, and primary emissions (PE) from humans and livestock. On average cattle contributed with 63%, humans with 20%, and pigs with 17% of the total nitrogen PE to land. Compared to the reference period (1992−1996) we then evaluated two types of scenarios for year 2070. i) An increased protein consumption scenario that led to 16% to 39% increased mean TN flux (kg per km^{-2}). ii) Four climate scenarios addressing effects of changes in river discharge. These scenarios showed increased mean TN flux from the northern catchments draining into the Gulf of Bothnia (34%) and the Gulfs of Finland and Riga (14%), while the mean TN flux decreased (−27%) for catchments draining to the Baltic Proper. However, the net effect of the scenarios showed a possible increase in TN flux ranging from 3−72%. Overall an increased demand for animal protein will be instrumental for the Baltic Sea ecosystem and may be a major holdback to fulfill the environmental goals of the Baltic Sea Action Plan.

Introduction

Eutrophication of our lakes, rivers, and seas is a continuing process far from steady state (*1*). Following the early modernization and industrialization of our society, eutrophication has accelerated globally during the 20th century and continues to do so. Since we became aware of the issue of eutrophication of the Baltic Sea in the 1950s, measures have been made to reduce the inputs of nutrients to our environment (*2*). Today most rivers in the Baltic Sea region are still moderately eutrophied (*3, 4*) and together with over fishing, eutrophication are regarded as the major threats to the Baltic Sea (*5*).

The Helsinki Commission convened a special Meeting of the Environmental Ministers of the Member States to adopt the Baltic Sea Action Plan (BSAP) on November 14−15, 2007 in Krakow, Poland (*5*). This can be regarded as a milestone for environmental governance in the Baltic Sea region, since environmental targets requiring clear reduction goals have been allocated to the riparian countries. At the Krakow meeting it was decided that allowable annual waterbourne inputs should be 600000 and 21000 tons of nitrogen (N) and phosphorus (P), respectively. This corresponded to a reduction of 135000 tons of N and 15250 tons of P, compared to the loads at the turn of the century. This very ambitious goal for the Baltic Sea should be reached in year 2021 (*5*). According to the BSAP the majority of the N reductions are to be made in Poland (62400 ton N y^{-1}) followed by Sweden (20780 ton N y^{-1}), Denmark (17 200 ton N y^{-1}), and Lithuania (11750 ton N y^{-1}). The major question that appeared is then “how will we achieve these reduction goals?” The BSAP suggests use Best Environmental Practice (BEP) and Best Available Technology (BAT) to reduce point sources. Also agricultural reductions should be achieved by control on animal stocks size, manure, and fertilizers and by issuing environmental permits for farms with livestock production.

However, in the near future eutrophication is likely to increase in the transitional countries in Eastern Europe due to industrialization of the agricultural sector (*6*). Today agriculture can no longer always be seen as a diffuse source of nutrients. Large animal farms can in some cases be regarded as point sources and not diffuse sources.

As previously shown by Smith et al. 2005 (*7, 8*) population density and river runoff can, on a global scale, be seen as robust proxies for the flux of total nitrogen (TN) from a river catchment. In this paper we will further develop this relationship for the Baltic Sea region and include emissions from animals as well.

We have chosen to use primary emissions (PE) as a driver for TN loading in this study rather than more commonly used Net Anthropogenic Nitrogen Input (NANI) (*9, 10*) of the concept of nitrogen surplus (*11, 12*). The NANI approach gives a rather good estimate of the anthropogenic nitrogen inputs within a catchment (*9, 13, 14*). However, when modeling large heterogeneous areas like the entire Baltic Sea catchment the quality and the homogeneity of the input data have to be considered. The NANI method requires detailed and homogeneous input data, i.e. net feed and food import and exports to each catchment with detailed statistics on crops and cattle (*9, 15*). Comparable and consistent data are not available on an international level for the entire Baltic Sea watershed. There are large variations in the amount, detail, and reliability of the input data between western countries and the eastern transitional countries. However data on population and livestock are relatively robust and homogeneous for all countries, and the emission factors for the animals can be calculated based on knowledge of production, which also is available for all areas. Hence, we have chosen to use a regression model based on primary emissions (PE), specific runoff, and atmospheric nitrogen deposition to describe the nitrogen fluxes from the catchments. We will further make an attempt to simulate future N fluxes to the Baltic taking climate change and increasing animal stocks in to account. We tested the hypothesis whether eutrophication is likely to decline in the future or whether the impact of a more modern agriculture in the transitional countries may increase the nitrogen export.

