Seasonal nutrient export into the Japanese and Okhotsk seas

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PREFACE

I would like to express my sincere gratitude towards prof. Carolien Kroeze and dr. Maryna Strokal for being excellent supervisors and who motivated me to become the best version of myself.

I am grateful for the input of Michelle McCrakin, who developed the DIN-S model and provided advice for the local application of her model. Also I would like to thank Mengru Wang for her generous help in providing NUFFER model data for the Amur river basin from her newly developed NUFFER county model.

During the process of applying a seasonal model to a local area I was very much depended on expert judgement for trustworthy data selection and input on unpublished matters. Therefore, many thanks to Tom Dongmin Kim (expert judgement South-Korea) and Satoshi Akaike (expert judgement Japan) for their advice and input.

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LIST OF ABBREVIATIONS

C	Carbon
DIN	Dissolved Inorganic Nitrogen
DIN-S	Dissolved Inorganic Nitrogen - Seasonal
DIP	Dissolved Inorganic Phosphorus
DON	Dissolved Organic Nitrogen
DOP	Dissolved Organic Phosphorus
FAO	Food and Agricultural Organisation of the United Nations
HAB	Harmful Algae Bloom
GDP	Gross Domestic Product
GO	Global Orchestration
ICEP	Indicator Coastal Eutrophication Potential
JPN-H	Japanese Sea - High Human Activity
JPN-L	Japanese Sea - High Human Activity
MEA	Millennium Ecosystem Assessment
N	Nitrogen
NEWS	Nutrient Export to WaterSheds
NUFFER	Nutrient flows in Food chains, Environment and Resources use
OKH-H	Okhotsk Sea - Human Activity
OKH-N	Okhotsk Sea - Natural Area
OS	Order from Strength
P	Phosphorus
Si	Silicon

SUMMARY

Human influences such as agriculture and sewage have increased river export of nutrients such as nitrogen (N) and phosphorus (P). Increased nutrients in water can lead to problems such as eutrophication, oxygen depletion and harmful algal blooms (HAB's). The Japanese sea has been dealing with algal blooms and eutrophication problems during the warmer months of the year on a regular basis. Records of HAB's and eutrophication problems have started as early as 161 AD (South-Korea) and have become more intense since the eighties'. The Global NEWS-2 model was designed to analyse trends in annual export of nutrients from land to sea. Global Nutrient Export from WaterSheds model (Global NEWS-2) can be used to analyse causes and effects of nutrients export on coastal eutrophication and to explore possible solutions. So far, applications of Global NEWS-2 to the Japanese and Okhotsk seas have been limited. Global NEWS-2 provides yearly averages of nutrient export by rivers. Eutrophication, on the other hand, depends largely on seasons due to the fact that many nutrient sources are seasonal and hydrology as well as other factors varies among seasons. Both the Japanese and Okhotsk seas have strong seasonal cycles. The Japanese Sea experiences four seasons. In contrast, thenorth of the Okhotsk Sea has two seasons because region is largely frozen over for about six months of the year.

The main objective of my MSc thesis research is thus to analyse nutrient inflow into the Japanese and Okhotsk seas by updating the Global NEWS-2 model with specific reference to seasonality. To reach this objective the following research questions are formulated:

1. What are trends in annual river export of nutrients, and which nutrient sources are missing for the Japanese and Okhotsk seas in the Global NEWS-2 model?
2. What is the effect of seasonality on the modelled river dissolved inorganic nitrogen export into the Japanese and Okhotsk seas?

Global NEWS-2 is designed to characterize the human influence on the river nutrient export by modelling the river export of dissolved and particulate nitrogen (N), phosphorus (P), carbon (C) and silica (Si). The model works with dissolved inorganic (DIN, DIP), organic (DON, DOP) and particulate (PN, PP) forms of N, P and C. Both natural and human sources for each of these nutrients are taken into account. Global NEWS-2 is a global, spatially explicit model and contains over 6000 river basins and can be run for the past (based on the year 1970 and 2000) and future trends (2030 and 2050). The future model output is built on the four Millennium Ecosystem Assessment (MEA) Scenarios. I apply the seasonal version of Global NEWS-2 (referred as the DIN-S model in the following text), designed by McCrackin et. al. (2014) to quantify river export of DIN by season for the Japanese and Okhotsk seas. DIN-S is different from Global NEWS-2 as it includes seasonality through three main compartments: temperature, N budget and hydrology. To account for the different seasons present in the Japanese and Okhotsk seas, I have determined effective seasons in which summer is defined by temperature rather than by calendar months. Four seasons are identified for the Japanese sea and the south of the Okhotsk sea: summer, winter, fall, spring. Two seasons are identified for the north of the Okhotsk sea: summer and winter.

River export of dissolved N and P to the seas increased by a factor of 1.2-2.5 between 1970 and 2000 (range for nutrient forms and seas). Higher increases are calculated for river export of DIN and DIP to both seas during this period, mainly due to urbanisation and fertilization usage. River export of DON and DOP was mainly from leaching of organic matter from non-agricultural areas in 2000. In the future, river export of DIN and DIP to the Japanese Sea may decrease up to 20% and river export of DON and DOP may stay at the level of 2000 between 2000 and 2050 (Global Orchestration (GO), Order from Strength (OS)). The decreases are associated with reduced agricultural activities as the import of food becomes more common and the population seeks jobs in different sectors. In contrast, river export of DIP to Okhotsk

Sea is projected to triple between 2000 and 2050 (GO). For DIN this increase is around 250%. The main reason for these increases is sewage for DIP and agriculture for DIN.

In addition, there are sources of nutrients missing in the model which might be important for the Japanese and Okhotsk seas. The land use maps of Global NEWS-2 need to be updated as they underestimate the local agricultural activities which are highly important for the Japanese and Okhotsk seas. Point sources, such as direct discharges of animal manure are important to account for in the model especially for the Chinese part of the Amur river basin. Aquaculture is considered as an important source of nutrients in the studied rivers too, but more at the local scale. Finally, atmospheric N deposition over the seas is a source that can bring N inputs into the coastal waters downwind from larger cities. Thus, direct N deposition on the coastal waters is recommended to be included in the model as well.

Modelled DIN river export varies largely among seasons for both the Japanese and Okhotsk seas. For the sea regions with four seasons (Japanese-Low Human activity, Japanese-High Human activity and Okhotsk-Human activity), high DIN export is calculated for spring (68, 190 and 66 kg/km^2/season respectively) and low DIN export is calculated for summer (20, 87 and 13 kg/km^2/season respectively). For the sea region with two seasons (Okhotsk-Non human activity), river DIN export happens mainly in summer (32 kg/km^2/season) and is close to zero in winter. For a comprehensive assessment of coastal eutrophication potential, it is therefore important to account for the seasonality.

I have provided the first seasonal river N export model for the Japanese and Okhotsk seas. The novelty of my model over the original DIN-S model is that my model has options for four and two seasons. Two seasons are important for seas closer to the poles. Thus, my approach can be used as example for other regions where four or two seasons are distinguished. The seasonal model allows to provide new insight into seasonal N export to the Japanese and Okhotsk seas. This information can help to formulate effective strategies to reduce coastal eutrophication in the Japanese and Okhotsk seas in the future.

CHAPTER 1: INTRODUCTION

Eutrophication: "*The addition of nutrients to water in lakes and rivers, which encourages plant growth that can take oxygen from the water and kill fish and other animals*" (Cambridge Dictionary). Though the word was introduced as recent as 1946, eutrophication has grown into a common problem on a global scale [1]. A common problem caused by human activities, that now poses a threat to the fresh water supply of the human population [2, 3].

Human influences such as agriculture and urbanisation have, among other things, led to increased river nutrients such as nitrogen (N), phosphorus (P) and carbon (C) [4, 5]. Increased nutrients lead to eutrophication-related problems such as, oxygen depletion and harmful algal blooms (HAB's) [6]. Especially during the warmer seasons the HAB's appear regularly, and cause damage to the local ecosystem. The local businesses depended upon clean suffer damage by it. The HABs are also a threat to human health as people are exposed to polluted water or contaminated sea food [1, 6-11]. Acquiring knowledge about cause, effect and timing of these phenomena is therefore essential. In this study, I focus on the Japanese and Okhotsk seas.

1.1 STUDY AREA: JAPANESE AND OKHOTSK SEAS

1.1.1 JAPANESE SEA

The Japanese Sea is a semi-enclosed sea surrounded by Japan, South-Korea, North-Korea and Russia (see Figure 1). The water flows circular and stays within the sea for a long period of time (c.a. 100 years). The sea water flows in through the Korean strait and can flow out either to the Okhotsk sea through the strait of Tartary in the north or into the Pacific through the strait of Tsugaru on the east (see Figure 1) [12].

Several countries surrounding the Japanese sea have experienced massive economic growth as well as population growth in combination with a strong urbanisation trend over the past five decades [13]. The annual Gross Domestic Product per capita (PPP) increase for Japan was roughly €250 per year, for South-Korea even over €800 per year between 1990 and 2015 [13]. Both countries have emphasised industrialization and developed import and export. This have created different kind of jobs away from agriculture and further stimulating urbanisation [14, 15]. On the Russian side of the Japanese Sea, there is limited urbanisation but mainly agricultural lands and natural areas with Vladivostok as the largest city (approximately 600,000 inhabitants)[16].

Due to the semi-enclosed coastal bays the Japanese Sea coasts are more sensitive to extreme eutrophication events [7, 17]. Around the South-Korean coast line the algal blooms have been reported as early as 161 AD, but as a natural-dominated process [18]. Records show that the algal blooms have become more frequent since the 80's [11, 18] due to strong economic development [19]. For South-Korea the economic damage due to these blooms have been approximately 8 million US dollars per year (1995-2008 average) [11]. Eutrophication and HABs in the Japanese Sea are seasonal, and are recorded mainly for the summer and fall [12, 18, 20-24]. Most blooms are called red tides as the red algae, *Cochllodinium polykrikoides,* are the dominant species that are responsible for massive fish kills. These red algae turns the water red. Commonly there are several blooms per year, the exact species of algae differs per bloom and per year [7, 18].

Figure 1. Map of the Japanese and Okhotsk seas with surrounding countries. Source: modified from Wikimedia Commons

1.1.2 OKHOTSK SEA

The Okhotsk sea is connected to the Japanese see in the south-west. It is much less enclosed than the Japanese sea, with more influence from the Pacific ocean. The sea is surrounded by Russia and in the south-west by Japan (see Figure 1). The north of the Okhotsk sea is frozen over about six months of the year and experiences only two seasons (summer and winter). The south of the sea has more dynamics in seasonality and experiences four seasons comparable to a moderate climate. Compared to the drainage area of the Japanese Sea, the drainage area of the Okhotsk sea has lower population density with a few smaller cities along the coastline and many small agricultural communities [13].

The south-west of the Okhotsk seas is under influence of the Amur River, a large basin starting in Mongolia and flows as a border between China and Russia, mouthing into the Okhotsk sea (see Figure 2). The outstretched Amur basin area includes large cities and intense agricultural areas making this river the main sources of terrestrial nutrients into the Okhotsk sea [25-28]. Though the main part of the Okhotsk sea is seen as mesotrophic (moderate amounts of dissolved nutrients), sea area's close to the Amur river mouth have been observed as eutrophic in the summer and early fall [29-32]. This eutrophic state influences the sea coast line all the way southward past Sakhalin island [33].

Figure 2. Map of the Amur river drainage basin flowing from Mongolia, as a border between China and Russia, and into the Okhotsk sea, slightly north from the Japanese sea's strait of Tartary. Source: modified from Wikimedia Commons

1.2 MODELLING RIVER NUTRIENT EXPORT

1.2.1 ANNUAL GLOBAL NEWS-2

Global Nutrient Export from WaterSheds model (Global NEWS, version 2) can be used to analyse causes and effects of nutrient export by rivers on coastal eutrophication and to explore possible solutions. Global NEWS-2 is designed to characterize the human influence on the river nutrient export by modelling the river export of dissolved and particulate N, P, C and silica (Si)[4]. The model works with dissolved inorganic (DIN, DIP), organic (DON, DOP, DOC) and particulate (PN, PP, POC) forms of N, P and C. Both natural and human sources for each of these nutrients are taken into account. Global NEWS-2 is a global, spatially explicit model and contains over 6000 river basins. The model runs for the past (based on the year 1970 and 2000) and future (2030 and 2050). The future model outputs are based on the four Millennium Ecosystem Assessment (MEA) Scenarios [5, 34]. The model includes the possibility to calculate the Indicator of Coastal Eutrophication Potential (ICEP), in which the potential of coastal eutrophication and thus the impact of river export of nutrients is evaluated. For further details on Global NEWS-2, please see chapter 2.2.

The model has been applied for numerous regional and global research projects. Seitzinger et. al. [5] applied Global NEWS-2 on a global scale, modelling with future scenarios. An example of regional application is that of Suwarno et. al. [35] in which the causes of changing nutrient export of Indonesian rivers over time was studied. Another example is Lüftner [36] who studied the effect of oil palm on the coastal eutrophication potential of Indonesia and Malaysia using the Global NEWS-2 model. So far, applications of Global NEWS-2 to the Japanese and Okhotsk seas have been limited.

1.2.2 SEASONAL GLOBAL NEWS-2 DIN-S

Global NEWS-2 provides yearly averages of nutrient export by rivers. Seasonality is important to account for river nutrient export due to the fact that many nutrient sources are seasonal and hydrology as well as other factors varies among seasons (e.g., temperature). Both the Japanese and Okhotsk seas have strong seasonal cycles.

The Global NEWS-2 DIN-Seasonal (referred as the DIN-S model in the following text) is developed by McCrackin et. al. [37] to quantify river export of DIN by season. This seasonal DIN-S model offers the opportunity to gain insight in timing and location of seasonal phenomena such as hypoxia and algal bloom [37]. DIN-S is different from Global NEWS-2 as it includes seasonality through three main compartments: temperature, N budget in soils and hydrology. The DIN-S model assumes a four season cycle and has been applied on a global scale. To study the Japanese and Okhotsk seas, a more specific seasonal modelling approach is needed, as not the full area experience four seasons.

1.3 MAIN OBJECTIVE AND RESEARCH QUESTIONS

The main objective of my MSc thesis research is thus to analyse nutrient inflow into the Japanese and Okhotsk seas by updating the Global NEWS-2 model with specific reference to seasonality. To reach this objective the following research questions are formulated:

3. What are trends in annual river export of nutrients, and which nutrient sources are missing for the Japanese and Okhotsk seas in the Global NEWS-2 model?
4. What is the effect of seasonality on the modelled river dissolved inorganic nitrogen export into the Japanese and Okhotsk seas?

