Managing the Nitrogen Cascade:

Analysis of the International Management of Reactive Nitrogen

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Abstract

Reactive nitrogen (Nr) plays a role in numerous environmental and human health concerns, including climate change, eutrophication, acid rain, respiratory illness and cancer. While produced naturally, increased human creation of Nr, primarily through the creation of nitrogenous fertilizer, is fueling a growing problem in today's world. It is anticipated that by 2050, humans will produce as much as eight times the current level of reactive nitrogen, further exacerbating these environmental and health concerns.

An issue that further complicates Nr management is the nature of Nr in the environment. Reactive nitrogen is capable of cycling through many different forms and compounds (NH_3, NOx, N_2O, etc.) before returning to the more stable state of N_2. This property, labeled the "nitrogen cascade" means that management of Nr pollution must occur simultaneously on multiple pollutants and in multiple media (atmospheric, aquatic, and terrestrial). This also means that an international effort is needed to combat Nr pollution.

To date, international policies have been relatively ineffective in combating Nr pollution, suffering from three main limitations: (1) geographic exclusion of developing countries, where it is anticipated that the greatest growth in Nr pollution will occur, (2) lack of enforceability, and (3) a lack of a multi-pollutant, multi-medium approach that accounts for the nitrogen cascade.

Considering these limitations, this analysis recommends that the international community develop a new global framework convention to combat reactive nitrogen. This convention should use regional bodies as its action units, require the creation of national level nitrogen emissions inventories, develop methods for sharing scientific information and best practices, and establish international targets for the reduction of Nr pollution in to the environment. However, there is a uniqueness to this problem that cannot be understated; Nr is essential for much of the world's food supply, causing this problem to be a very delicate balancing act between meeting growing human needs and mitigating damage to the natural environment.

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List of Abbreviations

BNF – Biological Nitrogen Fixation

CLRTAP – Convention on Long-Range Transboundary Air Pollution

CO_2 – Carbon Dioxide

EU – European Union

GWP – Global Warming Potential

HNO_3 – Nitric Acid

INI – International Nitrogen Initiative

NH_3 – Ammonia

N_2O – Nitrous Oxide

NO – Nitric Oxide

NO_3 – Nitrate

NOx – Nitrogen Oxides

Nr – Reactive Nitrogen

OECD – Organisation for Economic Co-operation and Development

SADC – Southern African Development Community

SIDS – Sudden Infant Death Syndrome

SO_2 – Sulfur Dioxide

UNCBD – United Nations Convention on Biological Diversity

UNCCD – United Nations Convention to Combat Desertification

UNCLOS – United Nations Convention on the Law of the Sea

UNECE – United Nations Economic Commission for Europe

UNEP – United Nations Environment Program

UNFCCC – United Nations Framework Convention on Climate Change

WHO – World Health Organization

Executive Summary

Reactive nitrogen (Nr) pollution is a growing concern in the world today. With potential impacts such as acid rain, climate change, eutrophication, ozone depletion, and myriad human health effects, among others, Nr pollution can have a dramatic effect on the natural environment and those living in it and dependent upon it for their survival. As such, this analysis seeks to address the question of:

"What policies should the international community implement to combat Nr pollution?"

Reactive Nitrogen

Background

The majority of global nitrogen exists in a very stable, inactive, triple bonded form of N_2. This form is entirely unusable by the vast majority of species on Earth. However, when those bonds are broken, Nr is produced, which is the form of nitrogen that makes life possible on Earth. Nr can take many forms throughout its active life, such as ammonia (NH_3), nitrogen oxide (NOx), nitric acid (HNO_3), and nitrate (NO_3) before returning to the elemental state.

This property, known as the "nitrogen cascade", provides considerable challenges for the management of Nr. By virtue of changing through many forms before returning to the common form of nitrogen, the impacts of Nr pollution cannot assuredly be tied back to simply one polluter or pollutant. Instead, the nature of the nitrogen cascade requires that management occur in such a way as to account for these cycling of pollutants and pollutant impacts.

Production of Nr

The production of Nr has both natural and anthropogenic sources. Naturally, Nr is produced via biological nitrogen fixation, as well as through the interaction of lightning with atmospheric N_2. For much of human history, these two methods were the only ways in which nitrogen was made useful to the plants and animals that inhabit the Earth.

There are now three methods through which humans have increased the global production of Nr: (1) fossil fuel combustion, (2) cultivation of N fixing crops, and (3) the Haber-Bausch process of fertilizer creation. The total amount of Nr produced through human action has been estimated to range between 140 Tg N per year to as much as 165 Tg N per year, more than

doubling the natural background rate of Nr production. Of the anthropogenically created Nr, more than 60% is produced in the form of nitrogenous fertilizer, with approximately 25% coming from cultivation and the remaining 15% from fossil fuel combustion.

However, since 1960, anthropogenic nitrogen production has increased dramatically, and it is projected that the rate of increase will continue to expand exponentially over the next fifty years, leading to as much as an eight fold increase in human production of Nr in 2050.

Impacts of Nr Pollution

There are considerable environmental and human health impacts associated with Nr pollution. Reactive nitrogen pollution has been linked to acid rain, climate change, eutrophication, ozone depletion, smog, acidification of soils and waters, and decreases in biodiversity. As Nr pollution increases in the environment, the impact of these various problems increases not only on an individual basis, but also through collective negative effects, such as the greater strain on local biodiversity caused by increased acid rain and acidification.

Human health is also at risk due to Nr pollution. Reactive nitrogen has been linked to health problems in both adults and children. Increased incidences of cancer, respiratory disease, lymphoma, and coronary disease have been found to be correlated with Nr pollution. Additionally, birth defects, spontaneous abortions, blue baby syndrome and even sudden infant death syndrome have also been linked with Nr pollution. There is also a considerable economic impact from Nr pollution, including impacted fisheries, tourist locales and loss of productivity due to illness.

Limitations of the Existing Policy Environment

There are 36 existing international agreements that deal with reactive nitrogen, either directly or indirectly. These agreements can be broken down in to six general categories: (1) global United Nations (UN) agreements, (2) regional seas agreements, (3) Organization for Economic Co-operation and Development (OECD) regional agreements, (4) United Nations Economic Commission for Europe (UNECE) regional agreements, (5) European Union (EU) Environmental Directives, and (6) river basin initiatives. There is considerable range amongst these documents in regards to their level of specificity, effective language, and overall approach to mitigating Nr.

Analysis of these agreements, looking in particular at their structure and effectiveness, found three important limitations. The coverage of developing nations in the existing policy framework is extremely limited. This is of concern because the projections of Nr pollution over the next 50 years show increases in the developing regions of the world ranging from eight to twenty times above existing levels.

Te existing policy environment does not provide a multi-pollutant, multi-media approach that is cognizant of or consistent with the management needs that arise from the nature of the nitrogen cascade. Only the EU has an integrated pollution control agreement, again leaving much of the anticipated increase in Nr pollution unaccounted for. Finally, there are few measures that ensure the enforceability of the existing agreements. This has always been a challenge in any type of international efforts; however environmental accords have consistently fared even more poorly when concerning compliance.

In light of these findings, it is clear that **the existing policy environment regarding the management of Nr pollution is not sufficient to deal with the anticipated increases in Nr production that will occur over the next fifty years**. In light of that, the international community must take steps towards developing some new means of regulating Nr pollution before it reaches a point of overwhelming the capacity of any regulatory structure.

Five Options to Combat Reactive Nitrogen Pollution

Any response to Nr pollution should be designed as a multi-pollutant initiative, aimed at two goals: (1) limiting the anthropogenic production of Nr and (2) preventing Nr from cycling through the nitrogen cascade while in the environment. To achieve those goals, I propose five potential options that can be used by the international community to define an appropriate response to Nr pollution.

1. *Rely on existing and newly created national Nr pollution policies*. Policies should be modeled on the circumstances of the nation to which they apply, thus providing tailored management strategies for each specific situation.
2. *Create Nr management agreements for all international, trans-boundary waterways*. This can provide scientific, social or economic insight in to management problems, but must include effort to account for the impact of agriculture and fertilizer run off.

3. *Establish regional agreements in regions without multi-pollutant Nr regulations*. Regions should be delineated based upon pollution impacts; however reliance on existing regional institutions or geographic regionality could be used instead.
4. *Develop new protocols to existing UN conventions to address Nr pollution.* Protocols could be developed as a means of addressing Nr pollution. These protocols could be designed similarly to the Kyoto Protocol to the UNFCCC, ensuring that there are appropriate restrictions placed on all countries.
5. *Develop a new framework convention designed to deal with Nr pollution.* The objective of such a framework convention should be to stabilize or reduce the emissions of Nr pollution in to the environment while creating a means for nations to exchange information, research, and best practices to improve the effectiveness of the international response to Nr pollution.

Four Criteria for Analysis

Each option was measured against four criteria. An option was successful based on its ability to: (1) maximize the effective global coverage of policy solutions, (2) maximize the potential reduction of Nr pollution, (3) maximize the effectiveness of the Nitrogen Cascade approach, and (4) maximize the cohesiveness of the new policy environment.

Recommendations

Based on the results of my analysis, I recommend that the international community seek to develop a new international framework convention designed to combat Nr pollution. This convention should rely on regional level efforts as its operational unit, modeled loosely on the United Nations Convention to Combat Desertification. Additionally, the new convention should establish international targets for the reduction of Nr pollution, national inventories to measure Nr production and use, and a general recognition of the unique cases involved in Nr production, such as the dependence on nitrogenous fertilizer for food production and the relative lack of adequate substitutes for Nr. While this does not specifically set out how reductions in Nr pollution can be met, there is considerable work currently being undertaken to answer those questions. This analysis is instead meant to provide a guide for how the most effective policy framework can be established so that such solutions are best utilized.

Chapter 1: Introduction

Reactive nitrogen (Nr) pollution is a growing concern in the world today. With potential impacts such as acid rain, climate change, eutrophication, ozone depletion, and myriad human health effects, among others, Nr pollution can have a dramatic effect on the natural environment and those living in it and dependent upon it for their survival.[1] While many of these issues are of grave concern right now, projections estimate that by 2050, global production of Nr pollution may be seven times greater than it is today (an increase from approximately 140 Tg N yr^{-1} to approximately 960 Tg N yr^{-1}).[2]

The majority of global nitrogen exists in a very stable, double bonded form of N_2. Through the creation of fertilizer, via the Haber-Bausch process, and the combustion of fossil fuels, humans are able to break apart that double bond and create radicalized nitrogen, or Nr.[3] Once Nr has been created, it enters what has become known as the "Nitrogen Cascade", whereby a single molecule of Nr may transition through many forms and lead to numerous environmental and health impacts before returning to the inert form of N_2.[4] This "cascade" makes management of Nr pollution a unique challenge, as it is not always possible to determine where Nr pollution originated from.

Additionally, runoff from agricultural fields and emissions from fuel combustion, both stationary and mobile sources, are the leading causes of Nr pollution entering the environment.[5] This further exacerbates the challenge of managing Nr pollution, for it is not readily apparent at which point management should be occurring, or whether it should be occurring on a local, regional or global level. This paper seeks to analyze the existing policy responses to Nr pollution and then produce recommendations on how the international community should proceed in an effort to properly and effectively manage Nr pollution in the global environment.

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[1] Galloway et al 2003
[2] Mellilo 2004
[3] Ramakrishna 2006
[4] Galloway et al 2003
[5] Galloway 2000

Chapter 2: Reactive Nitrogen

Background

Of the elements necessary for survival (nitrogen, carbon, phosphorous, oxygen and sulfur), nitrogen has the greatest abundance not only in Earth's atmosphere but also in the hydrosphere and biosphere.[6] However, with all of this abundance, 99% of all nitrogen is unusable for more than 99% of the organisms on Earth.[7] This lack of availability is do to the chemical make up of nitrogen, which mainly occurs in nature as elemental nitrogen, or N_2, a highly stable, triple bonded molecule that requires a huge amount of energy to break apart, allowing for only a select few specially adapted organisms to fill this role.[8]

Elemental nitrogen is largely unreactive and harmless. However, when the bond is broken, reactive nitrogen (Nr) is formed, which is the form of nitrogen that makes life possible and is the form that is used by all living things on Earth. Once an elemental nitrogen atom is converted to Nr it may transition through many different forms, such as ammonia (NH_3), nitrogen oxide (NOx), nitric acid (HNO_3), and nitrate (NO_3) before returning to the elemental state.[9]

This property, known as the "nitrogen cascade" (see Figure 1), is the essence of why Nr pollution is of growing concern.[10] Without the ability to link nitrogen pollution directly to a single source, the challenge of management becomes much greater, as traditional methods are not well designed to combating a pollutant that can change forms. Moreover, because of this ability to change compounds, Nr may have drastically different residence times in the environment, based upon what form it is currently in and what changes it undergoes, further limiting the ability for effective management.[11]

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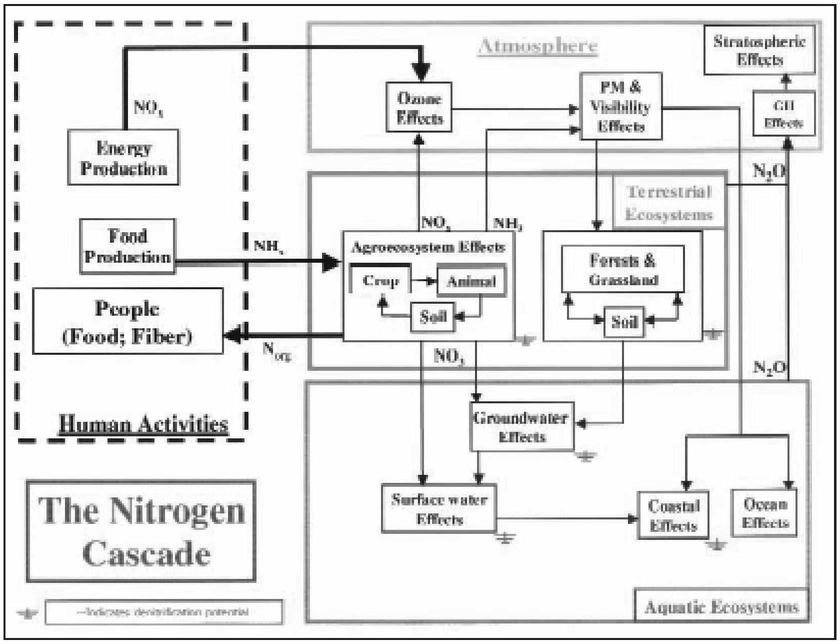
[6] Galloway et al 2003
[7] Mackenzie 1998
[8] Galloway et al 2003
[9] Galloway et al 2003
[10] Galloway et al 2003
[11] Galloway et al 2003

Figure 1: The Nitrogen Cascade[12]



Production

Reactive nitrogen is produced from natural and anthropogenic sources. For much of human history, natural production was the only means of generating accessible nitrogen. From 1860 to 1960, human production of Nr grew modestly, from approximately 15 Tg N per year to approximately 40 Tg N per year, mirroring global population growth.[13] However, since 1960, anthropogenic nitrogen production has increased dramatically, with almost 165 Tg N per year produced in 2000.[14] It is projected that the rate of increase will continue to expand exponentially over the next fifty years, leading to human production of Nr accounting for more than 90% of all Nr produced in 2050.[15] Both natural and anthropogenic production is explored further below.