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Material and Methods

The surface of the Baltic Sea is 415000 km^2, the watershed covers a drainage area of 1.6 million km^2, and about 85 million people live within the catchment. The majority of the population lives in the southern part of the basin. The land cover is predominantly boreal forests and wetlands in the north and agricultural land and deciduous forests in the southern part of the basin (*16, 17*). In this study we used a data set containing detailed spatial data for the 105 catchments surrounding the Baltic Sea. These data have been derived from the Baltic Environmental Database (BED; http://nest.su.se/bed.htm). The river fluxes can be accessed through the decision support system NEST (http://nest.su.se/models/river_inputs.htm) (*18*). We used the period 1992−1996 for our calculations, since for that period all necessary and consistent data sets (hydrology, riverine N data, statistics on livestock, crops and populations, atmospheric deposition) were available for all 105 catchments. This period was then used as a representative and stable baseline for our analyses of future changes. To normalize data for the different size of the catchments all data are expressed per km^2 of each catchment. The catchments were divided into subgroups according to which marine basin of the Baltic Sea they drain into. This has been done because of the large differences within the Baltic Sea catchment, with gradients in population density, land use, and hydrology. In this study we have divided the catchments into four groups i.e. Bothnian Bay and Bothnian Sea (BB and BS); Baltic Proper (BP); Gulf of Finland and Gulf of Riga (GF and GR); and Danish Straits and Kattegat (DS and KT). The BB and BS catchments are shared between northern Sweden and Finland with predominately boreal forests, wetland and bare land, high slopes, high specific freshwater discharge and low population and animal densities. The BP group consists of the catchments in southeastern Sweden, Poland, Estonia, Latvia, Lithuania, Denmark, Germany, Belarus, and Russia. Agricultural land, boreal forests, and wetlands dominate in these densely populated catchments with sometimes high animal densities. The specific discharge is low especially in the southeastern catchments. The GF and GR group consists of catchments in Estonia, Finland, Latvia, Lithuania, Belarus, and Russia. These drainage basins are characterized by agricultural land, wetlands, and relatively low slopes and specific discharge. The catchments in western Sweden, northeastern Denmark, and northwestern Germany belong to the DS and KT group with relatively low slopes and high specific discharge (*19*).

Hydrology and Nutrient Concentrations. The nutrient load data in NEST were originally compiled by Stålnacke et al. (1999) (*20*) and based on 110 sampling stations within the Baltic Sea catchment. This data set was updated for the period 1991−2000, using nutrient and water discharge data obtained from various environmental agencies. We have used monthly data to calculate average annual mean TN fluxes (kg N km^{-2} y^{-1}) and annual average specific runoff (Q^*) (m^3 km^{-2} y^{-1}) for the period 1992−1996.

Catchment Area and Land Use. The boundaries for the catchments were derived from the River and Catchment Database for Europe (CCM) EU-JRC, Ispra, Italy. The data on land cover were based on satellite images with a spatial resolution of 0.15 × 0.15 km provided by Metria miljöanalys and EU-JRC, Ispra, Italy. The area of the various land classes were calculated using ARC VIEW 8.1.

Atmospheric Nitrogen Deposition. Data on atmospheric nitrogen deposition for the catchments originates from the UNECE/EMEP emission database (http://www.emep.int) and can be assessed for all catchments from the EMEP module in NEST (*18*). Averages of total nitrogen deposition, i.e. both oxidized and reduced nitrogen in kg N km^{-2} y^{-1}, were calculated as an average of the years 1990, 1995, and 2000 since only data on a 5 year interval were available at the time.

Population Density. The data on population density and distribution are based on LandScan (*21*). The data on the distribution of the population were taken from Hannerz and Deustoni (*16*), who used night light distribution and intensity from satellite images to distribute national census data to individual catchments. Population density was calculated as number of inhabitants per km^2.

Livestock Density. In this paper we have only included cattle and pigs, as they are the most important agricultural animals in terms of PE. The cattle have been divided into "milk cows" and "other cattle", and the pigs have been divided into "slaughter pigs" and "sows". The animal densities for the catchments were based on national census data on animal stocks for the period 1992−1996 (*18*). The animal stock has been distributed over all agricultural land, and an average animal density per catchment has been calculated as heads km^{-2}.