CHAPTER 2: TRENDS IN ANNUAL RIVER EXPORT OF NUTRIENTS BY SOURCES INTO THE JAPANESE AND OKHOTSK SEAS

2.1 INTRODUCTION

The accuracy of any model's output is dependent upon the input variables it has to work with. For the Global NEWS-2 model, that input is a set of dominant river nutrient source variables. In the following chapter I look at the most important variables for the Japanese-Okhotsk region as calculated by the model. After that I look into source variables that have not yet been included in the Global NEWS-2 model but may be essential to the river nutrient flow and coastal eutrophication potential. By doing so I answer the first research question: **What are trends in annual river export of nutrients, and which nutrient sources are missing for the Japanese and Okhotsk seas in the Global NEWS-2 model?**

The chapter is structured into four main sections. Section 2.2 offers insight in what Global NEWS-2 is and does, as well as the Indicator for Coastal Eutrophication Potential (ICEP). In Section 2.3 the Global NEWS-2 model is applied for the Japanese and Okhotsk seas and the results of the most important drivers and trends found for river export of nutrients are explained. Also the calculated coastal eutrophication potential is shown and explained. Section 2.3 is therefore providing insight in this region's trends in annual river export of nutrients. Section 2.4 furthers on Section 2.3 by studying possible input variables (thus nutrient sources) that are not yet included in the Global NEWS-2 model but are essential or at least influential for accurate nutrient flow modelling. Section 2.5 is the concluding section in which I answer the research question based on the research provided throughout this chapter.

2.2 DESCIPTION OF GLOBAL NEWS-2 AND ICEP

2.2.1 GLOBAL NEWS-2

Human activities on land alters the natural river nutrient flows, and by that causing problems such as coastal eutrophication and hypoxia as well as a perturbation of the aquatic community [4]. The original Global Nutrient Export from WaterSheds model (Global NEWS-1) is designed to characterize the contemporary human influence on the river nutrient export by modelling the river export of dissolved and particulate nitrogen (N), phosphorus (P) and carbon (C). Both natural and human sources for each of these nutrients are taken into account. Global NEWS-1 is a global, spatially explicit model and contains over 6000 river basins hydrologically based on the water balance and transport model (WBM) [4].

The updated Global NEWS-2 can be run not only for contemporary human influence (based on the year 2000), but also the past (based on the year 1970) and future trends (2030 and 2050)[5, 38]. The future model output is built on the four Millennium Ecosystem Assessment (MEA) Scenarios, and thus providing four different possible futures for both 2030 and 2050. Global NEWS-2 uses the newer WBM_{plus} hydrological model and now also include dissolved silicon (Si) in the calculations, among other updates [5, 34].

Global NEWS-2 (from now on 'the model') works with dissolved inorganic (DIN, DIP), organic (DON, DOP, DOC) and particulate (PN, PP, POC) forms of N, P, C. Because the different forms have a very different 'life cycle'. With 'life cycle' I mean the way the form of a nutrient dictates its uptake and processing by nature and thus its influence on eutrophication issues. The smallest size of river shed is the 0.5° by 0.5° grids cell size. For every basin that is larger than 1 grid, the grid cells belonging to the watershed are merged to one unity.

The drivers behind nutrient sources are socio-economic reason why more or less nutrients become available to nature. For example, if the human population is growing this means that more food needs to be produced to feed that growing population. To do so agricultural activities will increase and the related manure and fertilization usage will allow more nutrients to become available to nature. A growing population also means more human related waste water with compounds from household activities. Therefore the population is a driver for river nutrient export. The same counts for the economic development of the region. If people have more money to spend, more waste is created. This includes waste water from industrial activities and elevated agricultural activities to meet higher living standards. The model takes these three main socio-economic factors into account: Gross Domestic Product (GDP), population density and sanitary statistics (connectivity to sewage systems, detergents, etc.) [4].

The nutrient sources themselves are separated into two types: diffuse and point sources. Point sources are by definition anthropogenic sources and encompass human waste emission (detergent etc.) and export of water from sewage treatment plants. Diffuse sources contain both natural and anthropogenic sources. For example, nature fixates N through biological processes which is a natural diffused N source. On top of that is the usage of fertilizers and manure on agricultural land as a diffused source of N [4].

The model has been applied for numerous regional and global research projects. A global application example is the research done by Seitzinger et. al. [5], who globally applied the model with future scenario analyses. They compared regional differences of nutrient export for the different scenarios. It was concluded that especially population growth and development of agricultural activities are the main reasons to expect higher levels of nutrient export in rivers in the future. Asia was found to dominate the global trends in nutrient export due to strong economic development and an already large population experiencing strong population growth [5].

An example of a regional application of the model is that of Suwarno et. al. [35] in which a closer look is taken at the causes of changing nutrient export of Indonesian rivers over time. They concluded that an increase in nutrient input is due to population growth and agricultural actives in the area. This increase is counterbalanced by a reduced basin discharge. Meaning that even though there are more nutrients discharged into the rivers, there is less water in the river to transport that to the coastal area. Therefore, the coastal eutrophication potential looks surprisingly stable over time despite the increasing amount of nutrients released to the watersheds [35]. The model can also be used to study the nutrient export and eutrophication risk coming from a specific source. In the dissertation of Konrad Lüftner [36] a specific look is taken at the nutrient flow caused by oil palm plantations in Indonesia and Malaysia. He concluded that the fertilizer usage for oil palm plantations on its own increases the coastal eutrophication potential, especially in Malaysia [36].

2.2.2 INDICTOR FOR COASTAL EUTROPHICATION POTENTIAL: ICEP

ICEP is used to determine the potential for coastal eutrophication resulted from river export of nutrients. The cause of harmful algae growth is not so much the presents of nutrients as it is the balance in which they are present. What kind of algae will grow (harmful or non-harmful) depends on the balance between P, N and Si in the water.

That eutrophication sensitive nutrient balance is captured in the Redfield ratio of Si:N:P:C = 20:16:1:106. The ICEP value in kg C-eq/km^2/day^{-1} shows to what extend the Redfield ratio is or is not met through equation 1 and 2 [9].

$$ICEP = \left[\frac{PFlx}{31} - \frac{SiFlx}{28-20}\right] * 106 * 12 \qquad if\ \frac{N}{P} > 16\ (P\ limiting) \quad (1)$$

$$ICEP = \left[\frac{NFlx}{14*16} - \frac{SiFlx}{28-20}\right] * 106 * 12 \qquad if\ \frac{N}{P} < 16\ (N\ limiting) \quad (2)$$

Where PFLx, SiFLx and NFLx stand for the total P, dissolved Si and total N respectively at the river mouth in kg/km^2/day[9]. Total P and total N include dissolved inorganic, organic and particulate forms. A negative ICEP value means that Si is in excess over N or P. The potential harmful algae growth in such conditions is limited. A positive ICEP value indicates and excess of N or P over Si and means a high change of non-siliceous algae growth, and thus HABs [5, 9].

2.3 GLOBAL NEWS-2 ANALYSES FOR THE JAPANESE AND OKHOTSK SEAS

I study the model's output for the past (1970 and 2000) and for two possible futures (2050). I have chosen to use two possible futures (MEA scenarios) to depict what might come: Global Orchestration (GO) and Order from Strength (OS). In the Japanese and Okhotsk seas there are five countries of whom, at present, several tending towards a GO mind-set and others more towards the OS. Also the two scenarios offer two extremes (total globalisation, total regionalisation), offering insight in two different 'worlds'.

In section 2.3.1 I show the results of the analysis on the socio-economical drivers this region. In the next section (2.3.2) I describe the nutrient sources related to those drivers over time. With the knowledge obtained in those two chapters I study the possible future coastal eutrophication problems, which I describe in section 2.3.3.

2.3.1 DRIVERS OF RIVER EXPORT OF NUTRIENTS

As explained previously, the drivers taken into account by the Global NEWS-2 model are Gross Domestic Product (GDP), population dynamics and sanitary statistics. In this chapter I describe the Global NEWS-2 model result for those drivers in the Japanese and Okhotsk seas, they are summarized in Table 1.

Economy developed fast during 1970-2000 for both sea regions and will continue in the future. GO projects faster economic development than OS, due to the strong emphasis on global trade. In OS the emphasis is on security, protection and the regional market, limiting the possible economic development [8]. In Okhotsk region the GDP increased up to 50% during 1970-2000, for the Japanese region the GDP even doubled. GDP is projected to double between 2000 and 2050 in GO and OS for both regions.

River basins of the Japanese Sea are more densely populated than river basins of the Okhotsk Sea. And, more people are connected to sewage systems in the Japanese sea basins. In 2016 the Japanese sea region has on average close to 100 people/km^2, where the Okhotsk sea region's average is 26 people/km^2. Both regions experienced strong population growth during 1970-2000: 50% increase for the Okhotsk region and 30% increase for the Japanese region. For the future scenarios the population growth will halt compared to the 2000 numbers. However the OS scenario estimates a decrease of 13% in the human population for the Japanese region where an increase of 10% is projected for the Okhotsk region by 2050. In the Japanese sea a third of the population is connected to a sewage system in 2000, which is expected to be 40% or higher in 2050 despite a growing population. In the Okhotsk sea region 19% of the population is connected to the sewage system in 2000, but the future prospect for sewage connections alter strongly per scenario. With OS the sewage connectivity will rise to a third of the population, with GO that would even be double of that (two-third) meaning an increase of 200% and by that having a higher connectivity percentage than the Japanese sea region.

Because the main focus of the OS scenario is on security, protection and the local market and less on development, the sewage connectivity will be mainly in line with urbanisation and not further implemented in the rural areas. Therefore the percentage of people connected to a sewage system will be lower than in the GO scenario [8].

River basins of the Japanese Sea have less agricultural areas compared to river basins of the Okhotsk Sea. Moreover, the amount of agricultural area in the Japanese sea region will slightly diminish towards the future. For the Okhotsk sea region the agricultural area remains either stable for the OS scenario, or also slightly diminish for the GO scenario. Due to the focus on global trade depicted in the GO scenario, there is a high productivity increase and thus there is less agricultural area needed to produce larger amounts of agricultural products [5, 8]. This explains the smaller agricultural area for this scenario.

Table 1. The socio-economic drivers for river export of nutrients into the Japanese and Okhotsk seas in 1970, 2000 and 2050. GDP = Gross Domestic Product at ppp = purchasing power parity, GO and OS are the Global Orchestration and Order from Strength scenarios of the Millennium Ecosystem Assessment, respectively. Source: Global NEWS-2 run 5 [4, 5].

Years	GDP(ppp) (1995US$ *1000/ inh/yr)	Total population (inh/km^2)	Urban population (%)	Population connected to sewage systems (%)	Agricultural areas (% of total drainage area)
Japanese Sea					
1970	6	73	19	11	8
2000	13	98	43	33	7
2050 GO	40	100	59	49	5
2050 OS	25	85	56	40	6
Okhotsk Sea					
1970	5	18	13	17	15
2000	8	26	19	19	19
2050 GO	26	26	29	58	17
2050 OS	13	29	49	31	19

2.3.2 TRENDS IN RIVER EXPORT OF NUTRIENTS

From the three main drivers that the model takes into account, there is reason to expect an increase of river nutrient export during 1970-2000. In the projected futures there is economic development and increasing sewage connectivity that will most probably cause an increase in river nutrient export by 2050, despite the stabilizing population.

The next step is to analyse the actual modelled river nutrient export. I focus on Dissolved Inorganic N (DIN), Dissolved Organic N (DON), Dissolved Inorganic P (DIP) and Dissolved Organic P (DOP). The dissolved nutrients are the most key for eutrophication problems. Plus N and P are directly influenced by human activities. Si is dependent upon rock weathering that for now I assume is stable.

In Table 2 I have summarized the alterations in percentages of river nutrient export between 1970 and 2000 for both sea areas. As expected there is a high increase in river nutrient export for all nutrients involved. Especially the inorganic form of N and P increased strongly. For the Okhotsk sea the increases are higher than for the Japanese sea. For DIP the increase for the Okhotsk sea even doubled.

Table 2. Changes in river export of nutrients into the Japanese and Okhotsk seas between 1970 and 2000 (% calculated from yields (kg/km^2/yr)). All values are positive, meaning changes are all increases of nutrient amounts. DIN: Dissolved Inorganic Nitrogen, DON: Dissolved Organic Nitrogen, DIP: Dissolved Inorganic Phosphorus, DOP: Dissolved Organic Nitrogen. Source: Global NEWS-2 run 5 [4, 5]

Changes in river export of nutrients 1970 - 2000 (%)	Japanese Sea	Okhotsk Sea
DIN	57	62
DIP	65	119
DON	17	22
DOP	16	21

In Figure 4 (page 17) the sources of each nutrient form is expressed for past and future. The increase of nutrient export over time is higher for the Okhotsk sea but the actual amount of nutrients received by the Japanese sea is much higher, despite the much smaller drainage area of the Japanese sea.

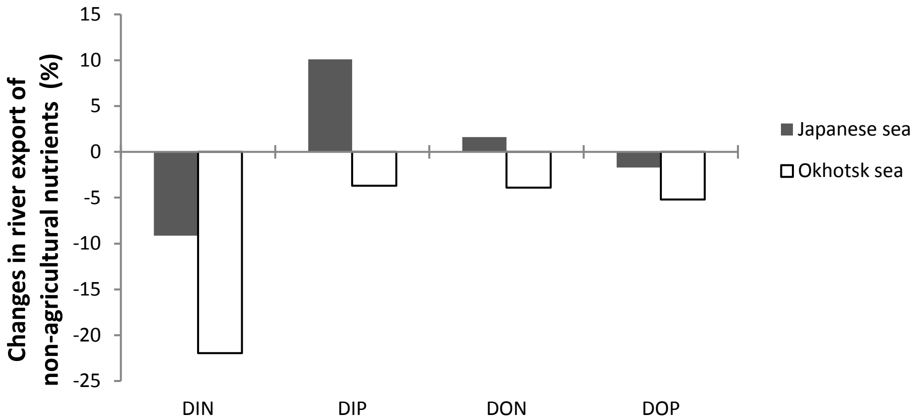


Figure 3. Changes in export of nutrients by rivers into the Japanese and Okhotsk seas from non-agricultural sources: Leaching of non-agricultural organic matter, weathering and sewage between 1970 and 2000 (%). DIN: Dissolved Inorganic Nitrogen, DON: Dissolved Organic Nitrogen, DIP: Dissolved Inorganic Phosphorus, DOP: Dissolved Organic Nitrogen Source: Global NEWS-2 run 5 [4, 5].

The share of non-agricultural sources to river export to the Okhotsk Sea decreased between 1970 and 2000. In contrast, the share of non-agricultural sources to river export of DIP and DON to the Japanese Sea increased during 1970-2000 (Figure 3). The increase of these nutrients for the Japanese Sea region is caused by a strong urbanisation trend with a slight decrease in agricultural area. In the Okhotsk sea region there is an increase of agricultural areas between 1970 and 2000, explaining the decrease of the total nutrient export from non-agricultural activities (see also Table 1).

2.3.2.1 THE JAPANESE SEA

Between 1970 and 2000, dissolved N and P export by rivers increased by half. Urbanization (for DIP and DON) and agriculture (for DIN, DIP and DOP) are main reasons for these increases, see Figure 4 (page 17).