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[12] Galloway et al 2003
[13] Ramakrishna et al 2006
[14] Ramakrishna et al 2006
[15] Mellilo 2004

Natural Production of Nr

Prior to the mid-19th century, Nr was produced solely through natural means. Two sources were responsible for providing the overwhelming majority of these essential nutrients, biological nitrogen fixation (BNF) and lightning.[16] Biological Nitrogen fixation is considerably more important in terms of overall production of Nr, with BNF in terrestrial ecosystems creating between 90 and 130 Tg N per year and lightning being responsible for the production of approximately 3 to 5 Tg N per year.[17] Of the naturally produced Nr, the vast majority is denitrified back to the unreactive N_2 molecular form.[18] The remainder, approximately 10%, or between 9 and 14 Tg N, remains as Nr and is either emitted to the atmosphere as NOx and NH_3.[19] Do to the limited emissions and general balance between biological nitrogen fixation and denitrification, little redistribution of Nr occurred on a global scale.[20]

Human Production of Nr

There are three methods through which humans have increased the global production of Nr: (1) fossil fuel combustion, (2) cultivation of N fixing crops, and (3) the Haber-Bausch process of fertilizer creation.[21] The total amount of Nr produced through human action has been estimated to range between 140 Tg N per year[22] to as much as 165 Tg N per year, more than doubling the natural background rate of Nr production.[23] Of the anthropogenically created Nr, more than 60% is produced in the form of nitrogenous fertilizer, with approximately 25% coming from cultivation and the remaining 15% from fossil fuel combustion.[24]

[16] Galloway 1998
[17] Galloway 1998
[18] Galloway 1998
[19] Galloway et al 1995
[20] Galloway et al 1995
[21] Galloway et al 2003
[22] Erisman et al 2005
[23] Ramakrishna et al 2006
[24] Erisman et al 2005

Chapter 3: Impacts of Reactive Nitrogen Pollution

Nr can have many significant environmental and health impacts as it makes its way through the nitrogen cycle. The same molecule of Nr may be involved in atmospheric, aquatic and terrestrial impacts and may have local, regional or global impacts.[25]

Environmental Impacts

The most common means of Nr pollution entering the environment is as runoff from agricultural fields. As increased levels of Nr gather in an aquatic ecosystem they may result in such effects as eutrophication, acidification of water, toxic algae growth and higher levels of toxicity from inorganic nitrogenous compounds (see Appendix 1).[26] This can lead to fish kills, impacts on the quality and accessibility of drinking water for human populations, and potentially permanent changes in the overall impacted ecosystem.[27]

Reactive nitrogen pollution may aerosolize, both from terrestrial and aquatic environments, and move into the atmosphere.[28] In addition, direct emissions of Nr pollution to the atmosphere come from both stationary sources, such as power plants and industrial complexes, as well as mobile sources, such as personal vehicles.[29] Once Nr has reached the atmosphere it contribute to stratospheric ozone depletion, climate change, formation of ground level ozone, acid precipitation and smog/increased particulate matter in the atmosphere (see Appendix 1).[30]

After residence in the atmosphere, Nr pollution will return to earth as acidic deposition, most notably in the form of acid rain.[31] Terrestrial ecosystems, particularly those in the north eastern United States and central and northern Europe, have seen profound impacts, including shifts in dominant ecotype and species distribution, which has changed the ecosystem dynamics

[25] Galloway et al 2003
[26] Camargo and Alonso 2006
[27] Ramakrishna 2006
[28] Galloway 2000
[29] Galloway et al 2003
[30] Galloway et al 2003
[31] Galloway et al 2003

of affected areas (see Appendix 1).[32] Leaf loss on trees, due to acid precipitation, has also led to disease outbreaks in some heavily impacted regions, as the trees, without the ability to photosynthesize, are unable to produce the necessary amount of energy to properly defend themselves from infection.[33]

Table 1 has a list of examples of the forms that Nr may take and the environmental impacts that it can have.

Table 1: Impacts of Nr Pollution on the Environment

Form of Nr	Medium	Impact	Scope
NOx	Atmosphere	Acid Precipitation	Regional
NOx, NH_3	Atmosphere	Ground Level Ozone	Regional, Local
NOx, NH_3	Atmosphere	Smog/Particulate Matter	Regional, Local
N_20	Atmosphere	Climate Change	Global
N_20	Atmosphere	Stratospheric Ozone Depletion	Global
NH_3, Nr	Aquatic	Eutrophication	Regional, Local
N_2O, NO, NO_3	Aquatic	Acidification	Regional, Local
NH_3	Terrestrial	Decreased Biodiversity	Local
NO, NO_3	Terrestrial	Acid Deposition	Local

At various points throughout the nitrogen cycle, Nr may be turned into non-reactive N_2, via denitrifying bacteria.[34] Denitrification only takes place in some soils and groundwater, wetlands, poorly ventilated corners of the ocean, and in seafloor sediments.[35] Due to human impacts, particularly the destruction of wetlands, the environments ability to naturally denitrify has become more limited in recent years.[36] In light of that, a larger portion of the Nr pollution in the environment may be re-entering the nitrogen cycle, further exacerbating its impacts.

[32] Galloway et al 2003
[33] DeHayes et al 1999
[34] Galloway et al 2003
[35] Galloway 2000
[36] Wetlands International

Human Impacts

Moreover, there are numerous detrimental effects on human health that can be linked to increased levels of Nr pollution. Health impacts are seen at all stages of human life, from birth to late adulthood. In the stages of life, human ingestion of Nr has been linked to methemoglobinemia ("blue baby" syndrome),[37] sudden infant death syndrome ("SIDS")[38] and may result in a greater likelihood of birth defects[39] or even spontaneous abortions.[40]

Moreover, ingestion of Nr increases the risk of non-Hodgkin's lymphoma,[41] coronary disease,[42] thyroid hypertrophy,[43] and insulin dependent diabetes mellitus[44] in adults. Long term consumption of nitrites and nitrates, even below the maximum contaminant levels recommended by the WHO, have also been linked to increased incidence of various cancers in adults, such as bladder,[45] ovarian[46] and digestive tract cancers.[47] There may also be indirect human health concerns, as increased nutrient loading in major waterways has been linked with outbreaks of the mosquitoes that carry malaria, encephalitis and West Nile virus.

These impacts on human health have a significant economic impact as well. The numerous illnesses that can be attributed to nitrogen pollution result in a considerable amount of lost man hours, let alone the cost of treating such illnesses and increased costs of health care. It is estimated that as much as $2 million is spent on public health costs annually in the US just to treat illnesses deriving from shellfish poisoning linked to nitrogen pollution.[48]

Economic impacts are not limited to human health, but instead include considerable ancillary effects. Losses from fish kills have had a considerable impact on fishery communities. A November 1987 outbreak of the algae *K. brevis* in North Carolina resulted in estimated losses of over $8 million from losses in the commercial harvest of finfish and invertebrates.[49]

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[37] Fwetrell 2004
[38] Klonoff-Cohen et al 2005
[39] Luca et al 1987
[40] CDC 1996
[41] Ward et al 1996
[42] Cerhan et al 2001
[43] Van Maanen et al 1994
[44] Van Maanen et al 1994
[45] Weyer et al 2001
[46] Weyer et al 2001
[47] Manahan 1992
[48] Hoagland et al 2002
[49] Tester et al 1991

Similarly, losses of $18 million were associated with three massive fish kills of farmed Atlantic salmon in Washington, United States in 1987, 1989 and 1990.[50]

In addition to fish kills, aquatic economic damages may include growing costs from clean up and monitoring of polluted sites, costs attributed to upgrading water treatment methods and general public concern over the safety and palatability of drinking water.[51] Even more importantly, losses from reduced tourism and decreases in local aesthetic value may have the largest economic impacts on an area, at least on the local scale.[52]

Costs from reduced usage and reduced visibility due to increased smog levels linked to increased levels of aerosolized Nr, in particular ammonium aerosols, can have massive economic impacts. The Great Smoky Mountains National Park in the United States has experienced increasing numbers of limited visibility days in recent years, as the impacts of growth along the eastern coast of the United States lead to increased levels of locally occurring Nr.[53] Situations such as these, which are continuing to occur throughout the world, will undoubtedly continue to impact the local communities, which are particularly dependent on the revenues generated from tourism to the area.

[50] Hoagland et al 2002
[51] Doka et al 2003
[52] Hoagland et al 2002, Doka et al 2003
[53] Hill 2004

Chapter 4: Scope of the Reactive Nitrogen Pollution Problem

While many of the most noticeable environmental impacts from Nr pollution occur on a local or regional level, there are still considerable global concerns. As has been seen by the science that has come out regarding climate change, local actions can have dramatic global impacts. The role that Nr plays in both climate change and stratospheric ozone depletion mean that the effects of such pollution are not only felt by the polluting nation and its nearest neighbors.

Moreover, the nature of the nitrogen cascade is such that limitations on Nr pollution in some regions of the world will not guarantee that impacts will not be felt in those regions. A single molecule of radicalized nitrogen can take on many different forms of Nr before returning again to its naturally bonded N_2 state.[54] In light of this, Nr pollution in the form of NH_3 as runoff in to a river basin, and eventually to the sea, may result in not only eutrophication of the water ways, but may be transformed in to aerosolized Nr and negatively impact the local atmosphere before transferring to the stratosphere and having global impacts on climate change and ozone depletion.[55] A single molecule of Nr may stay active as a pollutant, transferring between regulated and unregulated forms and even eliminating the ability to trace it back to its origin. Effective control of Nr pollution will only happen through a comprehensive management structure that somehow addresses these unique aspects of Nr's nature.

Finally, there is considerable international trade in Nr or in constituents that may lead to Nr pollution (i.e. fuel oil). According to the US Department of Energy, 29.4 million barrels of oil were exported every day from the top fifteen oil exporting countries in the world.[56] In the same year, almost 41 million tons of fertilizer was exported globally.[57] This doesn't include trade in food products produced from the use of these fertilizers. Clearly Nr is a global concern and must be managed accordingly.

[54] Galloway 2003
[55] Galloway 2003
[56] EIA DOE 2006 (http://www.eia.doe.gov/emeu/cabs/topworldtables1_2.html)
[57] IFIA 2006 (http://www.fertilizer.org/ifa/statistics/pit_public/pit_public_statistics.asp)

Chapter 5: Policy Responses to Reactive Nitrogen Pollution

Current Policy Environment

There have been 36 multilateral agreements, both global and regional, that either indirectly or directly address reactive nitrogen pollution.[58] These agreements range greatly in the level of specificity, effective language, and overall approach to mitigating Nr. The agreements can be broken down into six categories: (1) global United Nations (UN) agreements, (2) regional seas agreements, (3) Organization for Economic Co-operation and Development (OECD) regional agreements, (4) United Nations Economic Commission for Europe (UNECE) regional agreements, (5) European Union (EU) Environmental Directives, and (6) river basin initiatives.

Global UN Agreements

The United Nations has been responsible for the creation of four conventions that have at least an indirect relationship to Nr pollution. Two of these four conventions, the United Nations Convention on Biological Diversity (CBD) and the United Nations Convention on the Law of the Sea (UNCLOS) have only indirect references to Nr pollution, citing the needs to limit the impacts of such pollution on the natural environment without ever specifically mentioning Nr pollution. The CBD calls for minimizing the negative impact of human activities on biodiversity[59] and cites one of its overall objectives as the conservation of biodiversity,[60] an area where Nr pollution is having a negative impact.

The UNCLOS also has multiple references to issues on which Nr pollution has an impact. Article 192 of the UNCLOS establishes that states have an obligation to protect and preserve the marine environment.[61] Along those lines, states are expected to take whatever measures necessary to prevent, limit or control pollution of the marine environment, in particular pollution from land based sources.[62] The UNCLOS also compels states to create national legislation

[58] This information was gathered from the primary literature by the author between May 2005 and August 2005.
[59] UNCBD, Article 14
[60] UNCBD, Article 1
[61] UNCLOS, Article 192
[62] UNCLOS, Article 194

regarding marine pollution from land based activities,[63] from dumping,[64] and pollution of or through the atmosphere.[65] Without specifically citing Nr pollution, the UNCLOS provisions establish a means for regulating some of the major avenues that result in Nr entering the environment at large.

The other two UN conventions, the United Nations Framework Convention on Climate Change (UNFCCC) and the Vienna Convention for the Protection of the Ozone Layer (Vienna Convention) much more specifically cite Nr pollution as a concern, either explicitly identifying some form of Nr or by virtue of describing a general category of pollutants to which Nr belongs. Upon its inception in 1988, the Vienna Convention called for research and exploration of potentially ozone depleting substances, citing in particular NO and NOx.[66] While that research has resulted in findings suggesting that Nr does in fact contribute to ozone depletion, there has not been subsequent action to regulate Nr pollution under the Vienna Convention.

The UNFCCC establishes the need for individual states to stabilize their greenhouse gasses (GHGs) as a means of minimizing the impacts of climate change.[67] To that end, the convention calls for the establishment of national policies and specific commitments that each member state should undertake.[68] However, though Nr, in the form of N_20, is an extremely powerful greenhouse gas, there is no section of the UNFCCC that clearly enumerates the greenhouse gasses that are known to exist.

In 2005, this problem was somewhat resolved by the Kyoto Protocol to the UNFCCC (Kyoto Protocol), which established N_20 as a listed GHG.[69] Moreover, the protocol goes on to define sources of GHGs to include agricultural, industrial, energy production and waste production.[70] With such definitions in place, the protocol requires Annex I countries, as identified in the UNFCCC, to reduce their GHG emissions,[71] and goes on to establish specific targets to be reached by these member states based upon a 1990, or earlier, baseline of

[63] UNCLOS, Article 208
[64] UNCLOS, Article 210
[65] UNCLOS, Article 212
[66] Vienna Convention, Article 4
[67] UNFCCC, Article 2
[68] UNFCCC, Article 4
[69] Kyoto, Annex A
[70] Kyoto, Annex A
[71] Kyoto, Article 3

emissions.[72] As part of these reductions, N_20 is listed specifically as one of six GHGs that are intended to be included in the efforts to lower emissions.[73]

Regional Seas Agreements

In 1974, as a byproduct of the 1972 United Nations Conference on the Human Environment, the United Nations Environment Program (UNEP) launched the Regional Seas program. This program was responsible for establishing 13 regional seas, internationally shared water bodies where environmental management was an important concern.[74] Through the efforts expressed to properly manage these regional seas, the program was designed to have similar goals in each regional sea, but to allow for the tailored development of management programs based upon the unique circumstances in each locale.

As a function of such a design, many of the regional seas programs have developed a tendency to mimic the activities of other regions. To that end, there are conventions of protocols on the prevention of pollution from land based sources in ten of the regional seas and pending agreements in the remaining three.[75] Although each of these agreements is unique, there are consistent themes that are present throughout, in particular a focus on both aquatic and atmospheric forms of pollution.[76]

The specificity of the language in these agreements varies considerably, providing some important distinctions between the actions taken in each region. The majority of agreements rely on statements to the effect of preventing, reducing, or combating/controlling pollution from land based sources.[77] In the other regions, the preceding statement is used as a basis from which to develop more specific and complex requirements, in particular relating to Nr pollution.