Calculation of Primary Emissions. For calculation of annual primary emissions (PE) of N (kg N km^{-2} y^{-1}) in each catchment we used emission factors for humans and animals ranging from 3.9 to 101.6 (kg y^{-1} head/ind^{-1}) by Mörth et al 2007 (*22*). The primary emissions (PE) were calculated separately for milk cows, other cattle, sows, slaughter pigs, and humans. PE_{cattle} is the sum of $PE_{milk\ cows}$ and $PE_{other\ cattle}$; PE_{pigs} is the sum of PE_{sows} and $PE_{slaughter\ pigs}$. With "total PE" we mean the sum of $PE_{cattle} + PE_{pigs} + PE_{humans}$.

Nitrogen Flux Regression Equations. Total nitrogen (TN) emission (kg N km^{-2} y^{-1}) from a catchment was calculated as a linear regression of specific runoff (Q^*) per unit area (m^3 km^{-2} y^{-1}), atmospheric nitrogen deposition (kg N km^{-2} y^{-1}), and total PE (kg N km^{-2}y^{-1}). All input data were log-normalized, and to make the input variables comparable we also standardized the log-normalized values (i.e., by subtracting the mean and dividing by the standard deviation). The variables were tested for colinearity. Multiple regression analyses were done using SPSS 15 and Minitab 15.

Sensitivity Analysis. Sensitivity analysis has been performed by applying two Monte carlo (MC) simulations (n = 100000) on the regression equations. In the first MC we applied the estimated error (MC_1), and in the second we applied an error of 50% on all variables (MC_2), thereby varying population (±5%, ±50%), cattle (±10% ±50%), pigs (±10% ±50%), atmospheric deposition (±10% ±50%), streamflow (±10% ±50%), and emission data for PE (±25% ±50%). In an additional Monte simulation we randomly selected parameter values from their normal distributions and added random residual values from the distribution of model errors

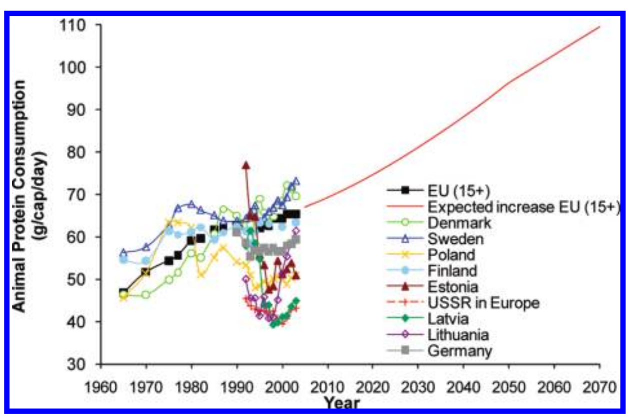

FIGURE 1. Animal protein consumption by humans (g/capita/day) for the countries surrounding the Baltic Sea as well as the EU-15 mean. The scenario line in red (y = 1.19E + 08x − 2.26 × 10^{11}) shows the scenario for increased animal protein consumption in the EU-15 until 2070.

to estimate model related (parameters, residuals) uncertainties (Supporting Information).

Modeling Scenarios. We applied two different types of scenarios to estimate future nitrogen fluxes from the Baltic Sea catchments. For all scenarios we applied both a general equation for the entire Baltic Sea catchment i.e. all 105 river catchments as well as specific equations for the sub-basins, referred to as "all" and "basin".

In the first scenario we estimated the potential increase in PE within the catchments in year 2070. We calculated the PE in 2070 based on an estimated increase in animal stocks that in turn was based on an estimated increase of the human animal protein consumption. To use protein consumption as a proxy for animal stock size appears justified as the number of livestock is highly correlated (r^2=0.8) to human animal protein consumption, as exemplified for Poland for the period 1970−2003 (Supporting Information). The human animal protein consumption can also be expressed as a function of economical growth i.e the higher the GNP the higher the protein consumption that translates to larger animal production or meat import (*23, 24*). However, human population growth was estimated to follow the EU Population projections for 2050 and assumed to remain constant until 2070 (*25*). The average animal protein consumption for Denmark, Sweden, Finland, and Germany in year 2000 was 66 g per capita and day compared to 47 g in Poland, Russia, and the Baltic States (Figure 1). In fact Poland's entry in the EU has led to higher productivity in the agricultural sector due to financial benefits from the Common Agricultural Policy (CAP). Some part of the Polish agricultural land is open for sale to foreigners, but most land is purchased by companies with mainly Polish owners. After accession Poland has become a net importer of agricultural products. This puts additional pressure on the modernization of the domestic agriculture to meet the domestic animal protein demand. Moreover, in the Russian Federation meat production increased with 6.5% in 2008, and the pig population is expected to continually grow aided by governmental support