Half of the DIN exported to the Japanese sea, either in past or future, is coming from fixation and deposition on Non-agricultural Areas (NA). NA can include natural areas, as well as industrial and urban and is expected to increase with industrial development and urbanisation. Between 1970 and 2000 the DIN from manure and fertilizers became more apparent, becoming almost half of the DIN nutrient source. For the future projections, the manure and fertilizer sources reduce back to 1970 values or even less, independent from which scenario.

Fertilizer was the largest source of DIP in 1970 and is as much as half of the total DIP nutrient amount. The main cause of DIP increase between 1970 and 2000 can clearly be seen in the higher level of DIP from sewage. Fertilizer and manure also increase in that time period, but much less then sewage. In the GO 2050 projection the sewage source increases further but is counterbalanced by a decrease in fertilizer and manure sources causing an overall decrease in DIP river export. For the SO 2050 projection, sewage remains equal compared to 2000 while manure and fertilizer sources show the same patters as in the GO 2050 projection. The SO 2050 scenario therefore has a lower DIP river export projection than GO 2050.

For DON the main source is leaching of organic matter from non-agricultural areas for past and future. The small increase in DON between 1970 and 2000 can be assigned to sewage becoming a slightly larger source. In both future scenarios, the amount of DON and its sources remain equal.

Similar to DON, DOP also mainly comes for leaching of organic matter from non-agricultural areas. In 2000 there is a slight increase in DOP, compared to 1970, mainly caused by fertilizer. For both future projections the fertilizer source slightly reduces again, but overall the DOP river export does not change much.

In the future, DIN and DIP export by rivers may decrease by 20% between 2000 and 2050. DON and DOP export by rivers may stabilize during this period. This is likely associated with decreases in agricultural activities at expense of urbanization. Stabilization trends in DON and DOP exports are because urbanization is not a major source of these nutrients in rivers

2.3.2.2. THE OKHOTSK SEA

The rivers exported more nutrients to the Okhotsk sea in 2000 than in 1970. This trend is similar to past trends for rivers of the Japanese sea. But, future trends are different, see Figure 4.

In 1970 the one main source of DIN for the Okhotsk sea was NA fixation and deposition. Between 1970 and 2000 the amount of DIN export due to NA fixation and deposition remained equal. Fertilizer, manure and agricultural activities became substantial sources increasing total DIN with 60% between 1970 and 2000. For both future scenario's this trend continues, with the exemption that the GO 2050 scenario projects a higher amount of DIN originating for sewage. A logic finding, as the sewage connectivity is higher for the GO 2050 scenario.

DIP shows a very strong increasing pattern over time for the Okhotsk sea, mainly due to sewage. Overall the numbers are low, varying between 2 up to 11 kg/km2/yr. In 1970 the source of DIP was fifty-fifty divided over sewage and NA P-weathering. In 2000 the sewage input for DIP doubled but still barely any sign of other possible DIP sources. For future projection that image changes, with fertilizer also becoming a foreseeable source of DIP. For GO 2050 the largest source of DIP remains sewage that again doubles compared to 2000. In OS 2050 the sewage source also increased compared to 2000, but to a much lesser extend then in GO 2050. This is foreseeable due to the GO scenario being more focused on increasing sanitary statistics (connecting people to sewage systems), where in OS there is less attention for that [5].

As with the Japanese sea, the main sources of DON and DOP is leaching of organic matter from non-agricultural areas. Be it in much lower actual amounts then for the Japanese Sea. On the other hand, DON is more clearly increasing over time (1970-2000), mainly due to leaching from Agricultural Area's (AA). In future DON projections, GO 2050 sewage becomes a more clearly visible source.

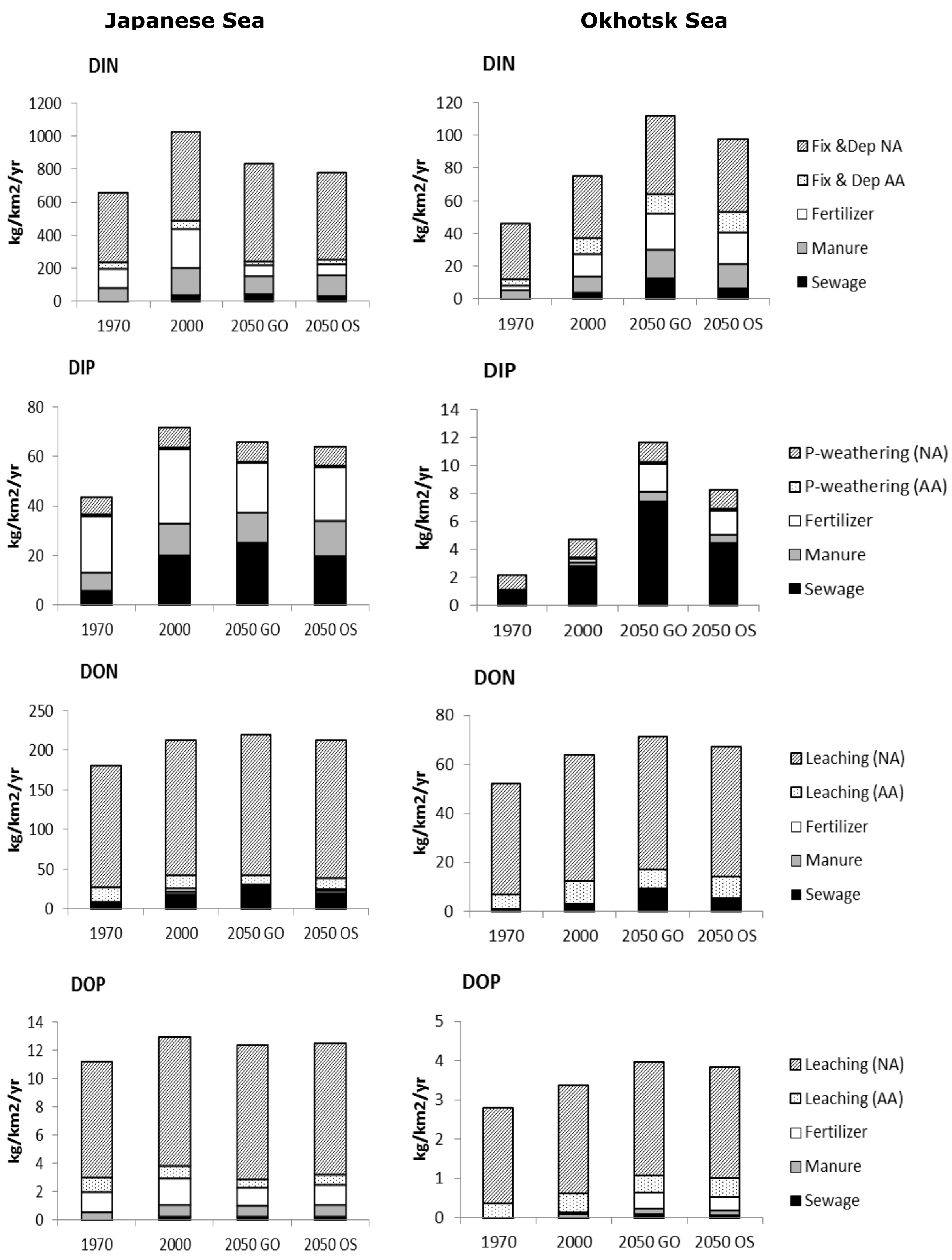


Figure 4. River export of dissolved inorganic (DIN, DIP), dissolved organic (DON, DOP) nitrogen (N) and phosphorus (P) in 1970, 2000 and in 2050. 2050 is based on the Global Orchestration (GO) and OS (OS) scenarios of the Millennium Ecosystem Assessment, NA and AA are leaching of organic matter and weathering of P-contained minerals from non-agricultural (NA) and agricultural (AA) areas. Fix and Dep are fixation and deposition of nitrogen from non-agricultural (NA) and agricultural (AA) areas. Data overview see appendix 1. Source: Global NEWS-2 Run 5 [4, 5].

For the OS 2050 projection the amounts stay close to equal as compared to 2000. For DOP the second source in both 1970 and 2000 is AA leaching. It is not until 2050 that fertilizer becomes a clear source of DOP, where for the Japanese sea fertilizer was a source in past and future. The increase of DOP between 2000 and 2050 is due to the introduction of fertilizer as a source, other sources remain equal.

In the future, rivers may export more N and P to the Okhotsk Sea. The possible reasons for this increase are more intensive agriculture (for DIN and DOP exports) and more people with sewage connections (for DIN, DIP and DON exports).

2.3.3 COASTAL EUTROPHICATION POTENTIAL

Global NEWS-2 quantifies that 55 of the 223 river basins in the Japanese and Okhotsk seas have a positive coastal eutrophication potential for the year 2000 (1-10 kg C-eq/km^2/day^{-1}), of which 12 rivers have a very high level, higher than 10 kg C-eq/km^2/day^{-1}, of eutrophication potential (see Figure 5).

In Figure 5 there are a few ICEP 'hot spots' visible. A 'hot spot' is watershed with an ICEP value of higher than 10 kg C-eq/km^2/day^{-1}, which in Figure 5 are coloured red. For the Japanese-Okhotsk region, 'hot-spots' only occur in the south of the Japanese sea. Four watersheds in South-Korea, namely: Nag Dong, Seomjin, Yeongsan and Ch'onmi-ch'on (Jeju Island). Five watershed in Japan, namely: Jinzū, Kurobe, Kuzuryū, Hino and Kobe. And finally there is one watershed in North-Korea, the Namdaechun river mouthing south from Sinchang, with a very high ICEP value. Most of the rivers mentioned are either part of a heavily urbanised area (Japan rivers, Nag Dong river), or are situated in large agricultural area's (Namdaechun).

Global NEWS-2 may underestimate river pollution by nutrients and thus costal eutrophication. This is because some sources are ignored in the model, but may contribute largely to nutrient pollution in the studied regions, see Section 2.4.

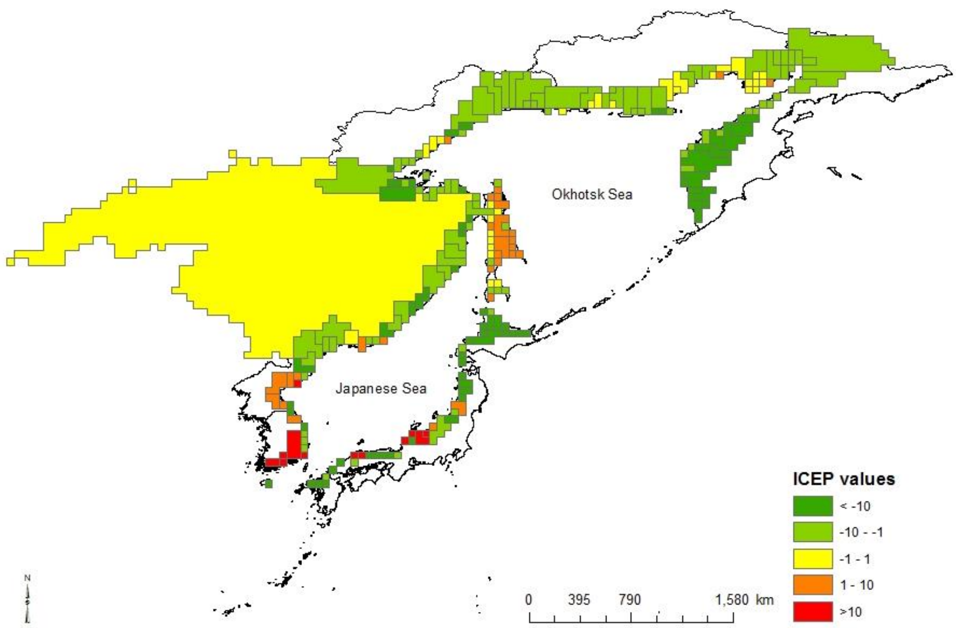


Figure 5. Indicator for Coastal Eutrophication Potential (ICEP) values (kg C-eq/km^2/day^{-1}) for the rivers draining into the Japanese and Okhotsk seas for the year 2000. Positive values indicate high potential for coastal eutrophication. Source: Global NEWS-2 run 5 [4, 39].

2.4 MISSING NUTRIENTS SOURCES

Recent studies have shown that due to development and alterations in economy, agricultural habits and culture there are new or altered nutrient sources at play that have not yet been included in the Global NEWS-2 model [40, 41]. In this section I go deeper into four new or altered sources of interest for the Japanese and Okhotsk seas: land use (Section 2.4.1), direct nutrient sources (Section 2.4.2), aquaculture (Section 2.4.3) and atmospheric N deposition over sea (Section 2.4.4).

2.4.1 LAND USE SOURCES

Land use alters over time. Economic and technological development influences the choice for investment in industrial, agricultural, natural or urban use of land. For river nutrient export the amount of agricultural land is a dominating factor. Land use in Global NEWS-2 is divided in agricultural and non-agricultural land [42]. Agricultural land includes legumes, upland crop, wet rice, and grassland (pastoral and mixed systems) as is shown in Figure 6.

To check if large alterations of land use have happened in the Japanese and Okhotsk seas, I compare the Global NEWS-2 land use map to a more recent high resolution (0.083° grids) FAO land use map [43]. FAO makes a distinction in intensity of agricultural activities, for example: moderate or large scale irrigation cropping and low, moderate or high livestock density (see Figure 7). Global NEWS-2 land use maps do not make such a distinction. It does, however, show a percentage of agricultural land use type per grid. Due to the high resolution (0.083° grids) of the FAO map, not all agricultural activities can be represented in the 0.5° grid land us map of Global NEWS-2.

Global NEWS-2 has a weaker representation of land use types for small basins (see Figure 8, page 22). This holds especially for the Japanese sea region where small basins with the drainage area of 2,000 – 25,000 km^2 are the only exporters of nutrients to the sea. Global NEWS-2 takes into account few agricultural activities in these basins. Updating the land use maps for the smaller basins would therefore provide a more accurate nutrient river export for this region.

For the large Amur river basin (drainage area: 1,750,000 km^2), Global NEWS-2 represents the dominant land use types well, but seems to underestimate some of the local areas with agricultural activities (see Figure 8, page 22). The Amur River basin is a dominant exporter of nutrients to the Okhotsk Sea and covers over two-third of the total drainage area of the Okhotsk Sea.

The accuracy of agricultural land use as an input variable for Global NEWS-2 is essential. For both regions the local agricultural areas are underestimated. To create more accurate modelling of river nutrient export for this region, the land us map needs updating.