The Protocol for the Protection of the Mediterranean Sea against Land Based Pollution makes specific reference to substances that have "an adverse effect on the oxygen content of the

[72] Kyoto, Annex B
[73] Kyoto, Annex B
[74] The 13 regional seas are: the Black Sea, the Wider Caribbean, the East African, the south East Asian, the ROPME Sea Area, the Mediterranean, the North-East Pacific, the North-West Pacific, the Red Sea and Gulf of Aden, the South Asian, the South-East Pacific, the Pacific, and the West and Central African
[75] See Appendix 4 for a further exploration of the existing agreements
[76] Review of the existing literature
[77] West and Central Africa region, South-East Pacific region, Red Sea and Gulf of Aden region, Eastern African region, South Pacific region, Baltic Sea region, Caspian region (not yet ratified)

marine environment, especially those which may cause eutrophication."[78] The ROPME region, made up of the countries surrounding the Persian Gulf, includes specific requirements for the development of regulations concerning human effluent, another source of Nr entry in to the environment.[79] Other agreements focus on reducing the influx of pollution from agricultural, municipal and industrial sources in to the marine environment.[80]

The most specific regulations, in regards to Nr pollution, come from the Black Sea region and the still pending protocol of the Wider Caribbean region. In the Black Sea agreement, nitrogen is specifically cited as a substance that needs to be managed or regulated in its discharges in to the environment.[81] Even more extensive, the Wider Caribbean region agreement, when it is finally ratified, will establish regulations for domestic waste water disposal, in particular effluent limits and the impact of nitrogenous substances released in to the environment.[82] Moreover, this agreement calls for actions to address non-point source pollution from agricultural runoff, the single largest means of Nr pollution entering the environment.[83] Finally, the Wider Caribbean region agreement specifically establishes nitrogen and nitrogenous substances as substances of special concern, for which action must be taken to reduce its emission in to the environment.[84]

OECD Regional Agreements

The OECD is comprised of 30 member states, largely comprised of nations with more developed economies located in the Northern hemisphere.[85] As an institution, the OECD has enacted two relevant agreements designed to mitigate the environmental impacts of Nr pollution: (1) the Control of the Eutrophication of Waters (Eutrophication) in 1974 and (2) the Control of Air Pollution from Fossil Fuel Combustion (Air Pollution) in 1985.

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[78] Mediterranean Sea region
[79] ROPME region
[80] OSPAR region and Caribbean region
[81] Black Sea region
[82] Wider Caribbean region
[83] Wider Caribbean region
[84] Wider Caribbean region
[85] The member states of the OECD are: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, the Slovak Republic, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States.

Due to the structure of the OECD, the organization was only able to put forth recommendations to the national governments who make up its membership to undertake efforts to control the specific types of pollution that each document recommended. For the Eutrophication recommendation, this control was to take place via whatever national level policies each government deemed was appropriate, with whatever actions were taken or planned to be reported back to the OECD within a year from the release of the recommendation.[86]

The Air Pollution recommendation carried much more specific instructions for national governments, specifically stating that nations should attempt to achieve greater control over emissions of NOx among other air pollutants.[87] Further, the recommendations included shifting economies towards more efficient energy usage, stricter control of emissions, and enhanced regional or internationally harmonization of legislation, control systems and emissions reduction efforts.[88]

UNECE Regional Agreements

The UNECE is one of five regional economic commissions set up the United Nations, incorporating 56 nations from the European Union, non- EU Western and Eastern Europe, South-Eastern Europe, the Commonwealth of Independent States (CIS) and North America.[89] As part of its mission to promote greater economic integration and cooperation amongst its member states, the UNECE developed five environmental conventions, two of which have some relevance in regards to the managements of Nr pollution.

As a response to the growing impact of acid rain in Northern Europe and Eastern North America, the UNECE created the Convention on Long-Range Transboundary Air Pollution (CLRTAP). The convention itself simply required nations to "limit, and, as far as possible, gradually reduce and prevent air pollution."[90] However, the two protocols that were later added to the convention, the Protocol to CLRTAP Concerning the Control of Emissions of Nitrogen

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[86] Control of Eutrophication of Waters, OECD
[87] Control of Air Pollution from Fossil Fuel Combustion, OECD
[88] Control of Air Pollution from Fossil Fuel Combustion, OECD
[89] The 56 nations of the UNECE are: Albania, Andorra, Armenia, Austria, Azerbaijan, Belarus, Belgium, Bosnia and Herzegovina, Bulgaria, Canada, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Georgia, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Kazakhstan, Kyrgyzstan, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, Monaco, Montenegro, Netherlands, Norway, Poland, Portugal, Republic of Moldova, Romania, Russian Federation, San Marino, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Tajikistan, The Former Yugoslav Republic of Macedonia, Turkey, Turkmenistan, Ukraine, United Kingdom, United States, and Uzbekistan.
[90] CLRTAP

Oxides or their Transboundary Fluxes (NOx Protocol) and Protocol to CLRTAP to Abate Acidification, Eutrophication and Ground-Level Ozone (Acidification Protocol) gave much more specific guidelines on the control of Nr pollution.

The NOx protocol, upon entering in to force in 1991, specifically instructs countries to reduce their emissions of NOx below the level of emissions from 1987.[91] The protocol goes on to outline means to achieve those reductions and timelines that should be met by member states.[92] In particular, implementation of new national emissions standards, specific technological innovations and the incorporation of unleaded gasoline were major steps recommended to reduce overall national emissions of NOx.[93]

The Acidification Protocol builds on these efforts by attempting to tackle the specific effects of Nr pollution in the UNECE region and area that may be affected by the transmission of NOx and NH_3 pollution via the atmosphere. In specific, the protocol requires member states to reduce their "nutrient nitrogen emissions" by specific amounts based upon historical emissions of NOx and NH_3.[94] These reduction levels are actually established as emissions ceilings for each country, loosely based upon a 1990 baseline, which require anywhere from no reductions to as much as a 60% or greater reduction from 1990 levels by the year 2010.[95]

The second UNECE environmental convention the impacts Nr pollution is the UNECE Water Convention. Specifically interested in preventing or limiting pollution of water bodies, the Water Convention is designed to encourage the harmonization of national level legislation that may impact the environmental quality of internationally shared waterways.[96] Additionally, the convention attempts to enact a polluter pays principle by stating that measures for control, prevention and reduction of water pollution should be taken at the source of that pollution, encouraging efforts at addressing non-point source pollution, an important source of Nr in the environment.[97]

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91 NOx Protocol, Article 2
92 NOx Protocol
93 NOx Protocol
94 Acidification Protocol
95 Acidification Protocol
96 UNECE Water Convention
97 UNECE Water Convention

EU Environmental Directives

The environmental agreements of the EU tend to much more closely reflect national level legislation, making them much more specific than any of the previous regional agreements. While still international in nature, the governing structure of the EU requires all countries to implement directives that are put forth by the European Union Council, unlike the common policy of allowing parties that fall within a region of interest not to ratify an agreement. In light of this, the three EU agreements that relate to Nr pollution have generally been more effective than the efforts of other regional organizations.

In 1991, the EU enacted the Nitrate Directive, a set of rules designed to limit the influx of nitrates in to the environment. Contained within this directive were stipulations to identify specific water bodies that are adversely affected by nitrate pollution as well as the lands that drain in to these water bodies.[98] With these areas of interest identified, the directive goes on to instruct member states to develop action plans to deal with this nitrate pollution, with a particular focus on run-off from agricultural fields.[99] The directive also provides general provisions for inclusion in to any action plans that are formulated[100] and methods to assess the effectiveness of the action plans by measuring nutrient loads in these waters.[101]

This directive was wrapped in to the larger EU Framework Directive on Water Policy (Framework). The Framework details environmental objectives for surface waters, ground water and protected areas,[102] while establishing monitoring requirements for all water types, including those listed above.[103] Specific strategies for combating pollution are also outlined in the Framework,[104] including references to nitrates as one of the major pollutants of concern.[105] However, the most important aspect of the entire Framework is the establishment of a combined approach to combat point and non-point sources of water pollution,[106] again bringing focus to one of the most important venues through which Nr pollution enters the environment.

The combined approach put forth in the Framework is reflective of a concerted effort by the EU to begin tackling pollution in general from an integrated perspective. This concept is

[98] EU Nitrate Directive, Art. 3
[99] EU Nitrate Directive, Art. 5
[100] EU Nitrate Directive, Annex III
[101] EU Nitrate Directive, Annex IV
[102] EU Framework Directive on Water Policy, Art. 4
[103] EU Framework Directive on Water Policy, Art. 8
[104] EU Framework Directive on Water Policy, Art. 16 & 17
[105] EU Framework Directive on Water Policy, Annex VIII
[106] EU Framework Directive on Water Policy, Art. 8

codified in the EU Council Directive Concerning Integrated Pollution Prevention and Control, a directive designed to encourage and establish efforts designed at combating pollution not simply in one medium or form, but as a more comprehensive approach to preventing pollution in multiple forms.[107] The specific goals of this directive are to "reduce emissions in the air, water and land from the abovementioned activities, including measures concerning waste, in order to achieve a high level of protection of the environment taken as a whole."[108] This remains a unique approach to pollution prevention, but one that could play an important role in the proper management of Nr pollution.

River Basin Initiatives

There are 261 international trans-boundary river basins in the world today.[109] While many of these rivers serve merely as a natural resource for the countries through which they flow, there have developed environmental management regimes and initiatives in many of the largest basins, including the Amazon, Danube, La Plata, Nile, Rhine, and Zambezi. While, much like the Regional Seas programs, each of these agreements is unique to its region, there are consistent themes that can be pulled out and assessed. Many of these agreements call for the rational usage of the natural resources of the river basin,[110] including particular citations of protecting the ecological balance of the river[111] as well as the preservation of the natural environment.[112]

The agreements on rivers that run in more developed regions of the world have even more specific requirements. The Convention on the Cooperation for the Protection and Sustainable Use of the Danube establishes a need to prevent the pollution of groundwater with nitrates,[113] as well as calling for the limitation of waste water run off, in particular citing agricultural run off of non-organic nitrogen and mineral fertilizers.[114] Similarly, on the Rhine, the Convention on the Protection of the Rhine establishes targets and goals for the reduction of

[107] EU Council Directive Concerning Integrated Pollution Prevention and Control
[108] EU Council Directive Concerning Integrated Pollution Prevention and Control
[109] Wolf (2002)
[110] Amazon, Mekong, Zambezi
[111] Mekong
[112] Amazon
[113] Danube, Art. 6
[114] Danube, Art. 7

pollutants,[115] specifically citing NH_3 and nitrites as substances to reduce because of their impact on the environment.[116]

The agreement with the largest reach of all is the Protocol on Shared Watercourse Systems in the Southern African Development Community (SADC) Region, covering all international trans-boundary waters in the SADC region. While the specifications of this agreement are much less specific, it does establish river management institutions[117] whose goal is to promote environmental protection measures and prevent all forms of environmental degradation.[118]

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[115] Rhine, Art. 3
[116] Rhine, Annex II
[117] SADC
[118] SADC

Chapter 6: Problem Statement

The existing policy environment regarding the management of Nr pollution is not sufficient to deal with the anticipated increases in Nr production that will occur over the next fifty years. While there are some steps that can be taken to reduce the necessity of Nr in the global society or to increase the effectiveness of denitrification in the natural environment, much of the reduction in Nr pollution must come from improved policy responses to the growing Nr problem. A discussion of the limitations of the existing policy environment follows as a means of highlighting the areas that may be of most importance in future policy developments.

Limitations of Current Policy Environment

While there are an extensive collection of international agreements that somehow seek to regulate Nr pollution, there are considerable limitations to the effectiveness of this patched together network of policies. These limitations can be grouped in to three general categories: (1) geographic coverage, (2) enforceability, and (3) approach.

Geographic Coverage

Looking solely at regional agreements, excluding the six UN global agreements, it becomes clear that there is a considerable disparity in the regulatory environments for Nr pollution based on the region of the world. Other than the Agreement on the Cooperation for the Sustainable Development of the Mekong River Basin, there are no international agreements covering South and South-East Asia, the area of the world expected to be responsible for the majority of Nr pollution in the near future.[119] The Middle East only has two agreements, both of which refer to the ROPME regional sea area. Likewise, in Africa and South America, the areas with the second and third largest projected production of Nr pollution respectively,[120] there are only five agreements each, all of which are either river basin agreements or regional seas protocols.

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[119] Galloway 2003
[120] Galloway 2003

Conversely, seventeen of the thirty regional agreements refer to Australia, Europe and North America. Moreover, these agreements cover the spectrum of potential pollution, from atmospheric to aquatic, enhancing the overall potential for effective management of Nr pollution is these regions. Even when the UNFCCC, Kyoto Protocol and the Vienna Convention are factored in, the only three UN agreements with specific requirements regarding Nr pollution, there are no requirements for countries that are considered to be "developing". Thus the UN agreements also have no real impact on Nr pollution in any of these countries, the vast majority of whom are in the under covered regions.

Enforceability

Even in areas that are covered by agreements, the ability to enforce the required reductions is limited, if not entirely non-existent. Part of this problem is due to a lack of enforceable measures written in to the agreements. Many of these documents have vague statements regarding the role of the nation state in the prevention of pollution, such as many of the Regional Seas agreements which simply call for preventing, reducing, abating or controlling pollution, but provide no real means of how that should be done.[121]

In those cases where there does exist enforceable language, there are few, if any, punitive actions that can be taken when states do not meet their obligations. Under the CLRTAP and its two protocols, there are very specific reduction levels set for each member country. As of 2002 reporting (2000 data), twenty-four of the twenty-eight parties that have ratified the Protocol, reported that they had reached and stabilized N0x emissions at 1987 levels.[122] The remaining four countries have increased emissions of N0x by various levels above their baseline (Spain – 26.6%, Greece – 12.5%, Ireland – 8.8% and the United States – .05%).[123] Although these countries have not met their agreed to reduction levels, there is no recourse for the other countries involved in the CLRTAP to force their compliance.[124]

[121] Regional Seas agreements/assessment
[122] EMEP EEA: Annual European Community CLRTAP emission inventory 1990-2002
[123] EMEP EEA: Annual European Community CLRTAP emission inventory 1990-2002
[124] CLRTAP, NOx Protocol, Acidification Protocol

Approach

Due to the nature of the nitrogen cascade, effective management of Nr pollution must take in to account all forms of Nr. This would be most effectively done under the context of a single agreement, such as the EU directive on integrated pollution control.[125] However, even in areas where there isn't one overarching unifying agreement, a collection of agreements that cover all media or forms of Nr pollution may serve the same purpose.

Unfortunately, the existing policies do not provide this type of coverage on a global level. As stated above, many of the developing countries of the world are involved in only a few policies that regulate Nr pollution. Of the agreements that cover the countries in Africa, South America, South and South-East Asia there are only loose regulations on Nr pollution, stemming largely from Regional Seas agreements and river basin management plans.[126] While many of these nations are party to the larger, global UN environmental conventions, there are no requirements for reduction of Nr placed on these countries by such agreements.