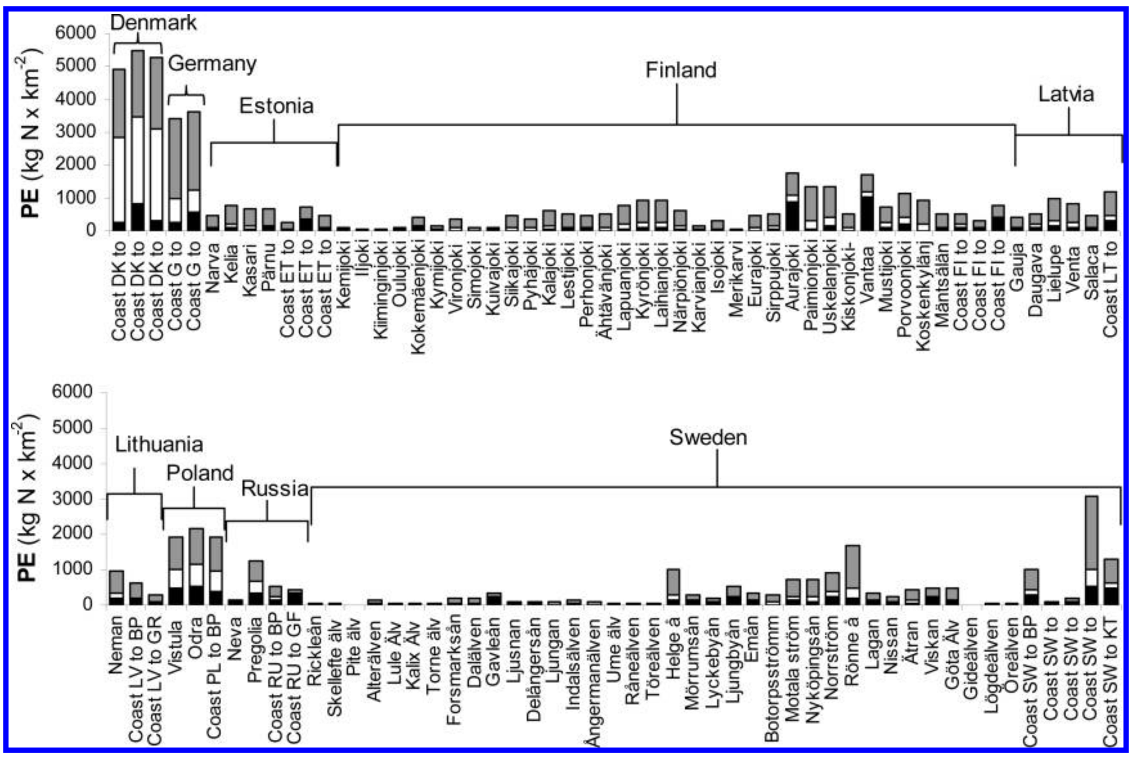

FIGURE 2. The sum of primary emissions (PE) for the 105 catchments surrounding the Baltic Sea in kg N km^{-2} y^{-1}. PE from humans is shown in black, PE from pigs is white, and PE from cattle is gray.