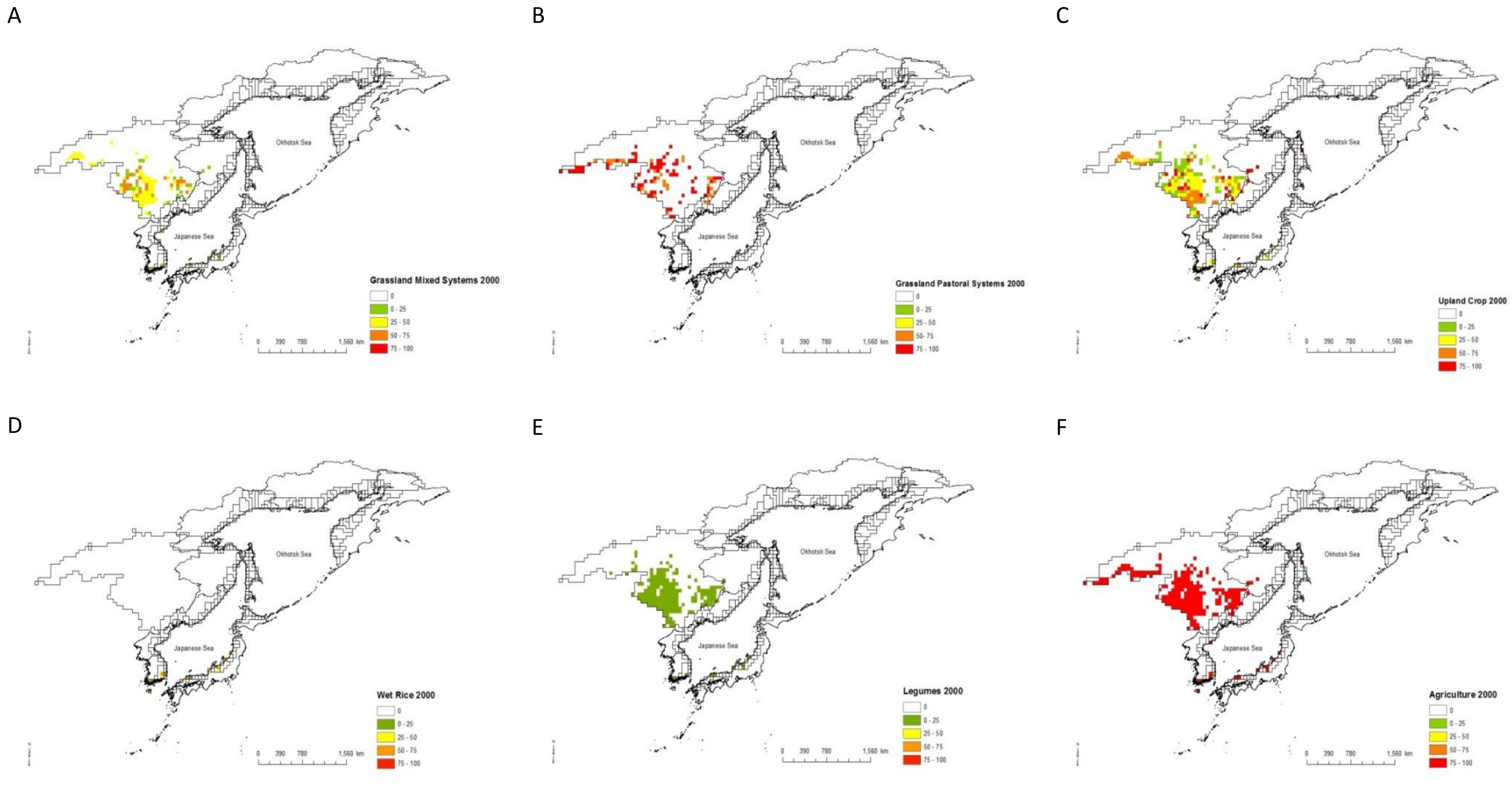


Figure 6. Global NEWS-2 land use maps (% per grid of 0.5° by 0.5°). A) Grassland mixed systems, B) Grassland Pastoral Systems, C) Upland Crops, D) Wet Rice, E) Legumes. Total overview of agricultural land as also used in Figure 8 incorporating land use types of map A – E in map F. Source: Global NEWS-2 run 5 [4, 39]

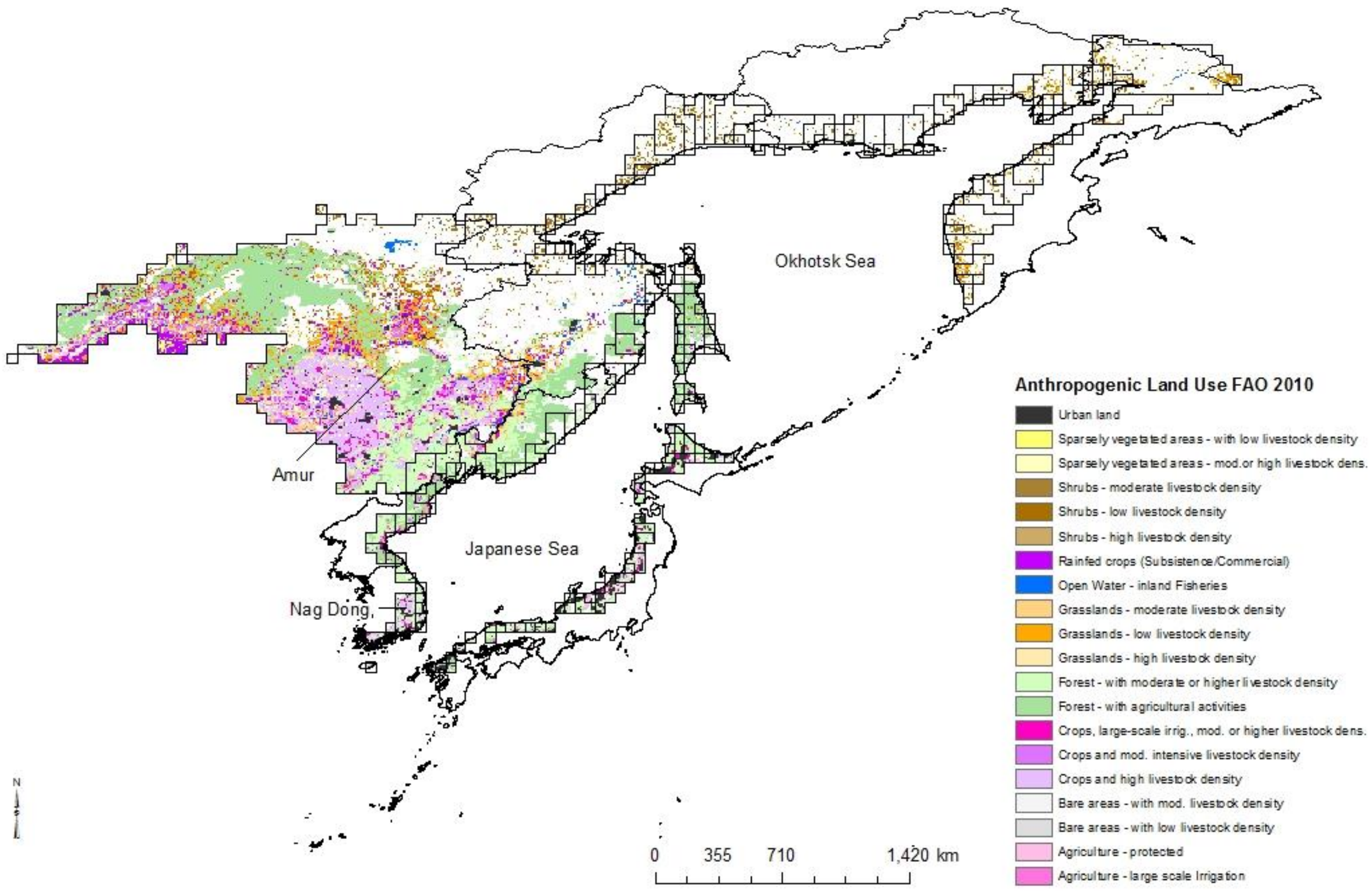


Figure 7. 2010 FAO land use map (0.083° by 0.083° grid) for the Japanese and Okhotsk seas including agricultural activities (livestock, shrubs, irrigated and non-irrigated land use). Source: [43].

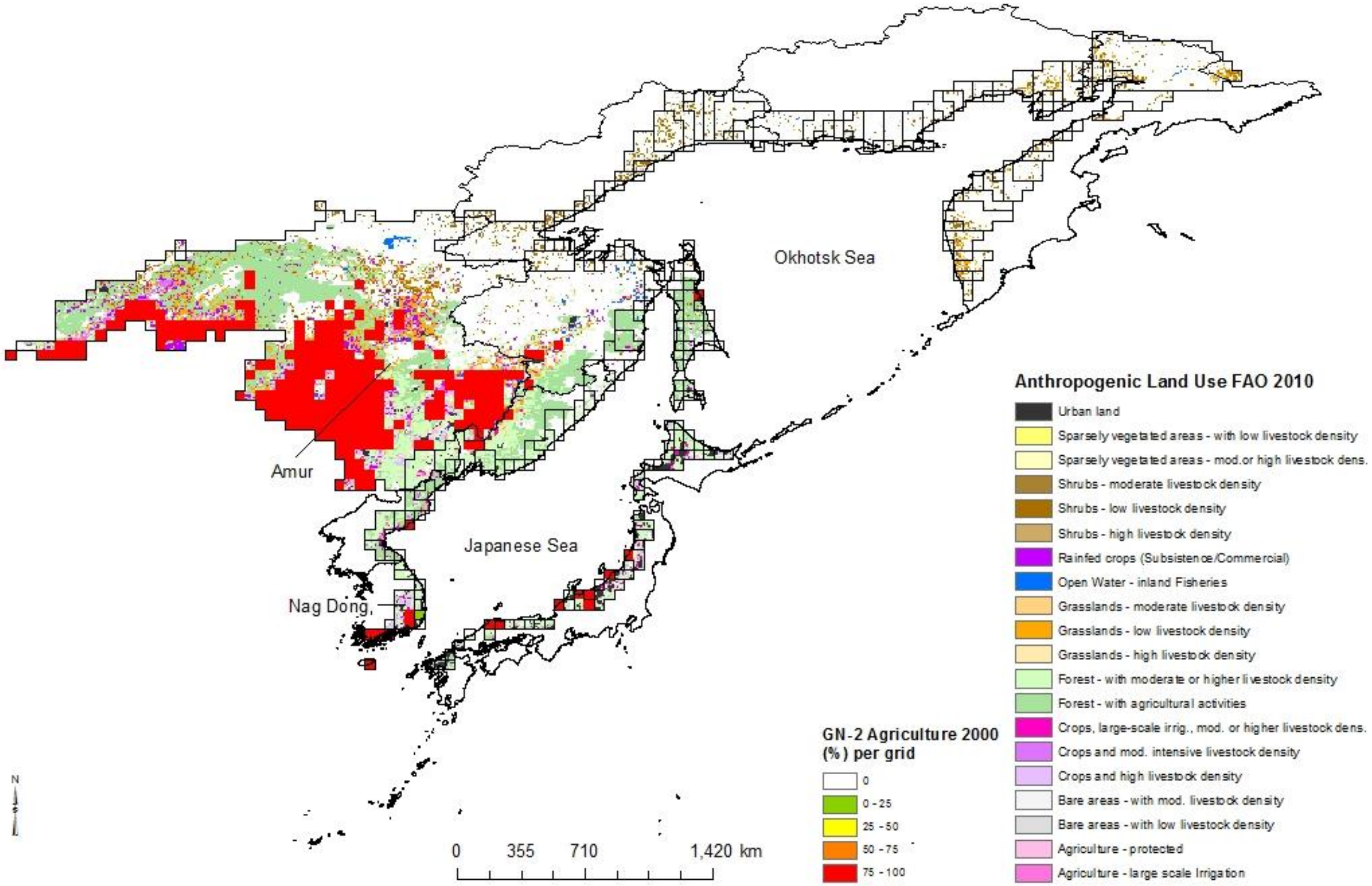


Figure 8. The FAO 2010 0.083° by 0.083° grid land use map containing agricultural activities in comparison to the Global NEWS-2 (GN-2) Agricultural map from 2000. Map F from Figure 6 is overlapped with the FAO map from Figure 7.

2.4.2 DIRECT INPUTS OF NUTRIENTS TO RIVERS

2.4.2.1 DIRECT ANIMAL MANURE DISCHARGE

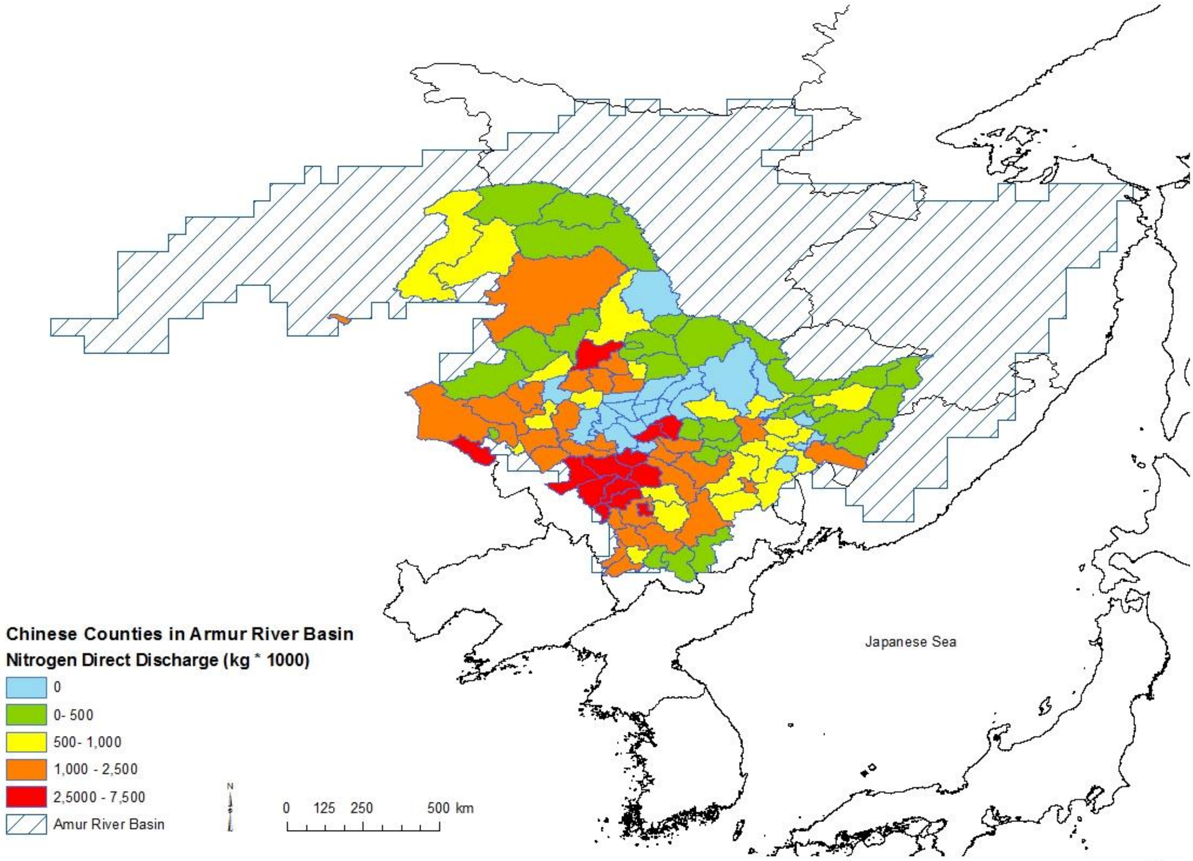
In Asia, especially in China, there is a change in how animal production is situated and managed. Due to the industrialization of animal production animal farmers are often located far from cropland. Manure is therefore rarely used as a fertilizer but often discharged as a waste product. Industrial animal production is mainly indoors in semi-urban areas [44]. In Global NEWS-2 the manure from animal production is considered a diffuses source as it is traditionally used to fertilizer crop fields [42]. A direct discharge (point source) of manure is not taken into account by the model. Strokal et. al. (2016) found that manure from industrial animal production should now be considered a point source in China. Due to farmers directly dumping manure in the river causing unexpected and intense river pollution. It was estimated that 30 - 45% of the N and 46 – 64% of the P from manure was directly discharged in rivers.