The result of this is that many of the areas of the world that are projected to have the largest outputs of Nr pollution by 2050 do not currently have an effective structure in place to mitigate the Nr pollution that is expected to occur.[127] This could potentially mean that as much as 845 of the 959 Tg N yr^{-1}, or 88% of all the expected Nr produced in 2050 is relatively unregulated, which would swamp the benefits of regulating Nr in other regions of the world.[128]

[125] EU Integrated Pollution Control Directive
[126] River basin and Regional Seas agreements
[127] Mellilo 2004
[128] Mellilo 2004

Chapter 7: Policy Question and Methodology

Policy Question

In light of the growing impact of Nr pollution on a global scale and the lack of existing institutions through which proper management and mitigation can occur, the following question was analyzed:

What policies should the international community implement to combat Nr pollution?

Methodology

For the purposes of this analysis, three primary research approaches were employed:

1. **Policy review** – I reviewed and synthesized of the international agreements, national government policies and academic literature related to Nr pollution.

2. **Interviews –** Informal interviews were conducted with relevant professionals, in particular those that were studying the environmental and human impacts of Nr pollution. These interviews were completed in conjunction with the International Nitrogen Initiative (INI), a group of scientists and policy makers focusing on exploring the issues surrounding Nr pollution.

3. **Best practices –** International environmental policies and agreements that do not directly relate to Nr pollution were assessed for best practices that may be effectively employed in the pursuit of answering the aforementioned research question.

Chapter 8: Options

Due to the nature of the process through which environmental agreements evolve, proposing specific stipulations and language is not truly meaningful. That being said, any framework should be designed as a multi-pollutant initiative, aimed at two goals: (1) limiting the anthropogenic production of Nr and (2) preventing Nr from cycling through the nitrogen cascade while in the environment.

To achieve those goals, I propose five potential options that can be used by the international community to define an appropriate response to Nr pollution.

6. *Rely on existing and newly created national Nr pollution policies*

   Most countries in the world already have some type of pollution legislation in place that lends itself to the management of Nr pollution. In countries of the world where legislation does not exist, development of such legislation should be encouraged to increase the global coverage of such policies. Policies should be modeled on the circumstances of the nation to which they apply, thus providing tailored management strategies for each specific situation.

7. *Create Nr management agreements for all international, trans-boundary waterways*

   Reactive nitrogen management agreements should be created for every international waterway. Building on the success seen in some river basins, management should be based on the sustainable development and use of the water resources of the shared basin. This may include the establishment of a secretariat or some other oversight body, as well as technical advisory committees that can provide scientific, social or economic insight in to management problems. In particular, a successful basing management plan must include some effort to account for the impact of agriculture and agricultural run off in the basin.

8. *Establish regional agreements in regions without multi-pollutant Nr regulations*

These agreements should be similar to the existing regional agreements that the European Union has enacted, as well as agreements such as CLRTAP and the Regional Seas programs. To the extent possible, regions should be based upon pollution impacts, such as seen in the CLRTAP countries. In areas where this isn't feasible, reliance on existing regional institutions (i.e. ASEAN or the EU) or geographic regionality (i.e. the Middle East) should be used to delineate the creation of regions.

9. *Develop new protocols to existing UN conventions to address Nr pollution*

The UNFCCC and Vienna Convention have 189 and 185 ratifying parties respectively.[129] This constitutes nearly every country on the globe, enabling access to almost all potential polluting parties. Under the auspices of these conventions, new protocols could be developed as a means of addressing Nr pollution. These protocols could be designed similarly to the Kyoto Protocol to the UNFCCC, ensuring that there are appropriate restrictions placed on all countries.

10. *Develop a new framework convention designed to deal with Nr pollution*

A new framework convention could be developed to address the current concerns regarding Nr pollution. The objective of such a framework convention should be to stabilize or reduce the emissions of Nr pollution in to the environment at some set level. Moreover, the convention should create a means for nations to exchange information, research, and best practices as a means to improve the effectiveness of the international response to Nr pollution.

[129] UNFCCC, Vienna Convention

Chapter 9: Criteria

As this is an analysis of the conceptual framework from which the international community should approach Nr pollution, certain criteria were not applied. A more complete analysis would consider both cost effectiveness and political feasibility, to the extent practicable. The following four criteria were used to analyze the options presented.

- *Maximize effective global coverage of policy solutions*

  It is imperative that as much of the world as possible is effectively involved in whatever measures are enacted to mitigate Nr pollution. Effectiveness is determined to be the combination of a country's participation in the policy and the likelihood that that country will meet its reduction requirements.

- *Maximize potential reduction of Nr pollution*

  Depending on the particular form of Nr, policy solutions have led to reductions as high as 25% of overall emissions of NOx.[130] Potential reductions must consider both the requirements put forth in the specific regulations and policies as well as the enforceability of such stipulations.

- *Maximize effectiveness of Nitrogen Cascade approach*

  Because of the nature of the nitrogen cycle, attempting to limit Nr pollution through regulating only one pollutant will not be successful.[131] While each option has conceptually been created as advocating a multi-pollutant approach, this criterion addresses the relative likelihood that such an approach would be put in to place.

- *Maximize cohesiveness of new policy environment*

  When attempting to regulate global pollution problems, a consistent policy environment ensures that all parties, such as businesses or private citizens, understand their obligations and can take appropriate action to meet them.

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[130] CLRTAP 2006
[131] Galloway 2003

Each criterion will be assessed on a four point scale: poor, fair, good, or excellent. To properly determine how these values will be applied to each option, Table 1 contains the metrics for each criterion.

Table 2: Ranking Metrics for Each Criterion

Criteria \ Ranking	Poor	Fair	Good	Excellent
Maximize Effective National Involvement	Few targeted countries effectively involved	Some targeted countries effectively involved	Many targeted countries effectively involved	Most or all targeted countries effectively involved
Maximize Reduction of Nr Pollution	Less than 5% potential reduction	5% to 10% potential reduction	10% to 25% potential reduction	Greater than 25% potential reduction
Maximize Effectiveness of Nitrogen Cascade Approach	Addresses only one form of Nr or medium of transmission	Addresses some of the forms of Nr or mediums of transmission	Addresses many of the forms of Nr or mediums of transmission	Addresses most or all forms of Nr and mediums
Maximize Cohesiveness of Policy Environment	Considerable differences in pollution standards and regulations amongst participating countries	Some agreement on pollution standards and regulations amongst participating countries	Considerable agreement on pollution standards and regulations amongst participating countries	Unity or near unity of pollution standards and regulations

Chapter 10: Analysis of Options

Each option was evaluated against the criteria and ranked according to the metrics in Table 2.

I. Rely on existing and newly created national Nr pollution policies

Max. Effective National Involvement	Max. Reduction of Nr Pollution	Max. Effectiveness of Nr Cascade Approach	Max. Cohesiveness of New Policy Environment
Good	Poor	Poor	Poor

1) Maximize effective national involvement: *Good*

   Nearly every country has some form of pollution legislation. This legislation may range from very specific and well developed sets of statutes and enforcement agencies, such as those in the United States and the European Union, to much more basic rules establishing a general anti-pollution concept. Traditionally in countries with industrializing economies, the national government places its focus largely on advancing economic growth before developing extensive pollution regulations. In either case, national level legislation provides much more enforceable statutes, as concerns over national sovereignty are eliminated.

2) Maximize reduction of Nr pollution: *Poor*

   Estimates of future Nr pollution, which take in to account existing national level pollution controls, have shown increases in all regions of the world.[132] However, it is clear that these policies are not sufficient to combat the increases in Nr pollution that come from population growth and industrialization.[133] The creation of new policies may mitigate some of these concerns, though to what extent is unknown.

   Moreover, while enforcement is more likely at the national level, it may not be as robust as would be liked or may be subject to political pressures. In light of that, limited enforcement or selective enforcement of statutes may further hinder pollution reduction.

[132] Mellilo 2004
[133] Mellilo 2004

3) Maximize effectiveness of nitrogen cascade approach: *Poor*

To date, national legislation has been very focused on establishing limitations for very specific pollutants from very specific sources. As an example, the United States has laws for regulating emissions of waste waters in to water bodies,[134] emissions of pollutants in to the air from mobile sources,[135] emissions in to the air from stationary sources,[136] and recommendations for fertilizer application levels,[137] amongst many other relevant regulations. Even though these largely are capable of covering the gamut of forms that Nr may take throughout the nitrogen cascade, these are not interrelated with one another, nor are these free from political interference, leaving little guarantee that the nitrogen cascade will be properly addressed. It can also be reasonably expected that the majority of other national pollution schemes will be less developed than those in the US, thus further limiting the ability or managing based on the nitrogen cascade.

4) Maximize the cohesiveness of the new policy environment: *Poor*

The US Department of State recognizes 193 independent countries in the world today.[138] To expect that there would be any reasonable level of cohesiveness amongst these nations would be a considerable leap of faith. While the UN may be able to provide some scientific guidance, the creation and enforcement of any national level regulations is so context specific that it is tough to ensure that each nations policies reflect those of its neighbors, regionally or globally.

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[134] Clean Water Act
[135] Clean Air Act
[136] Clean Air Act
[137] The USDA provides guidance for farmers and individuals on the recommended level of fertilizer to apply and when to apply it. (www.nrcs.usda.gov)
[138] US State Department 2006

II. Create Nr management agreements for all international, trans-boundary waterways

Max. Effective National Involvement	Max. Reduction of Nr Pollution	Max. Effectiveness of Nr Cascade Approach	Max. Cohesiveness of New Policy Environment
Fair	Good	Fair	Poor

1) Maximize effective national involvement: *Fair*

Nearly every country in the world is connected to another one via an international river basin or waterway.[139] While this provides the opportunity to incorporate many of the world's countries, the trend in river basin management is to devolve responsibility to the local level whenever possible.[140] Assuming that this trend will continue to apply in the near future, even as international agreements are made between nations, the actual impact on pollution reduction will be limited only to those areas of a country that fall within the boundaries of the river basin, limiting the nation wide effectiveness of such a management structure.

2) Maximize reduction of Nr pollution: *Good*

The majority of Nr pollution comes in the form of fertilizer and fertilizer run off in to the natural environment.[141] As such, river basin management is a good tool to get at the largest source of Nr pollution as it enters the environment. While industrial emissions and non-point source pollution from the transport sector remain uncovered, these have a much smaller impact on the overall preponderance of Nr in the environment, accounting for approximately 15%, than Nr related to agriculture.

Unfortunately, there has been little success in trying to mitigate run off from agricultural fields as yet. While river basin management appears to be a very possible solution to this problem, the effectiveness remains to be seen over the long term, particularly as demands on food production increase with increasing population growth.

[139] Wolf 2002
[140] Dinar 2006
[141] Galloway et al 2003

3) Maximize effectiveness of nitrogen cascade approach: *Fair*

Relying on water basin management severely limits the inclusion of the nitrogen cascade in management planning. Water basin management plans are inherently centered on issues surrounding the water resources of the area. As such, the management scheme will only incorporate pollution that directly impacts the waterway. In all likelihood this will result in regulations on agricultural run off, industrial waste water and municipal waste water.[142] While covering the largest single source of Nr pollution, fertilizer run off, this still leaves any form of atmospheric emissions completely uncovered, omitting an important part of the nitrogen cascade.

4) Maximize the cohesiveness of the new policy environment: *Poor*

Again, river basin management lends itself to more autonomy than managing at a higher level. This is an important and necessary facet of such management, as each basin is faced with its own unique circumstances and issues that it must confront. As such, cohesiveness on even a national level may be a little strained, as a country may possess multiple river basins, each requiring its own specific management plans and objectives.

[142] Carmago 2005

III. Establish regional agreements in regions without multi-pollutant Nr regulations

Max. Effective National Involvement	Max. Reduction of Nr Pollution	Max. Effectiveness of Nr Cascade Approach	Max. Cohesiveness of New Policy Environment
Good	Good	Good	Fair

1) Maximize effective national involvement: *Good*

Creating new regional agreements will inherently incorporate more nations, assuming that they agree to be regulated. Relying on agreements to be formed in all regions of the world may not result in complete coverage of necessary zones, as countries will have differing priorities and may choose not to participate in the agreements.[143]

Regional agreements that are currently in force have been some of the more effective approaches to reducing Nr pollution.[144] However, there are also some regional agreements that have had little impact whatsoever on Nr pollution,[145] thus it is important that the design of any regional agreement creates specific, realistic and achievable goals.

2) Maximize reduction of Nr pollution: *Good*

Studies have found that an international or multinational approach to regulating pollution is more effective than regulating on simply a national basis.[146] Reductions in pollution are dependent upon the type of agreement that is agreed to for each region; however, assuming that these agreements resemble those currently in existence, such as CLRTAP, 10 to 30% reduction in emissions could reasonably be expected to occur.[147]

This level of reduction may overstate the potential to reduce of a new agreement, as CLRTAP was developed in an area that was already accustomed to strict pollution limitations, whereas some of these new regional agreements may be developed in regions that are unaccustomed to such regulation.

[143] This can be seen in the differential participation rates between convention bodies and protocols, such as CLRTAP and the NOx and Acidification protocols, where each protocol has fewer parties than the original convention
[144] Gren 2001
[145] Regional Seas agreements
[146] Gren 2001
[147] CLRTAP Secretariat 2006

3) Maximize effectiveness of nitrogen cascade approach: *Good*

Regional agreements have had some success with local run off and non-point pollution and have allowed for more innovative approaches, such as in the EU, which has taken a multi-pollutant, multi-medium approach to regulating nitrogen.[148] Using the EU model as a guide, the nitrogen cascade could be established as the basis of any new regional agreement, thus making it the central aspect of reduction planning.

That said, it will be difficult to ensure that the nitrogen cascade is incorporated in all regions, as each region will be depended upon to develop its own agreements as the countries of that area see fit. The potential variability of regional solutions can be seen in the development of the various Regional Seas agreements, where some regions have very specific reductions to meet and actions to take[149] and others simply have broad general statements about the importance of preventing pollution of the seas.[150]

4) Maximize the cohesiveness of the new policy environment: *Fair*

As stated above, there is no guarantee that each region will develop the same approach to mitigating Nr pollution. Moreover, while the regional agreements may be similar in structure and purpose, nations within a region may attempt to meet their responsibilities through very different national legislation or programs. Without a specific template for each region and nation to follow, it is difficult to ensure that policy responses will be compatible amongst all nations.

[148] European Union 1996
[149] OSPAR
[150] ROPME, East Africa, South Pacific

IV. Develop new protocols to existing UN conventions to address Nr pollution

Max. Effective National Involvement	Max. Reduction of Nr Pollution	Max. Effectiveness of Nr Cascade Approach	Max. Cohesiveness of New Policy Environment
Fair	Good	Poor	Good

1) Maximize effective national involvement: *Fair*

The specific UN conventions for which a relevant protocol could be developed are the UNFCCC and the Vienna Convention.[151] These conventions cover 185 and 189 member states respectively, effectively covering the entire globe.[152] However, while the potential geographic coverage may be considerable, the effective coverage may be much more limited. While a country may be a party to the overarching convention, participation in the subsequent protocols may not be an assured thing, as can be seen by the differences in participation between the UNFCCC and the Kyoto Protocol.[153] Additionally, the Vienna convention only requires parties to take actions "in accordance with the means at their disposal and their capabilities", potentially further limiting the effectiveness of any policy solutions.[154]

2) Maximize reduction of Nr pollution: *Good*

Protocols have been the more effective tool of the convention/protocol approach that much of international environmental law has taken. The Kyoto Protocol takes the general guidelines established by the UNFCCC and sets specific reduction levels and target dates for member countries, where applicable.[155] Likewise, a new protocol could establish specific reduction schedules and consequences of not meeting those schedules. Unfortunately, it is difficult to establish meaningful consequences without infringing on the national sovereignty of the offending nation, making meaningful consequences nearly non-existent.