TABLE 1. Equations of TN (kg N km^{-2} y^{-1}) as a Function of Logarithimized and Standardized Specific Discharge, *Q* (m^3 km^{-2} y^{-1}), Atmospheric Nitrogen Deposition, atm. dep. (kg N km^{-2} y^{-1}), and Total Primary Emissions, PE (kg N km^{-2} y^{-1}) for All 105 Catchments and for the Sub-Basins[a]

					P-value			*T*-value		
basin	equation	*N*	RMSE	R-Sq (%)	*Q**	atm. dep.	total PE	*Q**	atm. dep.	total PE
all catchments	TN = 576 + 360 (*Q**) + 78.2 (atm. dep.) + 392 (PE)	105	375	62.1	0.000*	0.209	0.000*	9.1	1.27	6.22
BB and BS	TN = 318 + 91.6 (*Q**) + 100 (atm. dep.) + 145 (PE)	51	125	68.5	0.000*	0.002*	0.000*	3.78	3.31	5.10
BP	TN = 754 + 545 (*Q**) - 10.7 (atm. dep.) + 325 (PE)	23	243	85.5	0.000*	0.870	0.000*	9.51	0.17	5.03
DS and KT	TN = 1095 + 832 (*Q**) + 69 (atm. dep.) + 1113 (PE)	10	531	76.9	0.022*	0.798	0.010*	3.06	0.27	3.73
GF and GR	TN = 759 + 442 (*Q**) + 142 (atm. dep.) + 59 (PE)	21	377	58.9	0.000*	0.189	0.575	4.69	1.37	0.57

[a] The table includes equations, r^2-values (%), RMSE (kg N km^{-2} y^{-1}), *P*-values (* p < 0,05) and *T*-values. *Q* = annual average specific discharge (m^3 km^{-2} y^{-1}), atm. dep. = total nitrogen deposition = oxidized + reduced nitrogen (kg N km^2 y^{-1}), and PE = total annual primary emissions of N for humans, cattle, and pigs (kg N km^{-2} y^{-1}).

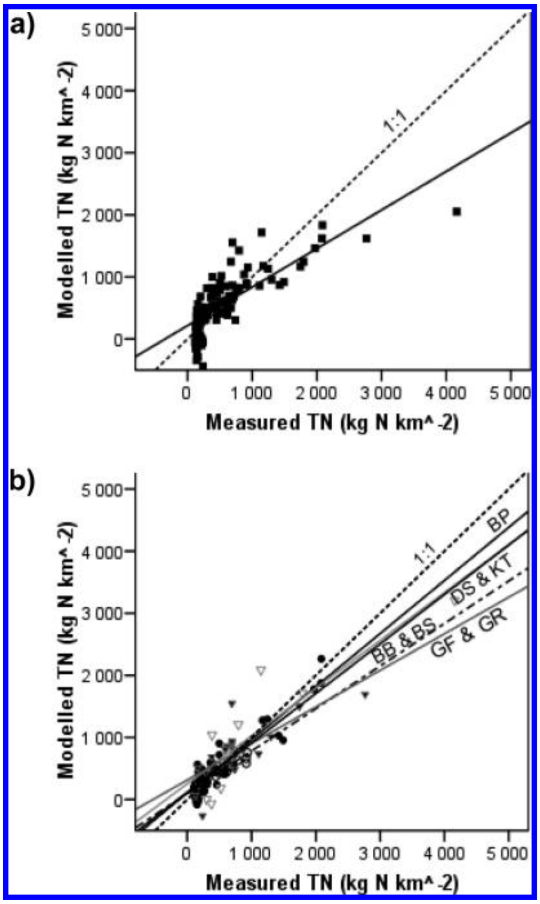

FIGURE 3. a shows the TN results of the general model for all 105 catchments versus the measured TN. The black line shows the linear regression (r^2=0.62), and the dotted line shows the 1:1 relationship. b shows the TN modeled with the four sub-basin models compared to the measured TN.

(*26*). We are aware that the agricultural market and the animal stock size are very dependent on market prices and governmental support and regulations. However, it is still likely that protein consumption in Eastern Europe will increase in coming decades (*27–31*), and we regard this estimate as a rough first order estimate to illustrate a possible development of eutrophication pressure to the entire Baltic Sea. Thus we calculated the regression equation (r^2=0.99) of the annual increase in human animal protein consumption (kg y^{-1}), derived from FAO Feed and Food balance sheets (*32*), for the EU 15 countries (eq 1), using the period 1970−2003 and extended this relationship until 2070. We have further assumed that all countries surrounding the Baltic Sea will have the same animal protein consumption as the EU 15 countries in 2070, which has been estimated to 109 g animal protein per capita and day (see Figure 1); a reasonable estimation compared to the 1999 EU-15 mean of 67 g (*32, 33*). The resulting increases from this scenario range from 49% to 120% depending on the region, with lowest estimated increases in Sweden and Denmark and highest in Poland and Lithuania. In the “PE Scenario 2070” we assumed that this potential increase in animal protein consumption per capita will be met by an equivalent increase of the animal stocks within the country

$$y = 1.19\text{E} + 08x - 2.26\text{E} + 11 \qquad (1)$$

where y = human animal protein consumption (kg y^{-1}), and x = year.