A substantial part of the Amur River basin is located in China. By using the Chinese NUFER-county (NUtrient flows in Food chains, Environment and Resources use) model [45] the estimated direct manure discharge for these region is studied (Figure 9). The NUFER-county model shows that the nutrient inputs through direct discharges of animal manure in rivers of the Amur river basin can, for certain counties, reach up to seven million kg of N and three million kg of P. To create a more accurate estimation of river nutrient export for the Japanese and Okhotsk seas it is important to take these large amounts of direct discharge of manure into account.

2.4.2.2 DIRECT HUMAN WASTE DISCHARGE

Global NEWS-2 accounts for collected human waste as a point source discharged by sewage systems. However, uncollected human waste can also be a direct source of nutrients in areas where open defecation is common. In Bangladesh, India and Pakistan the common practise of open defecation has been found to strongly influences the river nutrient export and increases the coastal eutrophication potential [6, 40, 46, 47]. To see if this may also be an issue for the Japanese and Okhotsk seas, I look into sewage connectivity statistics for each of the countries or regions connected to it.

Based on the available data the following countries / regions are analysed as an indication for the studied region: Japan, South-Korea, Sakahlin Island (Russia), Amur region (Russia) and the Kraj Chabarovsk region (Russia). I assume that households that are not connected to sewage or human waste collection systems, are practising open defecation. Japan and South-Korea show a high percentage of sewage connectivity (Table 3). For South-Korea, 14% of the rural population is not connected to sewage, meaning that about 500,000 people are not participating in any form of human waste collection systems [48]. Japan has a human waste collection system for rural areas, lowering the percentage of people without any sewage management to 0.07%. Still, that low percentage stand for 89,600 people (0.07% of 128 million) not connected to a sewage system [49].



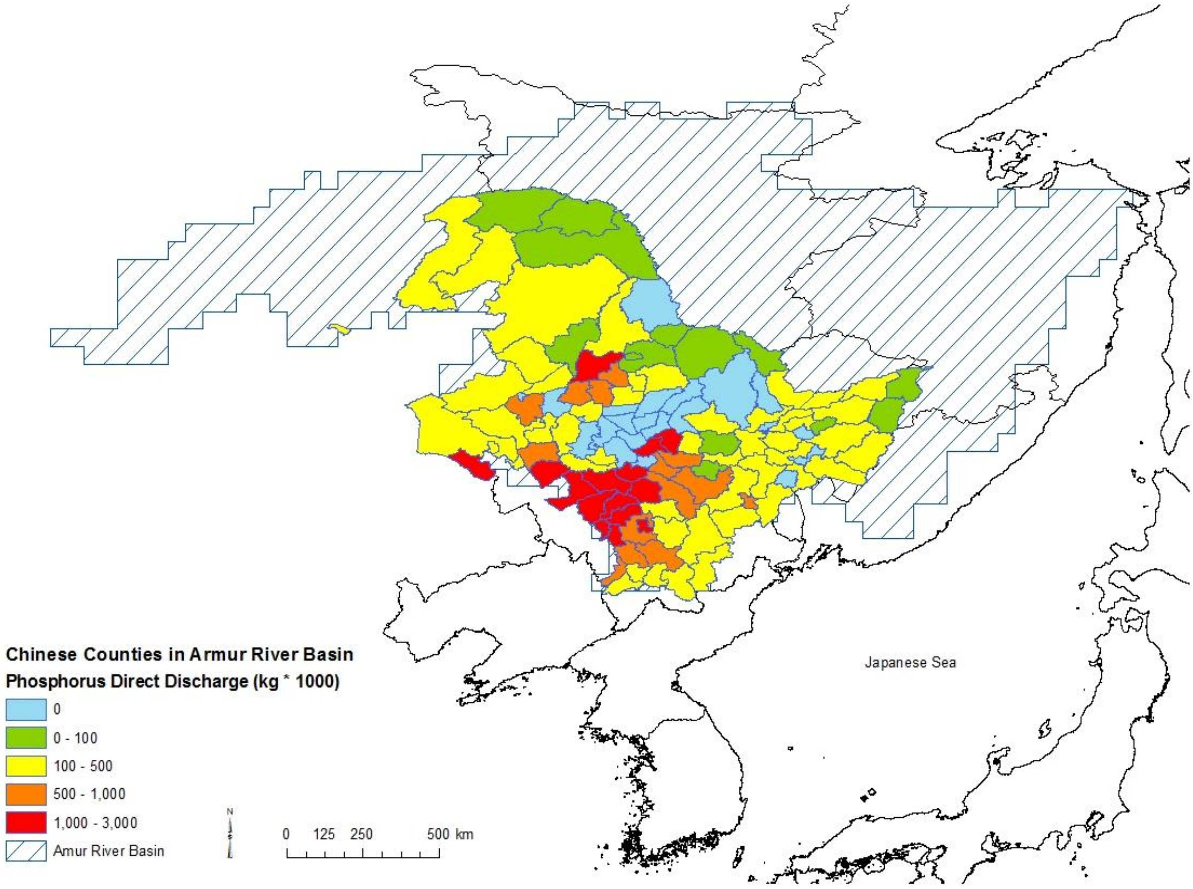


Figure 9. Direct discharge of nitrogen (N) and phosphorus (P) (kg *1000) to rivers from animal manure in Chinese counties covering the Amur River basin. Calculations from NUFER model (NUtrient flows in Food chains, Environment and Resources use) [45, 46].

In the far east Russian regions almost a third of the total population and more than half of the rural population is not connected to sewage systems. These numbers are counterbalanced by the low population density [50-53].The population density for the Kraj Chabarovsk region is around 1.6 people/km^2 while in comparison Japan has 520 people/km^2.

Table 3. Population that is not connected to sewage systems in South-Korea [48], Japan [49] and Russia (Amur region [50, 51], Kraj Chabarovsk region [52] and Sakhalin Island [53]). ** National percentages of connection to sewage systems.

Region	Area (km2 * 1000)	Total population (* 100,000)	Total population without sewage connection (%)	Rural population (*100,000)	Rural population without sewage connection (%)
South-Korea	100	520	1	36	14
Japan	378	1280	0.07	-	-
Russia, Sakhalin Island	76	2	12	-	-
Russia, Amur Region**	364	8	27	3	59
Russia, Kraj Chabarovsk**	789	13	27	2	59

Global NEWS-2 underestimates human waste discharges, but for the Japanese-Okhotsk region the input of direct human waste for the river nutrient export may be limited. For the Okhotsk sea region the population density is so low that the effect of human waste discharge may be neglected. For the Japanese see region, the low percentage of population not connected to sewage may still have an effect on the river nutrient export due to high population density.

2.4.3 AQUACULTURE

In aquaculture, aquatic plants or animals are bread for consumption, commonly in either a fenced area of a natural sea coast line or a riverine aquaculture for freshwater animals. Depending on the type of product, aquaculture can be either a sink or a source for nutrients. Most fish species bread in such environment are a nutrient source. Molluscs and seaweed on the other hand create a sink of nutrients as these species filter the water while living on the nutrients it provides [38].

Asia holds 90% of the world's aquaculture production and is still intensifying the growth of aquacultural products. The global trend is a steady amount of aquatic animals, but more coming from aquaculture and less from capture from both inland and marine/coastal aquaculture [54]. Fresh water aquaculture is not seen as a large nutrient source on a global scale, but has been found to be important and even a dominant nutrient source on local scale [55]. Marine aquaculture is a substantial sources of nutrients to the coastal waters. In some local areas, the nutrients released from marine aquaculture into the sea is comparable to the input from rivers [38]. Aquaculture therefore increases the coastal eutrophication potential. Coastal eutrophication can severely damage coastal aquacultural farms in return [7, 38, 56, 57].

Aquaculture is an important trade for the Japanese and Okhotsk seas. The increasing global trend for aquaculture is also found for each of the countries in this region as can be seen in Figure 10. Global NEWS-2 however, does not take aquaculture (either inland or marine) into account. To create a more accurate river nutrient export calculation, aquaculture should be included as a nutrient source.

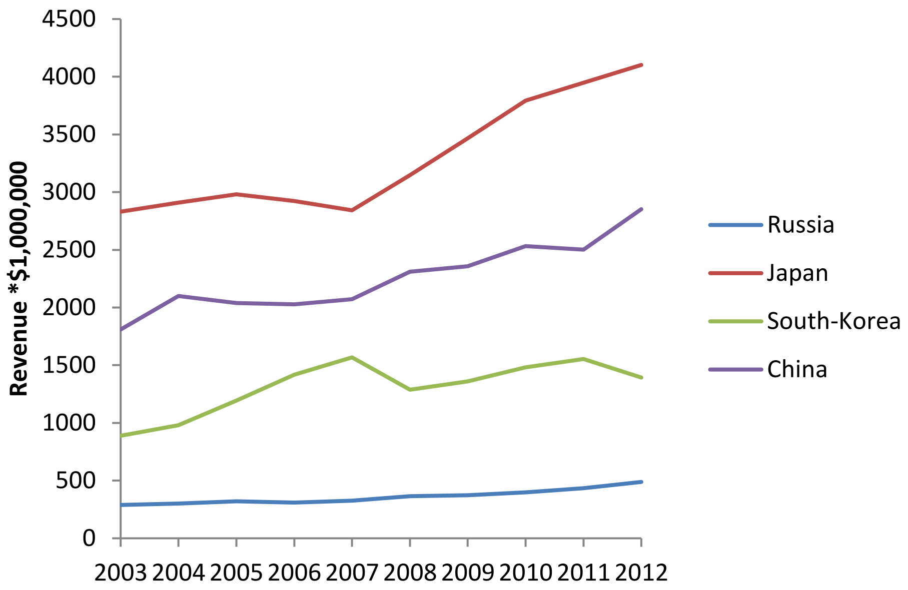


Figure 10. Aquaculture revenue (marine and riverine) in million dollars per country (2003 – 2012) [58].

2.4.4 ATMOSPHERIC N DEPOSITION OVER SEA

Human activities such as agriculture and urbanisation cause an increased concentration of reactive N in the air. Through deposition that N reaches land and sea surface, with serious implications for human health, ecosystems, biodiversity and the greenhouse gas balance [59, 60]. Increased N deposition is mainly found downwind from bigger cities [61]. Global NEWS-2 takes into account atmospheric N deposition over land, but does not included atmospheric N deposition over sea. Therefore I look into literature to find the impact of over sea atmospheric N deposition on the sea water N concentrations.

For Asia the atmospheric deposition of N over land and sea has been an issue under study for several years [59, 62, 63]. For the Japanese sea the status and effect of N deposition over sea has been studied as part of eutrophication and algal bloom research done by several institutes [61, 64]. Kim et. al. [61] measured and correlated N deposition over sea and sea water N of the Japanese Sea. They found that downwind from populated regions, there is an increasing trend in measured N deposition. The increasing trend of deposition was found to be strongly correlated to the increasing trend of sea water N and concluded that this trend was solely attributed by atmospheric N deposition. This conclusion was nuanced by Kim et. al. [64] that some of the measured increases in sea water N came from rivers, and in lesser extend from over sea deposition. At some locations in the Japanese sea near the Korean coastline, atmospheric N-deposition is seen as an important nutrient source to the coastal waters [11].

For the Okhotsk sea the situation is different, as the sea is strongly N limited and has not shown an increase of sea water N over time (1998 – 2000) [27]. With a distinct exemption of the sea surface water area around the Amur river mouth where the N concentrations are high and algal bloom happens [65]. Yoshikawa et. al. [27] observed that these elevated N values were in spring mainly from atmospheric N deposition, while in fall the discharge of the Amur river is the main source [27, 65].

Based on what I found in literature concerning the increasing N concentration caused by over sea deposition, Global NEWS-2 most probably underestimates atmospheric N deposition in total. Meaning that the model may underestimate the coastal eutrophication potential.

2.5 CONCLUSION

In this chapter I answer the following research question: **What are trends in annual river export of nutrients, and which nutrient sources are missing for the Japanese and Okhotsk seas in the Global NEWS-2 model?** The answer is found by 1) analysing the Global NEWS-2 model for the Japanese and Okhotsk sea regions, and 2) discussing the sources not yet included in Global NEWS-2 but that might be essential for the river nutrient export to these seas. An analysis of Global NEWS-2 is focused on past and future trends in river export of dissolved inorganic (DIN, DIP) and organic (DON, DOP) nitrogen (N) and phosphorus (P) to the seas. Drivers of the river export of the nutrients are also analysed. Future trends are analysed using the Global Orchestration (GO) and Order from Strength (OS) scenarios of the Millennium Ecosystem Assessment.

The Global NEWS-2 analysis shows that income per capita (GDP) of the total population and population with sewage connections increased by a factor of 1.1-3 between 1970 and 2000. The river basins of the Japanese Sea are generally more densely populated and export much more nutrients than the river basins of the Okhotsk Sea. River export of dissolved N and P to the seas increased by a factor of 1.2-2.5 between 1970 and 2000 (range for nutrient forms and seas). Higher increases are calculated for river export of DIN and DIP to both seas during this period, mainly due to urbanisation and fertilizer usage. River export of DON and DOP came mainly from leaching of organic matter from non-agricultural areas in 2000. The potential to cause coastal eutrophication (ICEP>0) was especially high for the rivers of the Japanese Sea in 2000. However, this may change in the future. River export of DIN and DIP to the Japanese Sea may decrease up to 20% and river export of DON and DOP may stay at the level of 2000 between 2000 and 2050 (GO, OS). The decreases are associated with reduced agricultural activities. In contrast, river export of DIP to Okhotsk Sea is projected to triple between 2000 and 2050 (GO). For DIN this increase is around 250%. The main reason for these increases is sewage for DIP and agriculture for DIN. For example, sewage may contribute to more than half of the DIP in rivers of the Okhotsk Sea in 2050 (GO, OS). This may increase the potential for coastal eutrophication in the Okhotsk Sea.