[151] UNFCCC, UNCBD, Vienna Convention
[152] UNFCCC, UNCBD, Vienna Convention
[153] UNFCCC
[154] Vienna Convention
[155] Kyoto Protocol

3) Maximize effectiveness of nitrogen cascade approach: *Poor*

Protocols cannot change the original intention of the convention from which they are derived. The UNFCCC speaks only of such things that may add to climate change,[156] whereas the Vienna Convention is focused specifically on stratospheric ozone depletion.[157] As such, any convention that could be developed would really only be able to address the forms of Nr that impact these phenomena, which is primarily N_2O in both cases. Only addressing a single pollutant will not satisfy the need to really incorporate the entire cascade in to management decisions.

4) Maximize the cohesiveness of the new policy environment: *Good*

The use of the convention/protocol approach has lead to some consistent environmental policies across country lines. The Kyoto Protocol established specific reporting mechanisms and formats for pollution that impacts climate change, as well as led to the development of new markets for carbon credits, which in their own way have harmonized national law.[158] Similarly, protocols to the CLRTAP have lead to the phasing out of leaded gasoline and the incorporation of catalytic converters on a regional basis across Europe and North America.[159] Again, protocols are limited by the conventions from which they come, thus they may not have quite the same power to unify the policy environment as stipulations in the original convention might.

[156] UNFCCC
[157] Vienna
[158] Kyoto
[159] CLRTAP

V. Develop a new framework convention designed to deal with Nr pollution

Max. Effective National Involvement	Max. Reduction of Nr Pollution	Max. Effectiveness of Nr Cascade Approach	Max. Cohesiveness of New Policy Environment
Fair	Poor	Excellent	Excellent

1) Maximize effective national involvement: *Fair*

A new framework convention can be designed specifically to address whatever concerns may be harbored by the parties involved in the negotiations. However, if the specifics of the convention are too strict, parties may choose not to sign on to it. In light of the challenge of mixing involvement with effective and meaningful policy, it is more important to get as many national governments involved early as is possible, even if this requires less meaningful policies.[160] As is seen by the UNFCCC and Kyoto Protocols, first getting governments to the table can lead to better policy developments in future negotiations, though this is not always guaranteed.[161]

2) Maximize reduction of Nr pollution: *Poor*

As stated above, simply creating a new international agreement is unlikely to have a significant initial impact on Nr pollution. Of the UN's environmental conventions, or conventions with environmental related themes, those that had the least initial requirements were most quickly ratified.[162] Others, which have considerable stipulations, took much longer to come in to force, as in the case of UNCLOS which took 12 years from the first country to ratify, Fiji, until it actually came in to force with the deposit of the articles of ratification of the sixtieth member.[163]

There is an important element of time to the development of such a convention, so drafting a document that is more likely to be ratified quickly is important, as waiting too long on the issue may prove to exacerbate any Nr pollution problems.

[160] Hunter et al 1998
[161] UNFCCC, Kyoto Protocol
[162] UNFCCC, Vienna, UNCBD
[163] UNCLOS

3) Maximize effectiveness of nitrogen cascade approach: *Excellent*

Again, a convention can be designed with any goal in mind, thus allowing for the incorporation of the nitrogen cascade in to the heart of the policy. While it has been previously stated here that there is benefit to having a weak or vague document, developing the premise for which the convention is to be created is of paramount importance, thus putting the nitrogen cascade and the impact of cascading Nr pollution at the heart of the convention.[164]

If, in fact, the document is weak at first, there can still be established the premise that this convention is being created and designed specifically to address the issues surrounding Nr pollution and the impact of the Nr cascade on such pollution.

4) Maximize the cohesiveness of the new policy environment: *Excellent*

Establishing an internationally agreed upon baseline standard for addressing Nr pollution will go a long way towards harmonizing the policy environment that would evolve after the creation of such an agreement. Using international agreements has been viewed as a good means of harmonizing domestic laws,[165] and the need for harmonization has even been specifically stated in the text of some international agreements.[166] While such stipulations may cause problems with maximizing the number of member states, it is important to set some basic level of regulation, even while ensuring that nations are encouraged to participate.

[164] Ramakrishna 2006
[165] Hall 2007
[166] Convention on Protection and the Use of Transboundary Watercourses and International Lakes

Chapter 11: Recommendations

To properly manage Nr on a global scale, I recommend a combination of a new international framework specifically designed to combat Nr pollution and regional agreements as an operational part of this framework (see Table 3). In concept, the convention should be quite similar to the United Nations Convention to Combat Desertification, which creates an international framework but then establishes national, sub-regional and regional action plans as the central method of achieving successful change.[167]

In applying this concept to the management of Nr, the international framework should depend on tools such as national Nr emissions budgets to determine the current extent of Nr pollution,[168] international standards or goals similar to those set in the UNFCCC and Vienna Convention,[169] and a general recognition of the unique cases involved in Nr production, such as the dependence on nitrogenous fertilizer for food production and the relative lack of adequate substitutes for Nr.[170]

Finally, this international framework must be designed in such a way that encourages the largest ratification possible by affected parties while not sacrificing the pressing urge of effectively managing Nr. Ideally, the regional nature of many of the pollution impacts should create pressure from a hesitant nation's neighbors, thus creating a greater impetus to be a part of a global solution and be a good member of the international society.

While this does not specifically set out how reductions in Nr pollution can be met, there is considerable work currently being undertaken to answer those questions. This analysis is instead meant to provide a guide for how the most effective policy framework can be established so that such solutions are best utilized.

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[167] UNCCD 1994
[168] Erisman et al 2005
[169] UNFCCC 1992, Vienna Convention 1988
[170] Ramakrishna 2005

Table 3: Complete Outcomes Matrix

Criteria / Options	Max. Effective National Involvement	Max. Reduction of Nr Pollution	Max. Effectiveness of Nr Cascade Approach	Max. Cohesiveness of New Policy Environment
National Pollution Policies	Good	Poor	Poor	Poor
Management by Trans-Boundary Waterways	Fair	Good	Fair	Poor
New Regional Agreements	Good	Good	Good	Fair
New Protocols to UN Conventions	Fair	Good	Poor	Good
Framework Convention for Nr Pollution	Fair	Poor	Excellent	Excellent

* Shaded areas indicate recommended options

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Appendices

Appendix 1: Environmental Impacts of Reactive Nitrogen Pollution

Though the impacts that derive from Nr pollution are all interrelated and cannot easily be decoupled, for the ease of discussion, the most important of these impacts have been broken down in to groupings based upon the medium in which they occur and are addressed below.

Atmospheric Environmental Impacts

Nr reaches the atmosphere largely from air emissions of NOx, NH_3 and N_20 from terrestrial and aquatic (particularly oceanic) sources.[171] Additionally, NOx is a by-product of the combustion of fossil fuels or biomass, with sources ranging from power production to the internal combustion engines of modern automobiles.[172] A National Research Council study in 2000 found that approximately half of all NOx emissions in the United States were attributable to mobile sources, which include automobiles, buses, and trucks.[173] This same study also found that electric power generation was responsible for an additional 42% of NOx emissions.[174]

Once Nr has reached the atmosphere, it becomes responsible for or contributes to the five following environmental impacts: (1) stratospheric ozone depletion, (2) climate change, (3) formation of ground level ozone, (4) acid precipitation and (5) smog/increased particulate matter in the atmosphere.[175] The long lived nature of atmospheric N_2O (greater than 100 year residence time)[176] results in much more globalized impacts from ozone depletion and climate change. On the other hand, the short atmospheric residence time of both NH_3 and NOx (hours to days)[177] result in much heavier regional impacts for such issues as ground level ozone, acid rain and smog/particulate matter.

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171 Galloway et al 2003
172 Galloway et al 2003
173 NRC 2000
174 NRC 2000
175 Galloway et al 2003
176 Galloway et al 2003
177 Galloway et al 2003

Stratospheric Ozone Depletion

When N_2O enters the stratosphere, it decreases the concentration of stratospheric ozone (0_3).[178] When N_2O reaches the stratosphere, it may be converted to nitric oxide (NO) which serves as a catalyst in the destruction of ozone by chlorine and bromine ions.[179] The impact of increased concentrations of N_2O in the atmosphere and stratosphere results in more frequent interactions between O_3 and NO, further exacerbating stratospheric ozone depletion.

Ground Level Ozone

Ironically, Nr pollution also produces ozone, however it produces ozone at the ground level, which is highly problematic. As NH_3 and NOx enter the lower atmosphere, they lead to the production of ground level ozone.[180] Radicalized nitrogen molecules interact with forms of water vapor to produce HNO_3 and, eventually, ground level ozone.[181]

Climate Change

As a greenhouse gas in the atmosphere, N_2O has a 310 global warming potential (GWP), or a 310 times greater impact per unit weight than carbon dioxide on the processes that are driving climate change.[182] This means that every molecule of N_2O in the atmosphere absorbs and reradiates approximately 310 times as much heat as a molecule of CO_2, which is set at a standard of 1 GWP. Additionally, N_20 is very long lived in the atmosphere, with an average residence time of 120 years.[183] As concentrations of atmospheric N_2O increase, so to will the rate at which climate change is occurring.[184]

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178 Galloway et al 2003
179 Cicerone 1982
180 Galloway et al 2003
181 Crutzen 1979
182 Houghton 1996
183 Houghton 1996
184 Houghton 1996

Acid Precipitation

The release of NOx into the atmosphere results in reactions with water vapor (H_20) that produce nitric acid.[185] This acid then mixes with other water vapor and is returned to Earth in the form of precipitation, either as wet deposition or dry deposition, each of which represents approximately half of the acidic atmospheric deposition back to Earth.[186] Wet deposition refers to acidic rain, fog, or snow and is most common in areas that have traditionally wetter weather.[187] Dry deposition, found largely in arid areas of the globe, occurs when atmospheric acids mix with dust or smoke and return to the Earth's surface in that medium.[188] While these acids can be transported considerable distances, acid rain is largely considered to be a regional concern, with few occurrences in areas of the world that do not produce significant amounts of sulfur dioxide (SO_2) or NOx.[189]

Particulate Matter and Smog

NH_3 and NOx entering the atmosphere lead to regional increases in particulate matter and smog. The main driver of this is the conversion of NOx to HNO_3, which eventually leads to aerosols, such as ammonium nitrate.[190] Likewise, NH_3 becomes aerosolized in the atmosphere, resulting in the creation of ammonium sulfate, amongst other aerosols.[191] The presence of these ammonium aerosols has been linked to increases of fine particulate matter and haze.[192]

Aquatic Environmental Impacts

Nr enters the aquatic environment via two general pathways, natural and anthropogenic. Natural sources of aquatic Nr can come from atmospheric deposition directly in to aquatic systems as well as surface and groundwater runoff.[193] In addition, certain organisms (primarily

[185] Grenfelt and Hultberg 1986
[186] Grenfelt and Hultberg 1986
[187] Grenfelt and Hultberg 1986
[188] Grenfelt and Hultberg 1986
[189] Grenfelt and Hultberg 1986
[190] Galloway et al 2003
[191] Galloway et al 2003
[192] Galloway et al 2003
[193] Camargo and Alonso 2006

prokaryotes) living in aquatic ecosystems are able to fix non-reactive N_2,[194] while other organisms (detritivores) biologically degrade and break down organic material, thereby creating Nr ions.[195]

Anthropogenic sources of Nr include both point and non-point sources.[196] Runoff of nitrogenous fertilizer from agricultural fields accounts for much of the non-point source anthropogenic nitrogen pollution, though; runoff of atmospherically deposited ionized nitrogen from any land mass qualifies as non-point source pollution.[197] Point source pollution ranges from industrial waste water, wastewater from large scale agricultural facilities to the release of treated and untreated human effluent.[198] Depending on the region of the world, the proportion of non-point to point source differs, as does the type of point source pollution that accounts for the majority of nitrogen pollution.[199] Increased levels of Nr in an aquatic ecosystem may result in any of four main environmental impacts: (1) eutrophication, (2) acidification of water, (3) toxic algae growth and (4) higher levels of toxicity from inorganic nitrogenous compounds.[200]

Eutrophication

Much of the world's coastal and estuarine environments are nitrogen limited, meaning that the input of nitrogen in to these systems is the determining factor driving primary production.[201] In freshwater environments, phosphorous is often described as the limiting factor, through nitrogen maintains an important role in net primary production.[202] Under natural circumstances, as nitrogen cycles through these systems a delicate balance is achieved, where primary production serves to fuel the ecosystem, as opposed to disrupting it entirely.

Unfortunately, over the last four decades human activities have dramatically increased N fluxes (mainly in the form of nitrate) into the coastal zone.[203] In the northeastern US, nitrogen inputs have increased by 6 to 8 times, whereas inputs into the Gulf of Mexico have increased by

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[194] Howarth 1988
[195] Wetzel 2001
[196] Camargo and Alonso 2006
[197] Camargo and Alonso 2006
[198] Camargo and Alonso 2006
[199] Camargo and Alonso 2006
[200] Camargo and Alonso 2006
[201] Neilson and Cronin 1981
[202] Elser et al 1990
[203] Vitousek et al 1997

a factor of 4 or 5.[204] Some of the highest increases have been seen in the European rivers that drain in to the North Sea, with increases between 6 and 20 fold.[205] These increases in nitrogen have resulted in increasing numbers of algal blooms, or eutrophication, in both coastal and fresh waters.