In the second group of scenarios we applied the predicted changes in river discharge from four regional SWECLIM (Swedish Regional Climate Modeling Programme) climate change scenarios, RCAO-H/A2, RCAO-H/B2, RCAO-E/A2, and RCAO-E/B2, described by Graham 2004 and 2007 (*34, 35*) and BACC Author team (2008) (*36*). In short RCAO stands for the Rossby Centre regional Atmosphere-Ocean model (*37*), and **H** = HadAM3H and **E** = ECHAM4/OPYC3 are the global models used (*38, 39*). The two CO_2 emission scenarios are IPCC SRES **A2** (high) and **B2** (modest) (*40*). We used the annual mean percent volume change of river discharge to the marine sub-basins of the Baltic Sea compared to the reference period of 1961−1990 to simulate the scenarios with a 30 year span between 2071−2100 (*34*). Since no estimations on runoff change were available for the sub-basins DS and KT, this group has been excluded in the climate scenario analysis.

Results and Discussion

Total primary emissions (PE) of nitrogen from the 105 catchments surrounding the Baltic Sea ranged from 14 kg N km^{-2} y^{-1} in Pite älv (northern Sweden) to 5480 kg N km^{-2} y^{-1} in Danish coastal areas (Figure 2). On average cattle contributed with 63%, humans with 20%, and pigs with 17% of the total N PE. The relative contribution varies between the catchments depending on how densely populated the watersheds are, i.e. the relative contribution from humans was larger in catchments where big cities are situated. However, it is evident that animal stocks dominated the PE, and thus animal PE were significant drivers for present and

TABLE 2. Mean TN Flux in kg km^{-2} y^{-1} from Each Sub-Basin and Percentage (%) Change Compared to the Measured Mean Loading (kg km^{-2} y^{-1}) of the Sub-Basin[a]

		BB and BS		BP		GF and GR		DS and KT	
		kg km^{-2} y^{-1}	%	kg km^{-2} y^{-1}	%	kg km^{-2} y^{-1}	%	kg km^{-2} y^{-1}	%
measured		318		754		759		1095	
modeled	all	332	+4	757	±0	667	−12	1216	+11
	basin	318	±0	754	±0	897	+18	1095	±0
PE scenario 2070	all	503	+58	958	+27	811	+7	1400	+28
	basin	385	+21	1020	+35	944	+24	1649	+51
RCAO-H/A2	all	407	+28	584	−23	686	−10	n.d.	n.d.
	basin	345	+8	509	−32	916	+21	n.d.	n.d.
RCAO-H/B2	all	415	+30	665	−12	728	−4	n.d.	n.d.
	basin	348	+9	624	−17	958	+26	n.d.	n.d.
RCAO-E/A2	all	580	+82	433	−43	758	±0	n.d.	n.d.
	basin	408	+28	297	−61	987	+30	n.d.	n.d.
RCAO-E/B2	all	526	+65	655	−13	823	+8	n.d.	n.d.
	basin	388	+22	610	−19	1051	+38	n.d.	n.d.

[a] n.d. = no data.

future TN fluxes to the Baltic Sea. The total PE from Denmark and Germany were much higher than the total PE from any of the other countries as a result of high animal densities in these watersheds. Germany and Denmark both have a long history of high animal densities and high meat production, and the question arises if these agricultural patterns will spread to the rest of the Baltic Sea region.