To increase the accuracy of the Global NEWS-2 model for the studied two sea regions, certain nutrient sources may need to be added. The land use maps of Global NEWS-2 need to be updated as they underestimate the local agricultural activities which are highly important for the Japanese and Okhotsk seas. Point sources, such as direct discharges of animal manure or human waste to rivers, have not been included in the Global NEWS-2 model. For human waste this point source might not be necessary to include for the study area because of high percentage of sewage system connection in the Japanese sea region, and low population density in the Okhotsk sea region. However, point source of animal manure is important to account for in the modelling of the Okhotsk sea. This is because intensive animal production farms directly discharge manure into Amur river basin. Aquaculture is considered as an important source of nutrients in the studied rivers too, but more at the local scale. Finally, atmospheric N deposition over the seas is a source that can bring N input into the coastal waters downwind from larger cities. In the Japanese sea and around the Amur River mouth higher levels of atmospheric N deposition have been reported in literature. Thus, direct N deposition on the coastal waters is recommended to be included in the model as well.

CHAPTER 3: SEASONAL EXPORT OF NITROGEN BY RIVERS TO THE JAPANESE AND OKHOTSK SEAS

3.1 INTRODUCTION

Eutrophication and algal bloom do not happen year round but are very much seasonal. For the South-Eastern part of Asia, algal blooms are most common in summer and early fall [7, 10, 22]. The seasonality of eutrophication is mainly caused by agricultural activities, as seen in the previous chapter. For crop production, the fertilizer usage and harvesting is depended on the crop season and is thus not equal over the year. Also the usage of e.g. household heaters during winter influences the atmospheric N deposition. When heaters are more frequently used, the N in the atmosphere increases and the deposition of N is higher [60]. Algal bloom is, besides the river nutrient export, depended on variables such as air and water temperature, solar radiation and other meteorological factors which are different each season [66].

Global NEWS-2 models with yearly averages. To make more accurate calculations for river nutrient export and eutrophication potential, it could be beneficial to updated Global NEWS-2 to a seasonal form. A Global NEWS-2 DIN seasonal model (from now on 'DIN-S') has been designed by McCrackin et. al. [37], in which the river nutrient export fluctuations between seasons became clearly visible [37]. In this chapter I will answer the research question: "**What is the effect of seasonality on the modelled river dissolved inorganic nitrogen export into the Japanese and Okhotsk seas?**".

I apply the DIN-S model for the Japanese and Okhotsk seas. In Section 3.2 I explain how the seasonal model was developed, first the original DIN-S model (Section 3.2.1), followed by the modifications I implemented to make DIN-S applicable for the Japanese-Okhotsk sea region (Section 3.2.2). I show the first results from the DIN-S Japanese and Okhotsk seas region model separately for each sea in Section 3.4. Finally I conclude by answering the research question in Section 3.5.

3.2 MODELLING SEASONAL DIN EXPORT BY RIVERS TO THE JAPANESE AND OKHOTSTK SEAS

I have developed a regionally applicable version of the DIN-S model for the Japanese and Okhotsk seas. The original DIN-S model is described in McCrackin et. al. [37], who based it on the Global NEWS-2 model described briefly in chapter 2.2. A schematic overview of DIN-S and its alterations from Global NEWS-2 are made visible in Figure 11, see also Table 4 and Table 5 for explanation of the variables and formulas. DIN-S (both global and regional) is different from Global NEWS-2 in three main compartments: temperature, N budget (Seasonal Input Calculator in Figure 11) and hydrology (Seasonal Hydrology Calculator in Figure 11). Most seasonal inputs are derived from the datasets of Global NEWS-2. Literature and expert knowledge is used for the missing information on seasonal model parameters. Some variables are given value limits to make sure they keep within natural boundaries, see Table 6. In the following sections I describe the regional seasonal approach for Japanese and Okhotsk seas.

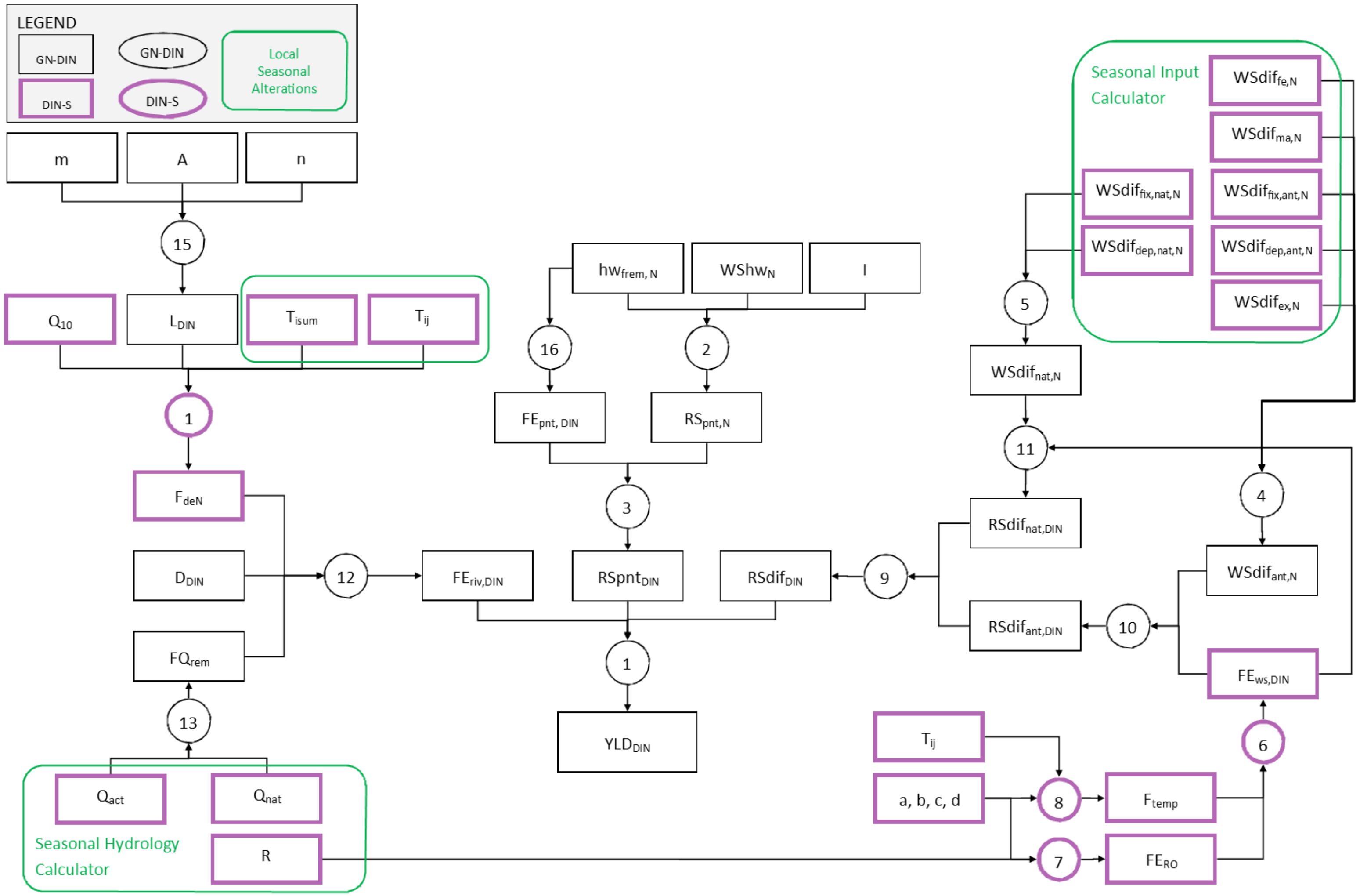


Figure 11. Flow Diagram of the Dissolved Inorganic Nitrogen – Seasonal (DIN-S) model for Japanese and Okhotsk seas. Boxes are variables, circles are equations. Purple lined variables (in boxes) and equations (in circles) are alterations from Global NEWS-2 (GN-DIN) to create DIN-S. The variables (rectangle) are explained in Table 4. The equations (circles) are explained in Table 5. The Seasonal Input Calculator and the Seasonal Hydrology Calculator are designed for region specific application of the model, see Sections 3.2.3 for N-budget and 3.2.4 for Hydrology. Source: DIN-S model [37].

Table 4. Dissolved Inorganic Nitrogen – Seasonal (DIN-S) model for Japanese and Okhotsk seas abbreviations and unites for the variables in Figure 11. Most inputs for the model variables and parameters are from the datasets of the Global NEWS-2 model [4, 37]. Literature is used to derive the information for the following variables and parameters: Q_{10}, T_{SUM}, T_{ij}, F_{deN}, Q_{act}, Q_{nat}, R, $WSdif_{fe,N}$, $WSdif_{na,N}$, $WSdif_{fix,ant,N}$, $WSdif_{dep,ant,N}$, $WS_{difex,N}$, $WSdif_{fix,nat,N}$, $WSdif_{dep,nat,N}$, $FE_{ws,DIN}$, a, b, c, d, F_{temp}, FE_{RO}. DIN = Dissolved Inorganic Nitrogen. Source: DIN-S model [37].

Abbreviation	Description	Unit
Basin	Name of the basin	name
A	Size of basin area	km^2
m	Fitted parameter in relationship between basin area (A) and river retention, set at 0.065	-
n	Fitted parameter in relationship between basin area (A) and river retention, set at 0.0443	-
Yld_{DIN}	River export of DIN at the mouth in yields	$kg/km^2/yr$
$FE_{riv,DIN}$	Export fraction of DIN in rivers reaching the river mouth	0-1
$RSpnt_{DIN}$	The export of DIN from the watershed to streams via point sources	$kg/km^2/yr$
$RSdif_{DIN}$	The export of DIN from the watershed to streams via diffuse sources, both natural and anthropogenic	$kg/km^2/yr$
$FE_{pnt,DIN}$	Fraction of $RSpnt_N$ emitted as DIN, linear empirical function of $hw_{frem,N}$	0-1
$RS_{pnt,N}$	Basin area normalized point-source emission (effluent) to streams of element N	$kg/km^2/yr$
$hw_{frem,N}$	Fraction of N in sewage influent removed via wastewater treatment	0-1
I	Fraction of the population connected to sewage systems	0-1
$WShw_N$	Gross human-waste source to the watershed	$kg/km^2/yr$
$WSdif_{ant,N}$	N inputs to agricultural areas of the watershed	$kg/km^2/yr$
$WSdif_{nat,N}$	N inputs to non-agricultural areas of the watershed	$kg/km^2/yr$
$WSdif_{fe,N}$	N input to land by synthetic fertilizers	$kg/km^2/yr$
$WSdif_{ma,N}$	N input to land by manure application	$kg/km^2/yr$
$WSdif_{fix,ant,N}$	N input to land by biological N fixation by crops	$kg/km^2/yr$
$WSdif_{dep,ant,N}$	N input over agricultural land by atmospheric N deposition	$kg/km^2/yr$
$WSdif_{ex,N}$	N export from land via harvested crops and animal grazing	$kg/km^2/yr$
$WSdif_{fix,nat,N}$	N input to land by ecosystem biological N fixation	$kg/km^2/yr$
$WSdif_{dep,nat,N}$	N input over non-agricultural areas through atmospheric N deposition	$kg/km^2/yr$
$FE_{ws,DIN}$	Export fraction of N gross inputs to land, reaching surface waters	0-1
FE_{RO}	Fraction of watershed N inputs exported to rivers as DIN as a function of aggregated monthly runoff prediction by season	0-1
F_{temp}	Temperature dependence factor	°C
R	Mean seasonal runoff from land to streams before consumptive water abstraction	mm/yr
T_{ij}	Average temperature for season (+41)	°C
T_{isum}	Average temperature of effective summer season (+41)	°C
a, b, c, d	Calibrated parameters per season	-
$RSdif_{DIN}$	Total diffuse-source watershed export to streams for DIN	
$RSdif_{expl,ant,DIN}$	Export of N as dissolved form DIN originating in explicit, diffuse sources and sinks over agricultural land	$kg/km^2/yr$
$RSdif_{expl,nat,DIN}$	Export of N as dissolved form DIN originating in explicit, diffuse sources and sinks over non-agricultural land	$kg/km^2/yr$
D_{DIN}	Discharge-weighted average of the DIN retention within reservoirs of a basin	0-1
FQ_{rem}	Consumptive water removal fraction	0-1
F_{deN}	Denitrification fraction in river channel	0-0.65
L_{DIN}	Retention fraction within river network	0-1
Q_{act}	Total river discharge at the mouth after human water withdrawal	km^3/yr
Q_{nat}	Total river discharge at the mouth before human water withdrawal	km^3/yr
Q_{10}	Adjustment factor based on differences in average air temperature relative to summer	-

Table 5. Dissolved Inorganic Nitrogen – Seasonal (DIN-S) model for Japanese and Okhotsk seas formulas. Numbering links back to the formula numbers in Figure 11. Most inputs for the model variables and parameters are from the datasets of the Global NEWS-2 model [4, 37]. Equation 6, 7, 8 and 14 are marked, as they are DIN-S specific formula's. Source: DIN-S model [37].