As primary productivity increases, the amount of dissolved oxygen in the water is diminished, resulting in hypoxic or anoxic conditions.[206] This in turn leads to extensive fish kills, both of invertebrates and fishes, particularly of benthic species, as organisms are no longer able to glean enough oxygen from the water to survive.[207] One of the more famous incidences of these fish kills can be found in the growing "dead zone" at the mouth of the Mississippi every summer, where, in 1999, an area of 7,728 square miles was anoxic, killing off millions of organisms and having profound impacts on the economies of Louisiana and Mississippi.[208]

Acidification

Nitrogen dioxide (N_20) and NO are considered to be the nitrogenous drivers of aquatic acidification.[209] These two molecules interact with water (H_2O) to produce nitric acid (NO_3^-),[210] which then increases the concentration of H+ ions present in freshwater systems.[211] The effect of increases in these ions is a decrease in pH towards more acidic values. Below a pH range of 5.5 to 6.0 (with 7.0 being perfectly neutral), it appears that damage will occur to more sensitive forms of aquatic biota.[212]

Impacts of increasing acidification range from hatching delays in fish and amphibian eggs,[213] declining species diversity,[214] reductions in net productivity[215] and developmental retardation in fish and amphibian embryos.[216] These issues are particularly presenting themselves in eastern North America and northern and central Europe, where pH values usually

[204] Vitousek et al 1997
[205] Vitousek et al 1997
[206] Rabalais et al 2002
[207] Breitburg 2002
[208] Breitburg 2002
[209] Schindler 1988
[210] Schindler 1988
[211] Irwin 1989
[212] Doka et. al 2003
[213] Morris et al 1989
[214] Huckabee et al 1989
[215] Schindler 1988
[216] Alabaster and Lloyd 1982

range between 4.5 and 5.8,[217] within the range of concern for permanent damage to the more sensitive aquatic organisms in these regions.[218]

Toxic algae

The synthesis of certain toxins by certain types of algae can result in increased toxicity to aquatic and terrestrial animals.[219] These toxins may either remain in the algal cells or be released in to the surrounding waters. As increased nutrient loads lead to greater primary production, the production of such toxins will also increase, increasing the impact of these toxins on the aquatic organisms that either consume the algae as food or simply take up the toxins from drinking water or absorbing water.[220]

Of even greater concern, algal toxins can be bioaccumulated and biomagnified in higher trophic level species as consumption of lower trophic organisms that are exposed to such toxins occurs.[221] As concentrations increase, these toxins begin to impact nervous system functions, liver and hepatopancreas health, and promote tumor growth and cell lysis.[222]

Toxicity from Inorganic Nitrogenous Compounds

The production of ammonia, nitrites and nitrates, created by human activity, can impair the ability of aquatic animals to survive, grow and reproduce.[223] Unionized ammonia is very toxic, particularly to fish, resulting in reduced feeding activity and fecundity.[224] As these activities decline, so to does individual survivorship and overall population size of the species. Nitrites and nitrates have the effect of changing oxygen carrying blood pigments so that they are incapable of transporting oxygen, thereby causing hypoxia and death.[225] Additionally, research suggests that nitrogen based fertilizers are contributing to the decline of amphibian populations near agricultural areas because of decreased body size, fecundity and survivorship.[226]

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[217] Driscoll et al 1998, Skjelkvale et al 2001
[218] Morris et al 1989
[219] Camargo and Alonso 2006
[220] Van Dolah 2000
[221] Van Dolah 2000
[222] Camargo and Alonso 2006
[223] Camargo et al 2005
[224] Camargo et al 2005
[225] Jensen 2003
[226] Birge et al 2000

Terrestrial Environmental Impacts

Terrestrial ecosystems receive the most direct, intentional application of Nr (mainly in the form of nitrogenous fertilizer) of any type of ecosystem.[227] In non-agricultural ecosystems, excess Nr enters the system via dry or wet deposition from the atmosphere, with occasional deposition from flooding or nutrient uptake in areas that border aquatic zones.[228] Terrestrial Nr changes the productivity of ecosystems, and, in so doing, changes the species distribution and richness of ecosystems eventually leading to decreases in biodiversity.[229] Increased levels of Nr also have the potential to change the limiting resources in an ecosystem, which will change the overall ecosystem dynamics, which may in turn lead to changes in dominant ecotype or additional losses in the local or regional biodiversity.[230]

[227] Galloway et al 2003
[228] Galloway et al 2003
[229] Galloway et al 2003
[230] Galloway et al 2003

Appendix 2: Human Impacts of Reactive Nitrogen Pollution

Nitrogen pollution has been shown to have impacts on both the physical and economic health of human society. Ranging from temporary inconveniences to chronic or even fatal diseases, nitrogen pollution has been linked to numerous significant health concerns. Likewise, extensive fish kills or changes in soil pH have resulted in decreased output from agricultural and fisheries based economies throughout the world. Both of these issues are explored in more specific detail below.

Human Health Impacts

Nr has been shown to lead to a number of human health concerns, ranging from asthmatic reactions to air pollution to increased incidence of cardiac disease and cancerous growths.[231] The impacts of such phenomena as climate change and the thinning ozone layer will clearly have implications for human health on a global scale. On more localized scales, human ingestion of Nr has been linked to methemoglobinemia ("blue baby" syndrome),[232] sudden infant death syndrome ("SIDS")[233] and may result in a greater likelihood of birth defects[234] or even spontaneous abortions.[235]

Moreover, ingestion of Nr increases the risk of non-Hodgkin's lymphoma,[236] coronary disease,[237] thyroid hypertrophy,[238] and insulin dependent diabetes mellitus[239] in adults. Long term consumption of nitrites and nitrates, even below the maximum contaminant levels recommended by the WHO, have also been linked to increased incidence of various cancers in adults, such as bladder,[240] ovarian[241] and digestive tract cancers.[242]

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[231] Galloway et al 2003
[232] Fwetrell 2004
[233] Klonoff-Cohen et al 2005
[234] Luca et al 1987
[235] CDC 1996
[236] Ward et al 1996
[237] Cerhan et al 2001
[238] Van Maanen et al 1994
[239] Van Maanen et al 1994
[240] Weyer et al 2001
[241] Weyer et al 2001
[242] Manahan 1992

In addition to direct human physical health impacts from Nr ingestion, increased nutrient loading of major waterways has been associated with outbreaks of cholera[243] and correlated with increased numbers of *Anopheles, Culex* and *Aedes* mosquitoes, species which may be carriers of malaria, encephalitis and West Nile virus.[244] Similarly, increased nutrient loading has lead to toxic blooms of cyanobacteria in drinking water reservoirs, lakes or rivers have resulted in such health effects as rashes, vomiting, pneumonia and other related minor illnesses.[245]

Human Economic Impacts

The numerous illnesses that can be attributed to nitrogen pollution result in a considerable amount of lost man hours, let alone the cost of treating such illnesses and increased costs of health care. It is estimated that as much as $2 million is spent on public health costs annually in the US just to treat illnesses deriving from shellfish poisoning linked to nitrogen pollution.[246] These numbers relate to only one facet of the potential costs that could be incurred from nitrogen pollution, allowing for the reasonable expectation that the annual costs on a global basis could be considerably higher than the aforementioned.

Moreover, losses from fish kills have had considerable effects on fishery communities. A November 1987 outbreak of the algae *K. brevis* in North Carolina resulted in estimated losses of over $8 million from losses in the commercial harvest of finfish and invertebrates.[247] Similarly, losses of $18 million were associated with three massive fish kills of farmed Atlantic salmon in Washington, United States in 1987, 1989 and 1990.[248]

In addition to fish kills, aquatic economic damages may include growing costs from clean up and monitoring of polluted sites, costs attributed to upgrading water treatment methods and general public concern over the safety and palatability of drinking water.[249] Even more importantly, losses from reduced tourism and decreases in local aesthetic value may have the largest economic impacts on an area, at least on the local scale.[250]

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[243] Townsend et al 2003
[244] Camargo and Alonso 2006
[245] Hitzfield et al 2000
[246] Hoagland et al 2002
[247] Tester et al 1991
[248] Hoagland et al 2002
[249] Doka et al 2003
[250] Hoagland et al 2002, Doka et al 2003

Costs from reduced usage and reduced visibility due to increased smog levels linked to increased levels of aerosolized Nr, in particular ammonium aerosols, can have massive economic impacts. The Great Smoky Mountains National Park in the United States has experienced increasing numbers of limited visibility days in recent years, as the impacts of growth along the eastern coast of the United States lead to increased levels of locally occurring Nr.[251] Situations such as these, which are continuing to occur throughout the world, will undoubtedly continue to impact the local communities, which are particularly dependent on the revenues generated from tourism to the area.

What may be of the largest economic concern is the runoff of nitrogenous fertilizer from agricultural lands. It is already estimated that fertilizer is used in excessive amounts, in some areas resulting in almost double the necessary amount being placed on agricultural fields.[252] Uptake of the beneficial nutrients from this type of fertilizer spreading is limited, resulting in massive runoff into aquatic ecosystems and considerable loss of investment for the agriculturalists that originally spread the fertilizer on the field.[253] Establishing appropriate suggestions and regulations for the use of fertilizers can have a three fold impact: (1) lowering the cost of inputs to farmers, (2) increasing the relative productivity of agricultural fields, and (3) greatly reducing the amount of Nr that runs off in to aquatic ecosystems and thereby enters the nitrogen cascade.

[251] Hill 2004
[252] Carpenter et al 1998
[253] Carpenter et al 1998

Appendix 3: United Nations Agreements

Convention	Entry into force	Signatories/Parties	Geographic Coverage	Media Covered	Provisions/Statutory Language	Oversight Body
United Nations Convention on the Law of the Sea	16-Nov-94	150 Parties	Global	Aquatic		UNCLOS Secretariat
Vienna Convention for the Protection of the Ozone Layer	22-Sep-88	185 Parties	Global	Atmospheric	**Annex I, 4, (b) -** this annex calls for research and systematic observations on certain potentially harmful compounds, making reference in this section to nitrogen substances ([i] Nitrous Oxide and [ii] Nitrogen Oxides)	Ozone Secretariat
United Nations Framework Convention on Climate Change	21-Mar-94	189 Parties	Global	Atmospheric	**Art. 2 -** states objective of stabilizing GHG's to minimize climate change, **Art. 4 -** outlines commitments for each party to the convention, including establishment of national policies to mitigate climate change as well as the use of the precautionary principle in all future considerations in regards to climate change	UNFCCC Secretariat
Kyoto Protocol to the UNFCCC	15-Feb-05	150 Parties	Global	Atmospheric	**Art. 3 -** requires Annex I countries to achieve reductions in GHG's, **Annex A -** defines nitrous oxide as a GHG, as well as defining sources of GHG's to include agricultural, industrial, energy, and waste, **Annex B -** establishes percentage reductions for parties to the protocol	UNFCCC Secretariat
United Nations Convention on Biological Diversity	29-Dec-93	189 Parties	Global	Aquatic/Terrestrial		CBD Secretariat

Appendix 4: Regional Seas Agreements

Convention	Entry into force	Signatories/Parties	Geographic Coverage	Media Covered	Provisions/Statutory Language	Oversight Body
Protocol for the Protection of the Mediterranean Sea Against Pollution from Land Based Sources	12-Feb-78	Albania, Algeria, Bosnia and Herzegovina, Croatia, Cyprus, Egypt, the European Community, France, Greece, Israel, Italy, Lebanon, Libya, Malta, Monaco, Morocco, Serbia and Montenegro, Slovenia, Spain, Syria, Tunisia, Turkey	Mediterranean Sea Region	Aquatic/Terrestrial	**Art. 6,1** - Limit land-based pollution as listed in Annex II, **Annex II, 11** - Substances that have an "adverse effect on the oxygen content of the marine environment, especially those which may cause eutrophication", **Annex II, 13 -** Non-toxic substances which may become problematic in high quantity	UNEP Co-Ordinating Unit for the Mediterranean Action Plan
Convention for Cooperation in the Protection of the Marine Environment of the West and Central Africa Region	5-Aug-84	Benin, Cameroon, Congo, Cote d'ivore, Gabon, Gambia, Ghana, Guinea, Liberia, Mauritania, Nigeria, Senegal, Togo	**Art. 1 -**This Convention shall cover the marine environment, coastal zones and related inland waters falling within the jurisdiction of the States of the West and Central African Region, from Mauritania to Namibia inclusive, which have become Contracting Parties to this Convention under conditions set forth in article 27 and paragraph 1 of article 28 (hereinafter referred to as the Convention area).	Aquatic	**Art. 7 -** prevent, reduce, combat pollution from land based sources, **Art. 9** - prevent, reduce, combat through or from the atmosphere	UNEP Regional Co-Ordinating Unit for the West and Central African Action Plan

Convention for the Protection of the Marine Environment and Coastal Area of the South-East Pacific (Lima Convention) /Protocol for the Protection of the South East Pacific Against Pollution from Land-Based Sources	19-May-86	Chile, Colombia, Ecuador, Panama, Peru	**Art. 1 -** The sphere of application of this Convention shall be the sea area and the coastal zone of the South-East Pacific within the 200-mile maritime area of sovereignty and jurisdiction of the High Contracting Parties and, beyond that area, the high seas up to a distance within which pollution of the high seas may affect that area.	Atmospheric/Aquatic/ Terrestrial	**Art. 4 -** prevent, reduce, control pollution from land-based sources as well as from or through the atmosphere	Comisión Permanente del Pacífico Sur (CPPS)
Regional Convention for the Conservation of the Red Sea and Gulf of Aden Environment (Jeddah Convention)	20-Aug-85	Djibouti, Egypt, Jordan, Palestine, Saudi Arabia, Somalia, Sudan, Yemen	The present Convention shall apply to the entire sea area, taking into account integrated ecosystems of the Red Sea, Gulf of Aqaba, Gulf of Suez, Suez Canal to its end on the Mediterranean, and the Gulf of Aden [From Ras Dharbat Ali (lat. 16d*39' N, long. 53d*03.5' E), thence to a point (lat. 16d*00' N, long. 53d*25' E), thence to a point (lat. 12d*40' N, long. 55d*00' E) lying ENE of Socotra Island, thence to Ras Hafun (lat. 10d*26' N, long. 51d*25' E)]	Aquatic/Terrestrial	**Art. VI -** prevent, abate, and combat pollution from land based sources, whether water-borne or air-borne	Regional Organization for the Conservation of the Environment of the Red Sea and Gulf of Arden (PERSGA)

Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Eastern African Region (Nairobi Convention)	30-May-96	Comoros, France, Kenya, Madagascar, Maritius, Mozambique, Seychelles, Somalia, Tanzania	**Art. 2 (a) -** "Convention area" shall be comprised of the marine and coastal environment of that part of the Indian Ocean situated within the Eastern African region and falling within the jurisdiction of the Contracting Parties to this Convention. The extent of the coastal environment to be included within the Convention area shall be indicated in each protocol to this Convention taking into account the objectives of the protocol concerned	Aquatic	**Art. 7 -** prevent, reduce, combat pollution from land based sources, **Art. 9** - prevent, reduce, combat airborne pollution	UNEP Regional Co-Ordinating Unit for the Eastern African Action Plan (EAF/RCU)
Convention for the Protection of the Natural Resources and the Environment of the South Pacific Region	22-Aug-90	Australia, Cook Islands, Federated States of Micronesia, Fiji, France, Marshall Islands, New Zealand, Papua New Guinea, Solomon Islands, United States of America, Western Samoa	South Pacific Regional Sea Area (130 deg E long. - 120 deg W long.; Tropic of Cancer to 60 deg. S lat.)	Atmospheric/Aquatic/ Terrestrial	**Art. 7** - prevent, reduce, control pollution from land based sources, **Art. 9** - precent, reduce, control discharges into the atmosphere	South Pacific Regional Environment Programme (SPREP)
Protocol for Protection Against Land-Based Sources (Kuwait Regional Convention for the Protection of the Marine Environment from Pollution)	2-Jan-93	Bahrain, Islamic Republic of Iran, Iraq, Kuwait, Oman, Qatar, Saudi Arabia, United Arab Emirates	The ROPME Sea Area (RSA) is defined as extending between the following geographic latitudes and longitudes, respectively: 16°39'N, 53°3'30"E; 16°00'N, 53°25'E; 17°00'N, 56°30'E; 20°30'N, 60°00'E; 25°04'N, 61°25'E.	Aquatic/Terrestrial	**Art. VI -** develop standards, regulations and permitting for the release of wastes, **Annex I -** pollution abatement through source controls, **Annex II -** joint or combined effluent treatment, **Annex III -** guidelines, regulations and permits for release of wastes	Regional Organization for the Protection of the Marine Environment (ROPME)
Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention)	17-Jan-00		The Baltic Sea Area shall be the Baltic Sea and the entrance to the Baltic Sea bounded by the parallel of the Skaw in the Skagerrak at 57° 44.43'N. It includes the internal waters	Atmospheric/Aquatic/ Terrestrial	**Annex III -** the annex is devoted to the "Criteria and measures concerning the prevention of pollution from land-based sources"	Helsinki Commission (HELCOM)