The general equation on TN fluxes for all 105 catchments had an r^2-value of 0.62, and the equations for the sub-basins had r^2-values ranging from 0.69 to 0.86 (Table 1 and Figure 3a,b). Streamflow and total PE had the highest explanatory power to explain the variability in TN flux in most equations except for the BB and BS basin equation where atmospheric N deposition is equally important and for the GF and GR where only streamflow was significant ($p < 0.05$). Monte carlo simulations showed that the error range of estimated current TN fluxes for 25% and 75% quartiles were (MC_1; MC_2) 9.3%; 34% for BP, 2.4%; 8% for BB and BS, 12%; 72% for DS and KT and 10%; 23% for GF and GR compared to the measured mean values 1992−1996 (Table 2, Supporting Information). We tested even for uncertainties and sensitivity of the multiple regression models by quantifying the magnitude of the variability in the N predictions that corresponds to the known errors in the parameter values. The uncertainty and sensitivity of the weighted mean loading is about 620−730 ± 270 kg km^{-2} y^{-1} (detailed information in the Supporting Information). Thus, the equations appear to describe the TN fluxes as rather robust. All the models have regression lines below the 1:1 line, i.e. the model generally underestimates the nitrogen export. This underestimation can be explained by long water residence times in the larger catchments, which this linear regression model does not take into account. It could be suggested that the two rivers with the highest loads (Figure 3) seem to have a strong effect on the equations, but in fact r^2 is almost unchanged if these two values are removed from the regressions. The intercept of the equation ranges from 318 kg N km^{-2} y^{-1} in the BB and BS basin to 1095 kg N km^{-2} y^{-1} in the DS and KT and can be seen as the accumulated nitrogen storage contributing to the nitrogen discharge from the catchments. This is coherent with what could be expected considering the differences in soil types, land use, vegetation, slope, etc., between the southern and the northern catchments. Based on these characteristics we can expect higher nitrogen levels the further south in the Baltic Sea catchment due to historic high nitrogen accumulation in the soils.

The PE scenario caused a +16 to +39% increase of the mean TN flux compared to the measured TN flux from all catchments; using both the "all" catchments model and the four "basin" models (Figure 4a and Table 2). The climate change scenarios (Figure 4b and Table 2) led to a +34% increased mean TN flux to the BB and BS and +14% from the GF and GR, while the mean TN flux decreased with climate change to the "BP". The net scenario, i.e. PE 2070 and climate scenarios combined (Figure 4c) showed increased TN flux compared to measured flux to all sub-basins, BB and BS (+72%), BP (+3%), and GF and GR (+26%). The magnitude of the change differed between the two models ("all" and "basin") but also depending on which climate scenario was applied. In general the percentage change in TN is larger for the A2 scenario than the B2 scenario, which could be expected since this scenario is more severe in temperature increase and thereby also expected change in runoff (*35–37*). The two models usually gave an increase or decrease that were in the same magnitude, but in the case they differ, the result from the "basin" model should be the most reliable because these models were fitted for the catchments within the sub-basins.

Combining the two scenario groups suggests that 1) in the southern parts of the Baltic Sea, an increase of TN flux from the catchments due to increased animal production