Eq. nr.	Equation	Description
1	$Yld_{DIN} = FE_{riv} \cdot [(RS_{pnt,DIN}) + (RSdif_{DIN})]$	Yield DIN
2	$RSpnt_N = (1 - hw_{frem,N}) * I * Wshw_N$	Point-source emissions of element N (effluents) to streams
3	$RSpnt_{DIN} = FE_{pnt,DIN} * RSpnt_N$	Export of DIN from the watershed to streams via point sources
4	$WSdif_{ant,N} = WSdif_{fe,N} + WSdif_{ma,N} + WSdif_{fix,ant,N} + WSdif_{dep,ant,N} - WSdif_{ex,N}$	N budget for agricultural areas of the watershed
5	$WSdif_{nat,N} = WSdif_{fix,nat,N} + WSdif_{dep,nat,N}$	N budget for non-agricultural areas of the watershed
<u>6</u>	$FE_{ws.DIN} = FE_{RO} * (1 - F_{temp})$	Watershed export fraction term
<u>7</u>	$FE_{RO} = b * R^a$	Fraction of catchment N inputs exported as DIN as a function of aggregated monthly runoff prediction by season
<u>8</u>	$F_{temp} = d\left(\frac{T}{100}\right)^c$	Temperature dependence factor
9	$RSdif_{DIN} = RSdif_{expl,ant,DIN} + RSdif_{expl,nat,DIN}$	Total diffuse-source watershed export to streams for DIN
10	$RSdif_{expl,ant,DIN} = FE_{ws,DIN} * WSdif_{ant,N}$	Export of N as dissolved from DIN originating in explicit, diffuse sources and sinks over agricultural land
11	$RSdif_{expl,nat,DIN} = FE_{ws,DIN} * WSdif_{nat,N}$	Export of N as dissolved from DIN originating in explicit, diffuse sources and sinks over non-agricultural land
12	$FE_{riv,DIN} = (1 - F_{deN})(1 - FQ_{rem})(1 - D_{DIN})$	Export fraction of DIN in rivers reaching the river mouth
13	$FQ_{rem} = 1 - \frac{Q_{act}}{Q_{nat}}$	Consumptive water removal fraction
<u>14</u>	$F_{deN} = L_{DIN} * Q_{10}^{\frac{T_{ij} - T_{isum}}{10}}$	Temperature based denitrification fraction in river channel
15	$L_{DIN} = m * \ln(A) - n$	Retention fraction within river network
16	$FE_{pnt,DIN} = 0.485 + 0.255 * \frac{hw_{frem,N}}{0.8}$	Fraction of $RSpnt_N$ emitted as DIN, linear empirical function of $hw_{frem,N}$

Table 6. Value limits for Dissolved Inorganic Nitrogen – Seasonal (DIN-S) model variables

Abbreviation	Motivations	Value limit [37]
$WSdif_{ant,N}$	A negative $WSdif_{ant,N}$ would imply depletion of N from the soil what cannot happen in reality. Negative numbers are avoided for modelling purposes	>= 0
FQrem	A fraction must be between 0 and 1	0 - 1
FE_{RO}	A fraction must be between 0 and 1	0 - 1
T_{ij}	Due to optimum dense water temperature at 4°C, the seasonal temperature in the model has a bottom limit of 4°C to represent water close to the soil. In the model T = T+41 to prevent negative numbers.	>= 4°C (45)
F_{den}	To avoid extrapolation error the values are set between 0 and 0.65	0 - 0.65

3.2.1 EFFECTIVE SEASONS AND BASIN GROUPING

To account for the different seasons present in the Japanese and Okhotsk seas, I have determined the effective seasons present in the regions. Effective seasons are the climatological seasons, other than the calendar seasons. Summer was determined by grouping the three months with the on average highest air temperature, the following seasons were ordered based on summer.

The Okhotsk sea has strong differences in seasonality when comparing north and south. The north two seasons, the area is frozen over roughly six months per year. The southern part includes the larger Amur river basin and experiences four seasons with summer from June till August. The Japanese sea experiences four seasons over the complete region. The summer for the northern part is from June till August, for the south it is July till September (See Table 7).

For making the most accurate separation between the north and south part of each sea, I have looked into the population density data present in the Global NEWS-2 model. There are many small basins in both sea regions. To account for accuracy the river basins included in the DIN-S model have to be larger than two grid points. The results is four different regions, two for each sea, see Table 7 and Figure 12. The N input budget and temperature details are determined per basin group, hydrology per river basin (explained in the following sections).

Table 7. Basin Groups for the Japanese and Okhotsk seas based on a) effective seasons and b) populations statistics. See Figure 12 for the locations of the basin groups.

Abbreviation	Description	Summer
OKH-H	Okhotsk sea - Human Activity	Jun - Aug
OKH-N	Okhotsk sea - Non Human Activity	May - Sep
JPN-H	Japanese sea - High Human Activity	Jul - Sep
JPN-L	Japanese sea - Low Human Activity	Jun - Aug

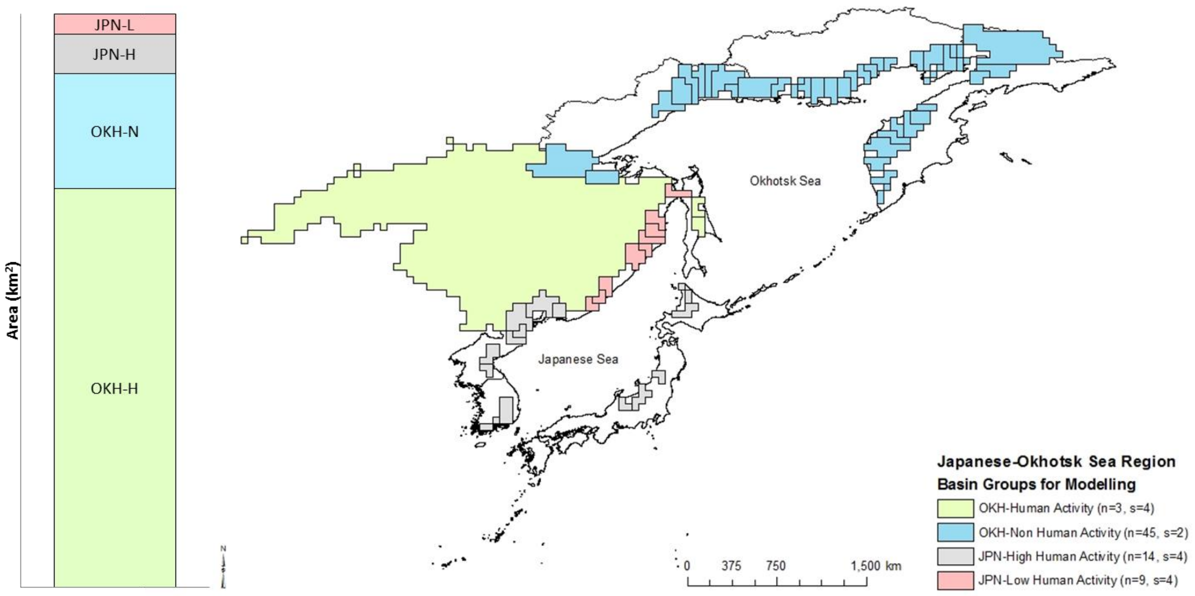


Figure 12. LEFT: Total area share per basin group (km^2). RIGHT: Map of Basin Groups in the Japanese and Okhotsk seas. OKH- Okhotsk sea, JPN= Japanese sea, n = number of basins, s = number of seasons.

3.2.2 TEMPERATURE

Throughout the seasonal model, temperature is included in two variables (following McCrackin et. al. [37]): Removal DIN in river network by denitrification as function of basin area and temperature (F_{deN}), and fraction of diffuse DIN sources that is transported from soils to the river network ($FE_{WS,DIN}$).

F_{deN} is made depended upon the seasonal temperature. Summer has the highest average temperature (effective season, see 3.2.1 Effective Seasons and Basin Grouping), and thus the F_{deN} is then equal to the retention fraction within the river network (L_{DIN}). For the other seasons the difference in average temperature from summer is calculated as a reducing factor (see equation 14, numbers of the equations are equal to Figure 11 and Table 5). The Q_{10} variable in equation 14 is the adjustment factor for temperature differences (2.71 for T<12ºC and 2.54 for T>12ºC) [37].

$$F_{deN} = L_{DIN} * Q_{10}^{\frac{T_{ij} - T_{isum}}{10}} \quad (14)$$

The fraction of diffuse N sources that is transported from soils to the river network (FE_{ws}) is made temperature depended. This is done by including the fraction of catchment N exported as DIN as a function of temperature (F_{temp}) (see equation 6 and 8, numbers of the equations are equal to Figure 11 and Table 5).

$$FE_{ws.DIN} = FE_{RO} * (1 - F_{temp}) \quad (6)$$

$$F_{temp} = d\left(\frac{T}{100}\right)^{c} \quad (8)$$

3.2.3 N-BUDGET

The Global NEWS-2 yearly N-budget is divided over the seasons per basin group according to Table 8 for OKH-N, and Table 9 for the JPN-H, JPN-L and OKH-H. The percentages per season came about through expert judgement, country statistics [67-69] and literature research [70-80].

Human waste ($WShw_N$) is expected to stay equal throughout the year as human excrement is not so much seasonally dependent. The statistic websites of South-Korea, Japan and Russia [67-69] show a detailed overview of the crops grown, area size and weight. These inputs have been used to create an estimations of fertilizer use per country ($WSdif_{fe,N}$). For South-Korea and Japan the most dominant grown crop is paddy rice, 80% and 45% of the total cropping respectively. According to literature [75] and expert judgement these rice fields are dominantly fertilized in spring and some small fertilizing in autumn. In Japan there is also a certain percentage (12%) of the total cropping dedicated to vegetables which are fertilized in spring, summer and fall depending on the specific vegetable species [67]. The remaining percentages are divided among several cropping types such as wheat, feed and forage crops, fruit trees and pulses. In the far east region of Russia the dominant crop is soybeans, followed by cereals, potatoes and forage crops. Soybeans do not require fertilization as the crop species N fixation capacity [76]. While for cereals the soil is fertilized in winter and spring [78] for potatoes the fertilization happens dominantly in summer [73, 79].

For manure application to land ($WSdif_{ma,N}$), in the Japanese sea region the manure is collected throughout the year, then fermented and applied to the land in late winter and the beginning of spring (expert judgement). This method is common in the regions with paddy rice production (expert judgement), which is the most dominant crop species in the JPN-H river basin group [68] In the Okhotsks sea region, manure is used mainly in spring for planting season. Some smaller amounts are added to the land in summer for the further growth of the crop and in fall after harvest so the land can recover from the summer crop season and in some parts of the OKH-H basin group to prepare for winter cropping [69].

The biological N deposition for both agricultural land ($WSdif_{dep,ant,N}$) and non-agricultural land ($WSdif_{dep,nat,N}$) are taken from measured deposition values published by Onitsuka et. al. [72]. Biological N fixation for agricultural land ($WSdif_{fix,ant,N}$) depends on the crop growth season which is dominantly in spring and summer [77]. The biological N fixation for non-agricultural land ($WSdif_{fix,nat,N}$) follows a more natural seasonal variation where spring and summer have high values as the plants and trees are developing leaves and grow. In fall the leaves fall off and the N fixation stops, throughout winter there is no N fixation due to the freezing temperatures [80].

Finally there is also removal of N through harvesting of crops and grazing ($WSdif_{ex,N}$). The paddy rice harvest is in early fall (JPN-H), the spring wheat, potatoes and soybeans are harvested late summer through to early fall (JPN-L and OKH-H) [67-69]. Grazing happens in spring, summer and fall. In winter time the animals are kept inside and thus no grazing occurs (expert judgement).

To calculate the division per season shown in Table 8 and 9 for each river basin, I developed the Seasonal Input Calculator (see Figure 13). Each basin has an annual value for each of the N-budget values which serves as an input. The calculator then divides this annual value over seasons according to percentages determined for the basin's basin group.

Table 8. Seasonal N-Budget (% of yearly N-budget), for Okhotsk sea – Non Human activity (OKH-N) basin group.

Abbreviation	description	Basin Group	summer	winter
$WShw_N$	raw total elemental N emission to watershed from human waste (excrement)	OKH-N	50	50
$WSdif_{fe,N}$	N input by synthetic fertilizers	OKH-N	100	0
$WSdif_{ma,N}$	N input by manure application	OKH-N	100	0
$WSdif_{fix,ant,N}$	N input by biological n fixation by crops	OKH-N	100	0
$WSdif_{dep,ant,N}$	N input over agricultural land by atmospheric N deposition	OKH-N	100	0
$WSdif_{ex,N}$	N withdrawal in harvested crops and animal grazing	OKH-N	100	0
$WSdif_{fix,nat,N}$	N input by ecosystem biological N fixation	OKH-N	100	0
$WSdif_{dep,nat,N}$	N input over non-agricultural areas through atmospheric N deposition	OKH-N	90	10

Table 9. Seasonal N-Budget (% of yearly N-budget per season), for the Japanese Sea – High human activity (JPN-H), the Japanese Sea – Low human activity (JPN-L) and Okhotsk sea – Human activity (OKH-H) basin groups.

Abbreviation	Description	Basin Group	summer	fall	winter	spring
$WShw_N$	Raw total elemental N emission to watershed from human waste (excrement)	JPN-L	25	25	25	25
		JPN-H	25	25	25	25
		OKH-H	25	25	25	25
$Wsdif_{fe,N}$	N input by synthetic fertilizers	JPN-L	30	10	30	30
		JPN-H	20	20	10	50
		OKH-H	30	10	30	30
$Wsdif_{ma,N}$	N input by manure application	JPN-L	25	25	0	50
		JPN-H	10	10	40	40
		OKH-H	25	25	0	50
$Wsdif_{fix,ant,N}$	N input by biological N fixation by crops	JPN-L	50	0	0	50
		JPN-H	50	0	0	50
		OKH-H	50	0	0	50
$Wsdif_{dep,ant,N}$	N input over agricultural land by atmospheric N deposition	JPN-L	17	37	21	26
		JPN-H	18	27	27	28
		OKH-H	17	37	21	26
$Wsdif_{ex,N}$	N withdrawal in harvested crops and animal grazing	JPN-L	40	45	0	15
		JPN-H	10	75	5	10
		OKH-H	40	45	0	15
$Wsdif_{fix,nat,N}$	N input by ecosystem biological N fixation	JPN-L	40	10	0	50
		JPN-H	40	10	0	50
		OKH-H	40	10	0	50
$Wsdif_{dep,nat,N}$	N input over non-agricultural areas through atmospheric N deposition	JPN-L	17	37	21	26
		JPN-H	18	27	27	28
		OKH-H	17	37	21	26

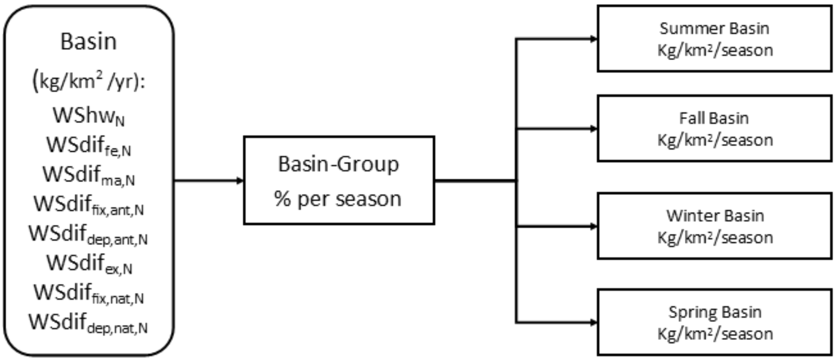


Figure 13. Flow diagram of Seasonal Input Calculator. The individual basin annual input from Global NEWS-2 (kg/km2/yr) is divided over the four seasons according to the percentages of the basin group it is in (see Figure 10 for location of the basin groups, see Table 8 and 9 for abbreviations and percentages per basin group). For the Okhotsk-Non Human activity basin group (OKH-N) the output would be for winter and summer only, as it has only two seasons instead of four. Rounded box = Global NEWS-2 data, squared box is DIN-S model data. DIN-S = Dissolved Inorganic Nitrogen – Seasonal.

3.2.4 HYDROLOGY

Different from the McCrackin method is the hydrology, calculated per basin using the hydrology calculator I have developed, see Figure 14. The calculator takes two inputs: monthly river discharge at the mouth after human water withdrawal (Q_{act}) [34] and the Global NEWS-2 annual Q_{act} and annual river discharge at the mouth before human water withdrawal (Q_{nat}) [4]. Though the hydrology is calculated per basin, the sum of seasons in final step op the hydrology calculator is done according to the effective seasons of the basin groups (see Table 7, page 32).