Protocol on the Protection of the Black Sea Marine Environment Against Pollution from Land Based Sources	31-Oct-96	Bulgaria, Georgia, Romania, Russia, Turkey, Ukraine	Black Sea Countries (Bulgaria, Georgia, Romania, Russia, Turkey, Ukraine)	Aquatic/Terrestrial	**Art. 6 (a)** - reduce pollution from municipal sewage, **Art. 6 (d)** - reduce pollution from agricultural and forest areas, **Annex II, 7** - specifically nitrogen as a substance to be regulated	Permanent Secretariat of the Commission on the Protection of the Black Sea Against Pollution
Convention for the Prevention of Marine Pollution from Land Based Sources (OSPAR Convention)	25-Mar-98	Belgium, Denmark, Finland, France, Germany, Iceland, Ireland, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom	The maritime area covers the North-East Atlantic (westwards to the east coast of Greenland and southwards to the Strait of Gibraltar), including the North Sea, and comprises the internal waters and the territorial sea of the Contracting Parties, the sea beyond and adjacent to the territorial sea under the jurisdiction of the coastal state to the extent recognized by international law, and the high seas, including the bed and subsoil thereof.	Aquatic/Terrestrial	**Art. 3 -** prevent and eliminate pollution from land based sources (point and diffuse), **Annex I, Art. 2** - calls for regualtion and monitoring of point source discharge into maritime environment, **Annex I, Art. 3 (b)** - the Commission is to draw up programs to reduce inputs of nutrients from urban, municipal, industrial, agricultural, and other sources	OSPAR Secretariat
Protocol Concerning Pollution from Land-Based Sources and Activities to the Protection and Development of Marine Environment of the Wider Caribbean Region	Not yet ratified	Colombia, Costa Rica, Dominican Republic, France, Netherlands, United States	Wider Caribbean Region as defined by the UN Regional Seas program	Aquatic	**Annex I B -** lists priorit sources, including agricultural and non-point sources, **Annex II C (1) -** lists pollutants of concern, including (l) nitrogen compounds, **Annex III -** establishes regulations for domestic wastewater disposal, including (C) effluent limitations and (C,3,a) requires each party to take in to account the impact of the nitrogenous compounds that they release, **Annex IV -** deals with agricultural and non-point sources of nitrogen	UNEP-CAR/RCU

Convention for Co-operation in the Protection and Sustainable Development of the Marine and Coastal Environment of the North-East Pacific (Antigua Convention)	Not yet ratified	Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, Panama	Maritime areas of the Northeast Pacific, defined in conformity with the United Nations Convention on the Law of the Sea	Atmospheric/Aquatic/ Terrestrial	**Art. 6 (a) -** prevent, reduce, control and remedy pollution originating from **(i)** land based sources, **(ii)** atmpspheric sources, **Art. 6 (c) -** prevent, reduce, control and remedy destruction of coastal habitats,	Central American Commission for Maritime Transportation (COCATRAM)
Framework Convention for the Protection of the Marine Environment of the Caspian Sea	Not yet ratified	Republic of Azerbaijan, Islamic Republic of Iran, Republic of Kazakhstan, Russian Federation, Turkmenistan	Caspian Sea Countries	Aquatic/Terrestrial	**Art. 7 (a) -** prevent, reduce and control pollution from land based sources, **Art. 11 -** prevent, reduce and control pollution from "other human activities"	A Secretariat is established within the convention

Appendix 5: OECD Agreements

Convention	Entry into force	Signatories/Parties	Geographic Coverage	Media Covered	Provisions/Statutory Language	Oversight Body
OECD: The Control of Eutrophication of Waters	14-Nov-74	OECD Countries	OECD Countries	Aquatic	**Art. I -** recommends that member countries take measures to reduce pollution that has led to eutrophication of waters	Member countries
OECD: Control of Air Pollution from Fossil Fuel Combustion	20-Jun-85	OECD Countries	OECD Countries	Atmospheric	**Art. 1 -** parties should seek methods to control emissions of nitrogen oxides into the atmophere from mobile and stationary sources, **Art. 3 -** develop emissions control strategies on regional and national basis, **Annex -** establishes "Guiding Principles" to follow which address methods to reduce emissions from all sources as well as information exchange and monitoring priorities	Member countries

Appendix 6: UNECE Agreements

Convention	Entry into force	Signatories/Parties	Geographic Coverage	Media Covered	Provisions/Statutory Language	Oversight Body
Convention on Long-Range Transboundary Air Pollution	16-Mar-83	49 Parties	UNECE Region (North America, Europe, Central Asia)	Atmospheric	**Art. 2 -** limit, reduce and prevent air pollution, including long-range transboundary air pollution	UNECE, Executive Secretary
Protocol to CLRTAP Concerning the Control of Emissions of Nitrogen Oxides or their Transboundary Fluxes	14-Feb-91	28 Parties	UNECE Region (North America, Europe, Central Asia)	Atmospheric	**Art. 2, 1 -** parties shall reduce their national annual emissions of nitrogen oxides so that they do not exceed the 1987 level (The Protocol proceeds to document certain means to reduce emissions and set timelines for those reductions)	UNECE, Executive Secretary
Protocol to CLRTAP to Abate Acidification, Eutrophication and Ground-Level Ozone	Not yet ratified		UNECE Region (North America, Europe, Central Asia)	Atmospheric	**Art. 2 (b)** - reduce nutrient nitrogen emissions to levels described in Annex I, (The Protocol proceed to document certain measures to reduce emissions and set timelines for those reductions)	UNECE, Executive Secretary
UNECE Water Convention	17-Mar-92	34 Parties	UNECE Region (North America, Europe, Central Asia)	Aquatic	**Art. 2** - measures for control, prevention and reduction of water pollution should be taken at the source, **Art. 3 -** To prevent, control and reduce trans-boundary impact, the Parties shall develop, adopt, implement and, as far as possible, render compatible relevant legal, administrative, economic, financial and technical measures,	Member countries

Appendix 7: European Union Agreements

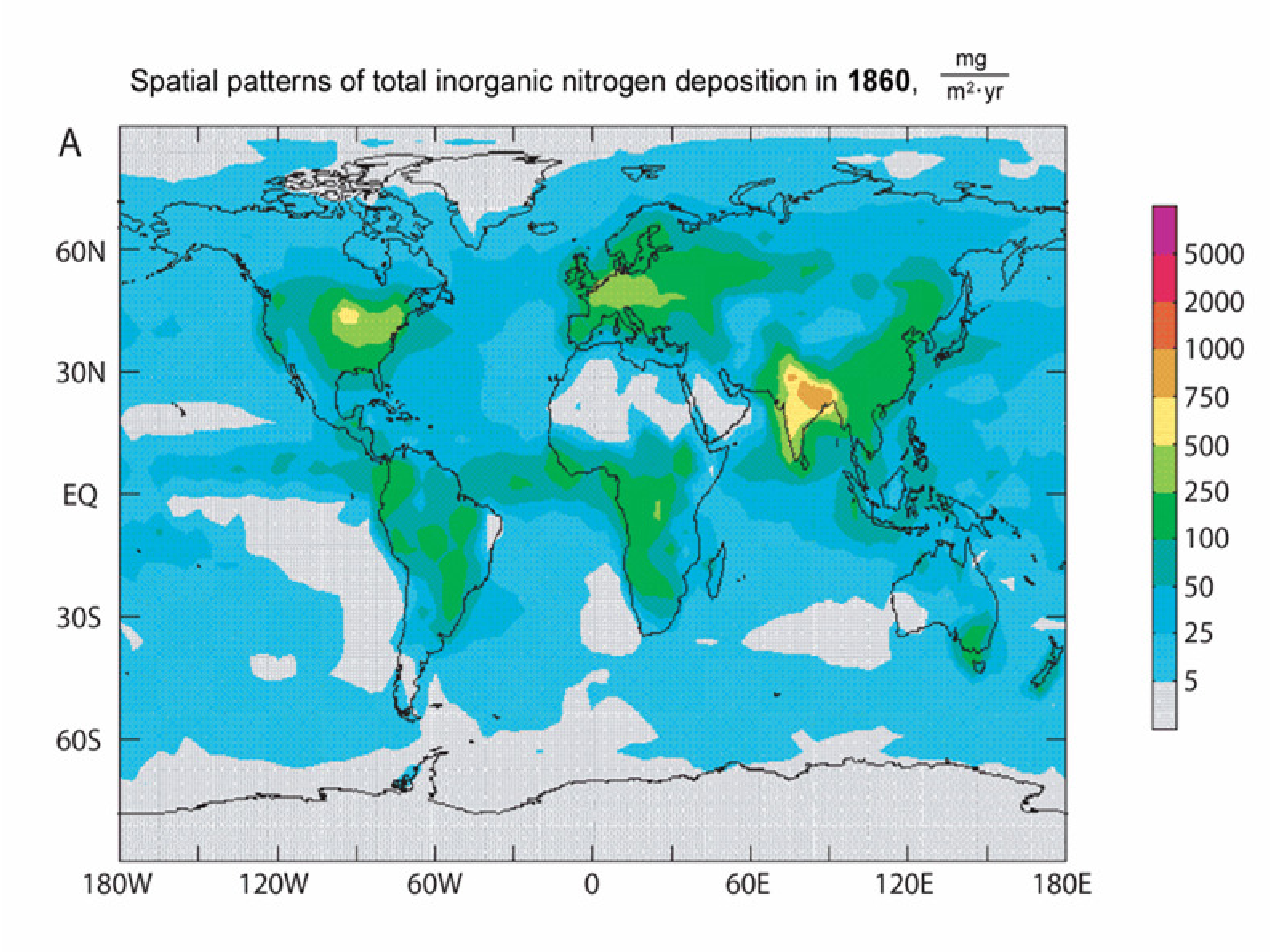
Convention	Entry into force	Signatories/Parties	Geographic Coverage	Media Covered	Provisions/Statutory Language	Oversight Body
European Union Nitrate Directive (Directive 91/676/EEC)	12-Dec-91	European Union	European Union	Aquatic/Terrestrial	**Art. 3 -** identify waters affected by nitrate pollution and designate lands that drain into these waters and cause this pollution, **Art. 5 -** members shall develop action plans to reduce and prevent water pollution from nitrates from agricultural sources, **Annex III -** establishes measures to be included in action programs, **Annex IV -** establishes reference methods of measurement for these waters	Member countries
European Union Council Directive 96/61/EC of 24 September 1996 concerning integrated pollution prevention and control	24-Sep-96	European Union	European Union	Atmospheric/Aquatic/ Terrestrial	**Art. 1 -** establishes the purpoes of the directive to achieve integrated pollution control through the use of Best Available Techniques (BAT), **Annex I -** lays out categories of installations covered by the directive, **Annex III -** lists the main pollutants to be considered, including nitrogen oxides, and substances that contribute to eutrophication	Member countries
European Framework Directive on Water Policy (Directive 2000/60/EC)	23-Oct-00	European Union	European Union	Aquatic	**Art. 4 -** details environmental objectives for (a) surface waters, (b) groundwater, (c) protected areas, **Art. 8** - establishes monitoring requirements for all water types, **Art. 10 -**establishes a combined approach to combat point and non-point pollution, **Art. 16 & 17 -** outline strategies to prevent water pollution, **Annex VIII, 11** - lists nitrates as one of the main pollutants to consider, **Annex IX -** maps of ecoregions of various waters	Member countries

Appendix 8: River Basin Agreements

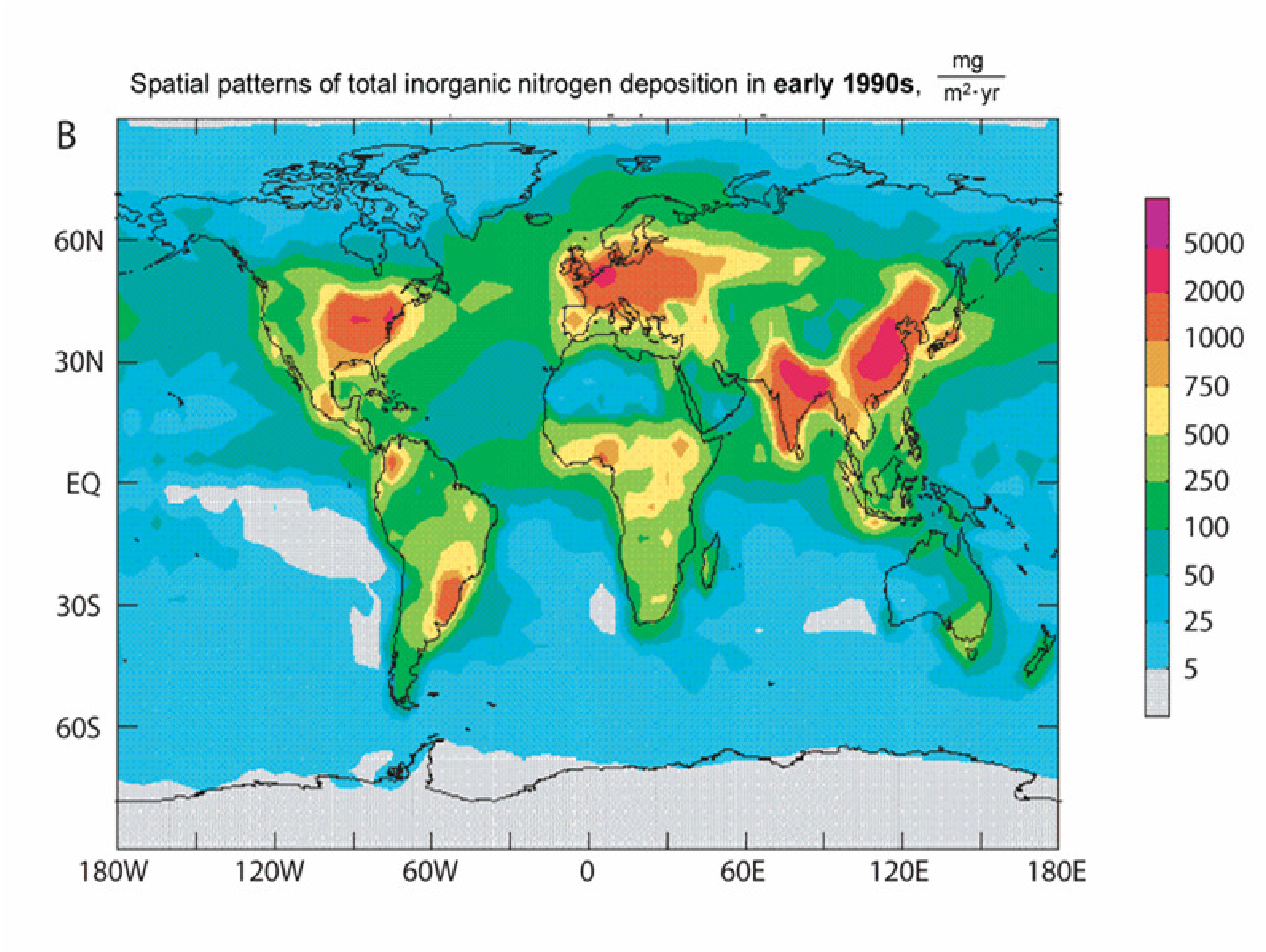
Convention	Entry into force	Signatories/Parties	Geographic Coverage	Media Covered	Provisions/Statutory Language	Oversight Body
Treaty for Amazonian Cooperation	2-Aug-80	Bolivia, Brazil, Colombia, Ecuador, Guyana, Peru, Suriname, Venezuela	Amazon River Basin	Atmospheric/Aquatic/ Terrestrial	**Art.1 -** calls for development while achieving the "preservation of the environment, and the conservation and rational utilization of the natural resources of these territories", **Annex 3 -** lists and identifies programs and projects meant to satisfy the mandates of this agreement	There is a treaty secretariat, as established by Art. XXII
Agreement on the Action Plan for the Environmentally Sound Management of the Common Zambezi River System	28-May-87	Botswana, Mozambique, Tanzania, Zambia, Zimbabwe	Zambezi River Basin	Atmospheric/Aquatic/ Terrestrial	**Annex I -** this contains the essence of the plan, which is predicated on the need to enhance "environmentally sound water resources management of the common Zambezi river system (**Preamble**)", **Annex I (I) (14) -** identifies the main problems that should be dealt with, **Annex I (II) -** provides suggested actions for dealing with said problems,	
Convention on Cooperation for the Protection and Sustainable Use of the Danube River	22-Oct-98	Austria, Bulgaria, Croatia, Czech Republic, European Union, Germany, Hungary, Moldova, Slovenia, Romania, Serbia and Montenegro, Slovak Republic, Ukraine	Danube River Basin	Aquatic	**Art. 6 (b) -** prevent the pollution of groundwater from nitrates, **Art. 7 -** calls for limiting emissions of waste waters as well as discharges from point and non-point sources **(3)** that are outlined in **Annex II** [manufacture of mineral fertilizers (**Part 1, 4**, **(d)**) and inorganic nitrogen compounds (**Part 2, A, (g)**) are specifically identified], **Annex III -** provides general guidance on water quality, specifically citing the need for a "reduction of average pollution loads and concentrations"	International Commision for the Protection of the Danube River (Secretariat as established by Article 7)
Agreement on the Cooperation for the Sustainable Development of the Mekong River Basin	5-Apr-95	Cambodia, Laos, Thailand, Vietnam	Mekong River Basin	Aquatic	**Art. 3 -** protect the environment, natural resources, aquatic life and conditions and ecological balance from pollution or other harmful effects resulting from any use of the Mekong Basin	Mekong River Commission Secretariat