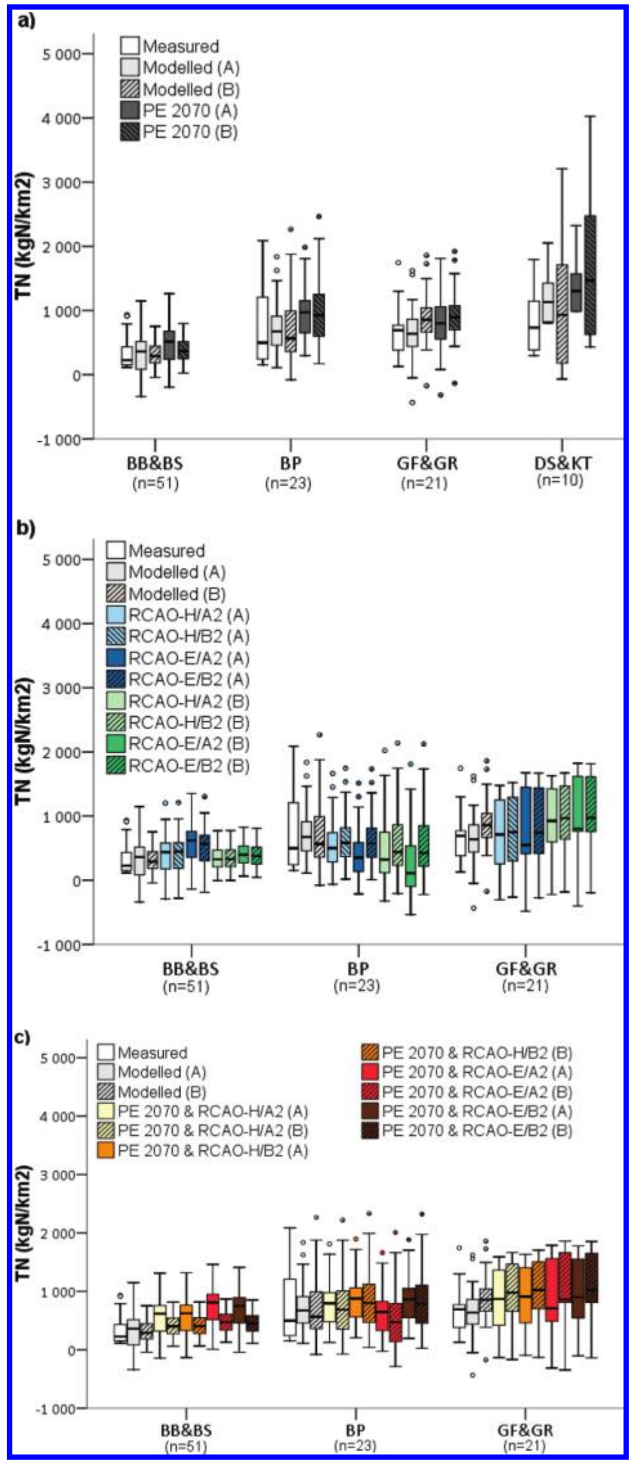

FIGURE 4. a-c: Boxplots with measured (mean 1992−1996), modeled (modeled for 1992−1996), and simulated TN fluxes (kg N km^{-2} y^{-1}) for the four sub-basins, Bothnian Bay and Bothnian Sea (BB and BS), Baltic Proper (BP), Gulf of Finland and Gulf of Riga (GF and GR), and Danish Straits and Kattegat (DS and KT) using the all catchment regression (A) or the basin specific regressions (B), nonarea weighted data. a) Primary emissions scenario "PE 2070". b) The four climate scenarios "RCAO-X/XX". c) The net scenarios with both changed primary emissions (PE 2070) and changed climate (RCAO-X/XX).

could be compensated by a decrease in TN flux due to decreased runoff i.e. climate change. 2) In the BB and BS on the other hand climate change will further strengthen a potential increase of TN loading from the catchments caused by increased human animal protein consumption.

Further, we would like to emphasize that the TN load estimates for 2070 are scenarios not predictions. The scenarios are based on a spatial model that do not take changes in future management strategies or economical feedback mechanisms into account nor give any information on temporal variations or inertia that may differ in the various watersheds.

Nevertheless, the potential development of the agricultural sector in the transitional counties in the eastern part of the Baltic Sea catchment indicates that we may only have seen the beginning of eutrophication of central parts of the Baltic Sea. These parts are the most sensitive due to the strong vertical stratification (halocline) found in these basins. An increased demand of animal protein in the range 20% to 80% will definitively lead to increased animal stocks in the Baltic Sea catchment, though a minor part of the protein demand may be met by import from outside the Baltic Sea catchment. These animals may also be unevenly distributed within the catchments since large animal farms are likely to be established where the current use of agricultural land is low or inefficient i.e. in the transitional countries. The effects from a growing agricultural sector can be dampened by using best available agricultural practices and handling of manure from animals. The eventual increased nitrogen output from agriculture may also be compensated by increased cleaning and higher connectivity in municipal wastewater treatment plants (MWWTP). However, the contribution from MWWTP to the total TN load to the Baltic is estimated to be about 10% (*18, 22*), thus this effect is limited. Today connectivity to MWWTP is relatively low in some eastern European countries (*5*). Although several measures on both point and nonpoint sources are taken to decrease eutrophication of the Baltic Sea, the development of the economies in the eastern part of the basin might lead to increased nitrogen export from these areas. Our scenarios show that it might be difficult to reach the 135000 tonnes N reductions agreed upon in the BSAP if the demand for animal protein continues to grow and is met by domestic animal breeding.

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Supporting Information Available

Background data on animal protein consumption, Monte Carlo simulations, sensitivity analysis, statistics on the protein scenario regression and scenario calculations, and data for the 105 catchments and statistics for the "all" and "basin" regressions. This material is available free of charge via the Internet at http://pubs.acs.org.

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