Protocol on Shared Watercourse Systems in the Southern African Development Community (SADC) Region	28-Sep-98	Botswana, Lesotho, Malawi, Mauritus, Namibia, South Africa, Swaziland, Tanzania, Zambia, Zimbabwe,	Shared waterways throughout Africa	Aquatic	**Art. 3-** establishes river basin management institutions, **Art. 5 d (i) -** a stated goal of these institutions is to promote environmental protection measures and prevent all forms of environmental degradation	Southern African Development Community
Convention on the Protection of the Rhine	1-Jan-03	European Union, France, Germany, Luxembourg, Netherlands, Switzerland	Rhine River Basin	Aquatic	**Art. 3 -** establishes targets and goals for the parties, additionally this Convention maintains all previously formulated law on pollution into the Rhine, especially the following articles from the Convention for the Protection of the Rhine from Chemical Pollution: **Art. 1 (b) -** reduce pollutants from Annex II, **Annex II (8) -** specifically cites ammonia and nitrites as substances to reduce do to their impact on the oxygen balance	International Commision for the Protection of the Rhine Against Pollution

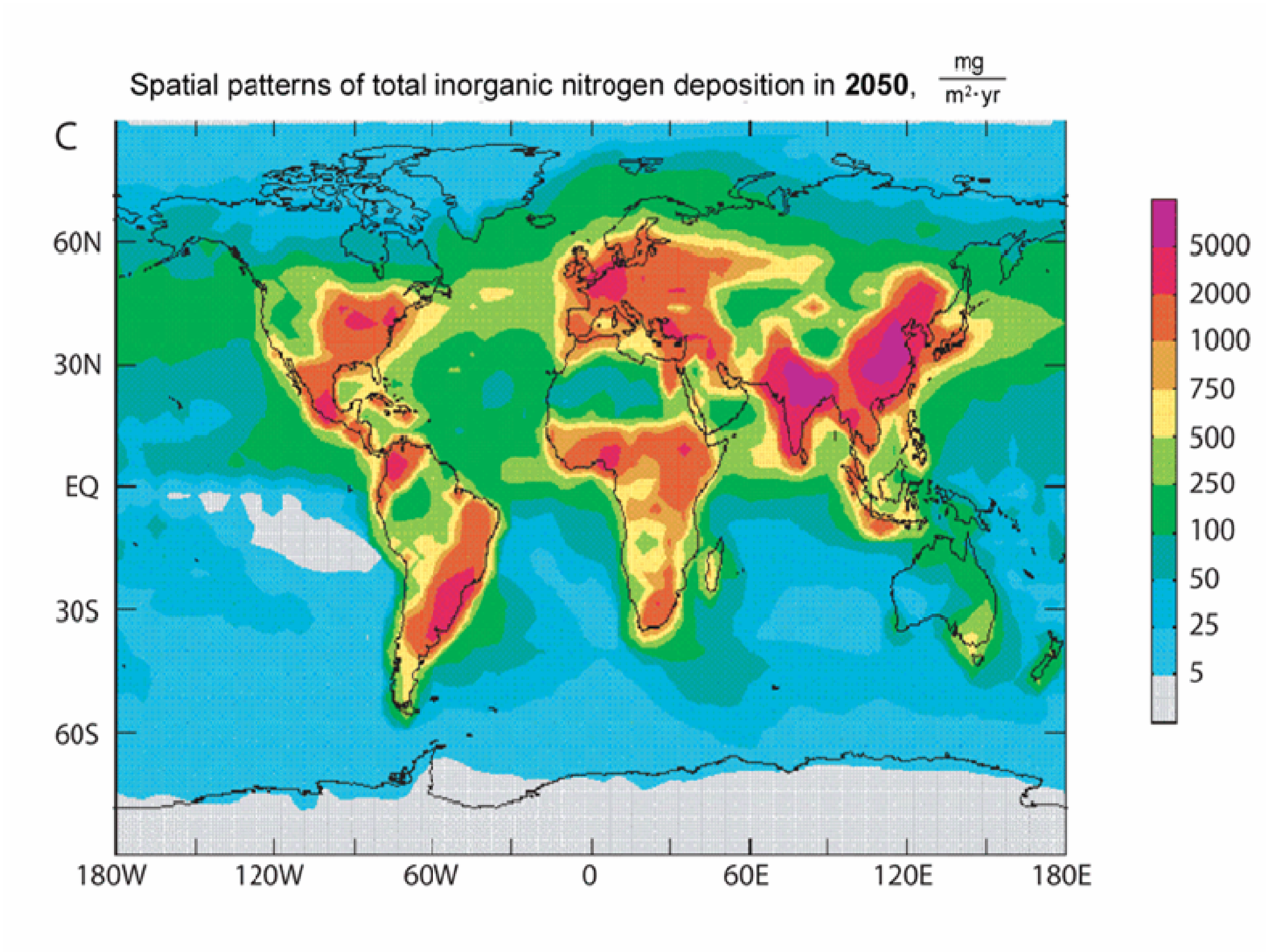
Appendix 9: Maps of Global Nitrogen Deposition



Adapted from *Green et al 2004*

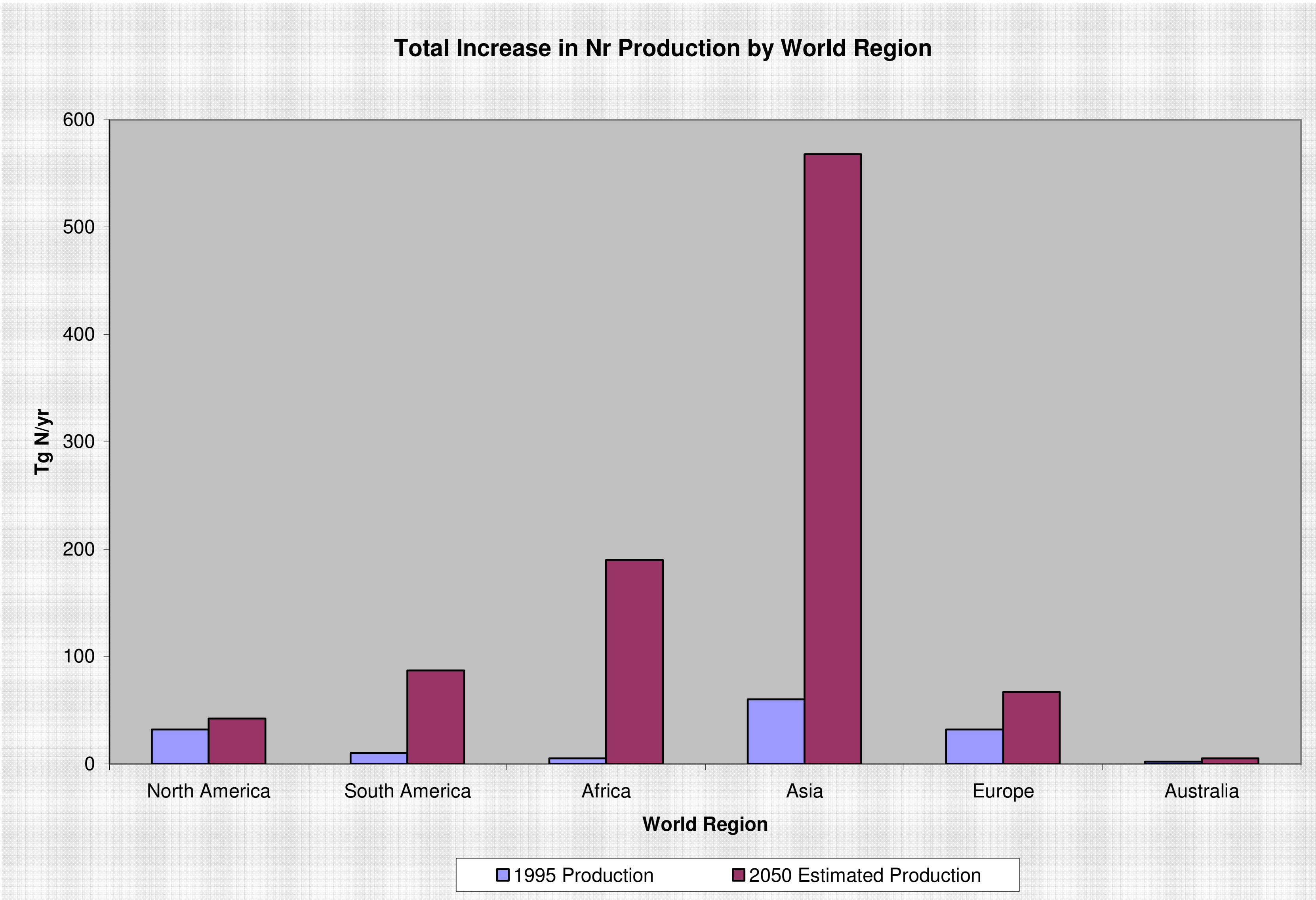


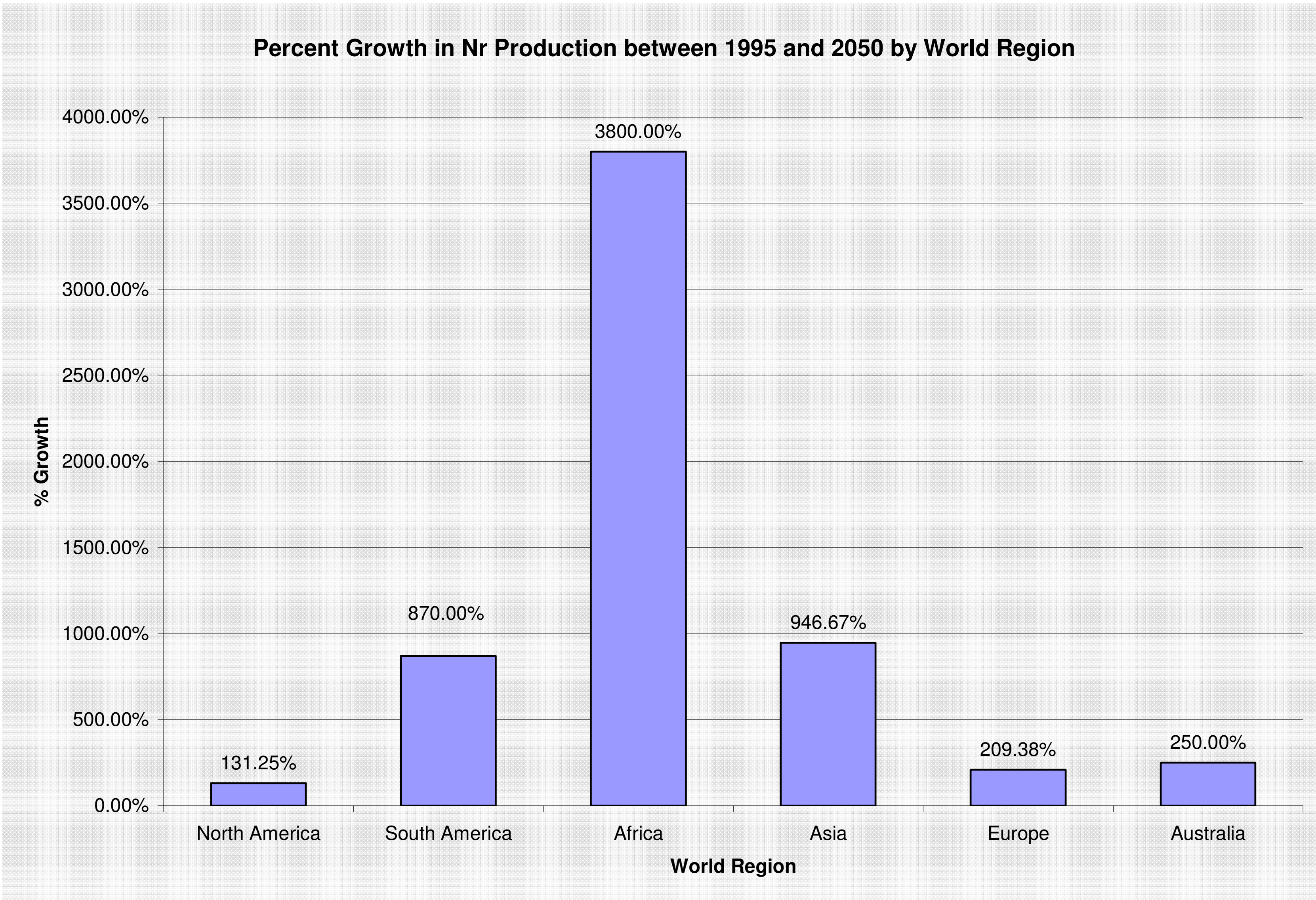
Adapted from *Green et al 2004*



Adapted from *Green et al 2004*

Appendix 10: Change in Nr Production by World Region




Percent Growth in Nr Production between 1995 and 2050 by World Region
% Growth
4000.00%
3500.00%
3000.00%
2500.00%
2000.00%
1500.00%
1000.00%
500.00%
0.00%
131.25%
870.00%
3800.00%
946.67%
209.38%
250.00%
North America
South America
Africa
Asia
Europe
Australia
World Region