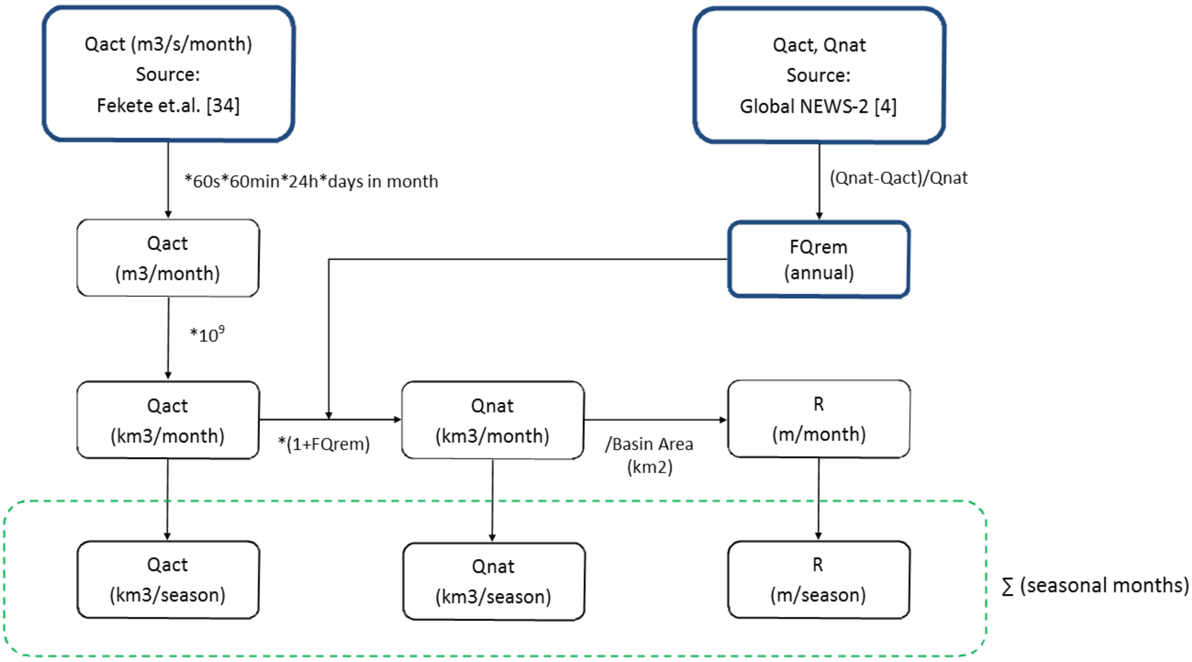


Figure 14. Hydrology calculator flow chart applied per river basin for both the Japanese and Okhotsk seas. Hydrology is calculated per river basin according to the effectives season of basin group the river basin is in. Blue boxes are input, variables in green box are outputs which are summed to the effective seasons. For abbreviations see Table 4, for effective seasons see Table 7.

3.3 SEASONAL DIN RIVER EXPORT TO THE JAPENSE AND OKHOTSK SEAS

3.3.1 JAPANESE SEA

For the Japanese sea, the differences in river DIN export per season are strong, see Table 10 and Figure 15. In the JPN-H basin group roughly two third of the yearly DIN export happens in winter and spring. For the JPN-L basin group half of the yearly DIN export happens in spring only, a third of the DIN export happens in fall.

For the JPN-H basin group the DIN export to coastal waters is highest for winter and spring, which is related to the agricultural activity of paddy rice growth. The land is prepared with fertilizer and manure in late winter and early spring. The JPN-L basin region has a peak in spring and fall, also in this region there is paddy rice cropping with land preparation in early spring. But there is winter cropping as well in this area, for which the land is prepared in fall.

Table 10. seasonal DIN river export per basin group for the Japanese Sea in percentage (%) of total yearly DIN river export. JPN-H = Japanese Sea- high human activity basin group, JPN-L = Japanese sea – low human activity basin group. Source: see Section 3.2 for the model description.

DIN river export	Summer	Fall	Winter	Spring	Total
	%	%	%	%	%
JPN-H	15	16	35	34	100
JPN-L	14	25	11	50	100

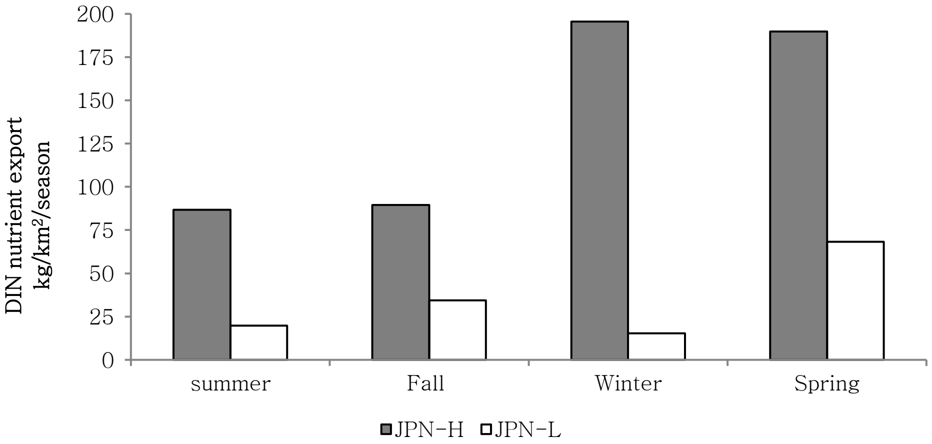


Figure 15. Seasonal DIN river nutrient export for the Japanese sea. JPN-H = Japanese sea – high human activity basin group, JPN-L = Japanese sea low human activity basin group. Source: see Section 3.2 for the model description.

I selected the Nag Dong and Tumnin river as examples to show DIN export by individual rivers. The selected rivers have larger drainage areas than other rivers in the two basin groups. The average pattern of the basing groups are visible in each of the rivers. High DIN river export is found in either winter and spring for JPN-H (Nag Dong) or fall and spring (Tumnin) (Figure 16). In Figure 17 (page 39) the alterations of DIN nutrient export for each individual river basin is made visible in a map. The seasonal variance is different for individual basins, some river basins have a strong seasonal variance, while others are less defined.

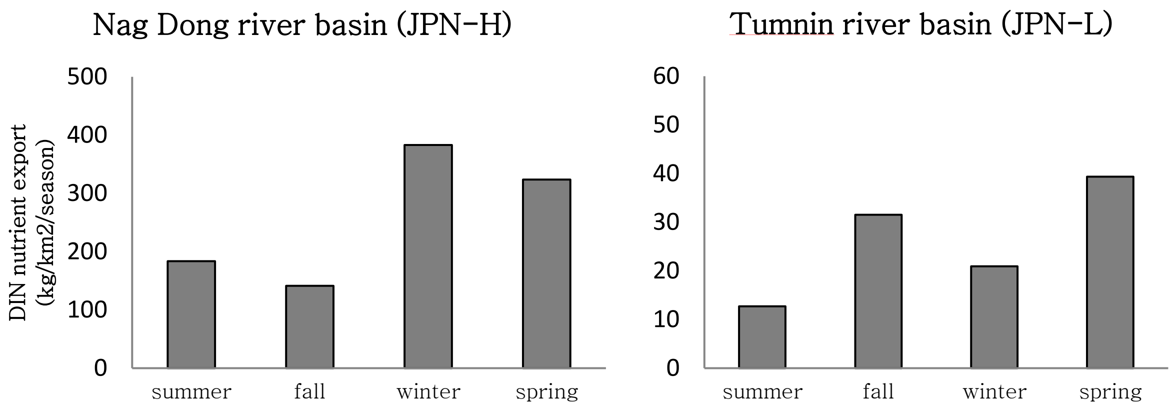


Figure 16. Seasonal DIN river nutrient export for Nag Dong river basin (South-Korea) and for Tumnin river basin (Russia). JPN-H = Japanese sea - high human activity basin group, JPN-L = Japanese sea low human activity basin group. Source: see Section 3.2 for the model description.

Global NEWS-2 calculates 694 kg/km^2/yr for the Japanese sea (basins >2 grids), where the DIN-S model calculates a total of 355 kg/lm^2/yr. For an comparison between DIN-S and Global NEWS-2 DIN yield per rivers basin see Appendix 2.

3.3.2 OKHOTSK SEA

In the Okhotsk sea region there are the two basin groups with each different effective seasons. For the OKH-H basin group with four seasons, half of the DIN river export is in spring and a third is exported in winter. The OKH-N basin group has two seasons, for which 96% of the DIN river export happens in summer, see Table 11 and Figure 18. This is explained by the severe winters in this region, where rivers and soil are frozen for almost six months each year.

Table 11. seasonal DIN river export per basin group for the Okhotsk Sea, in percentage of the total yearly DIN river export (%). OKH-H = Okhotsk Sea - Human activity basin group, OKH-N = Okhotsk sea - Non human activity basin group. OKH-N has 2 season (summer and winter). Source: see section 3.2 for the model description.

DIN river export	Summer	Fall	Winter	Spring	Total
	%	%	%	%	%
OKH-H	9	16	28	46	100
OKH-N	96		4		100

The DIN-S model has the tendency to underestimate the total DIN yield (sum of seasons) in comparison to the Global NEWS-2 model due to the denitrification becoming temperature dependent.

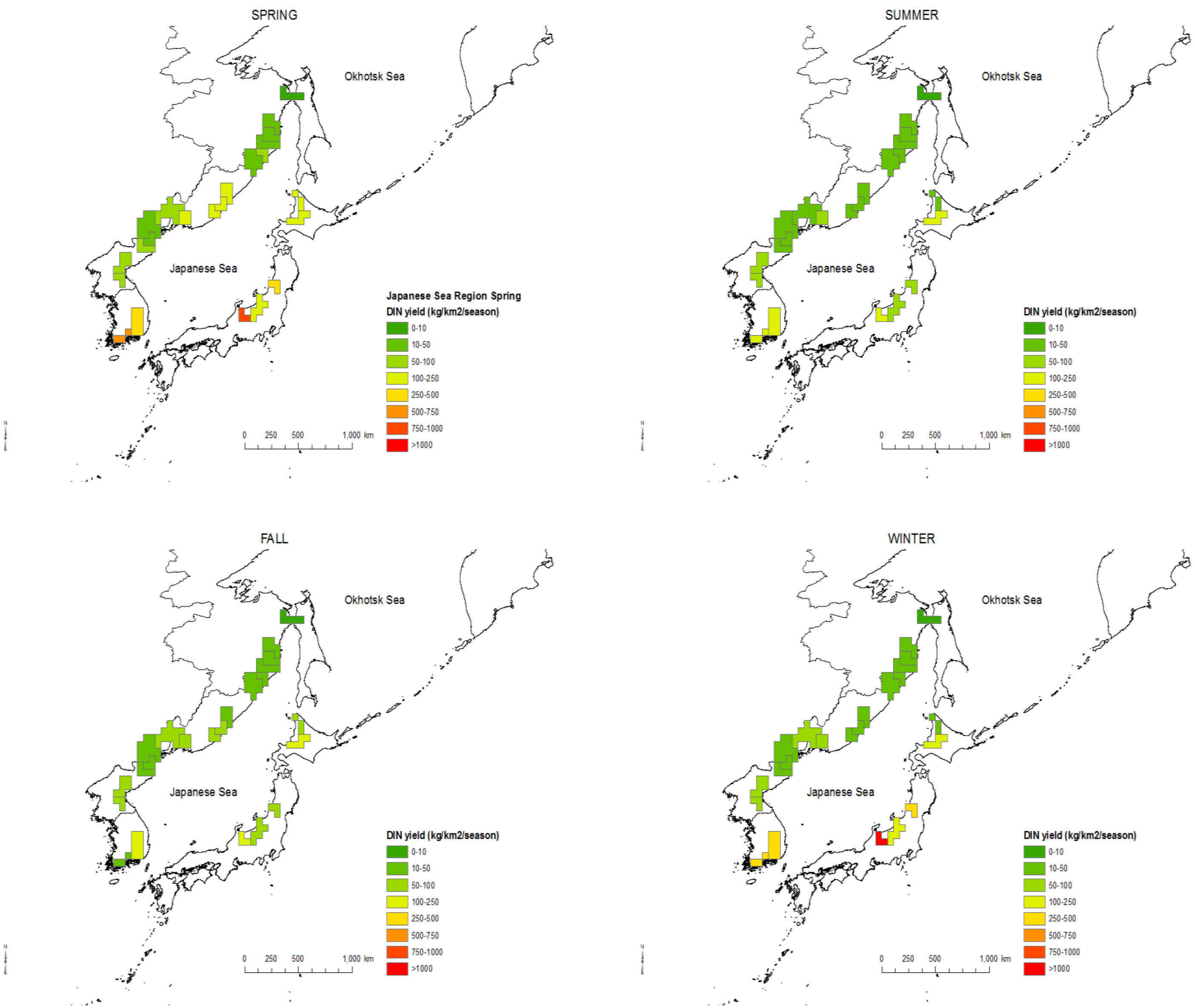


Figure 17. Seasonal DIN river nutrient export (kg/km^2/season) for the Japanese Sea. Source: see section 3.2 for the model description.

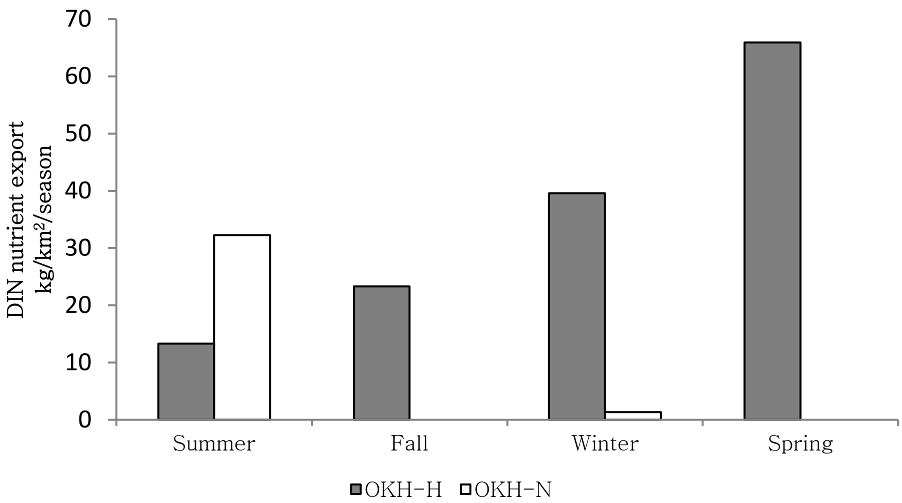


Figure 18. Seasonal DIN river nutrient export for the Okhotsk Sea (kg/km^2/season). OKH-H = Okhotsk Sea - Human activity basin group (four seasons), OKH-N = Okhotsk sea - Non human activity basin group. OKH-N (two season: summer and winter). Source: see Section 3.2. for the model description.

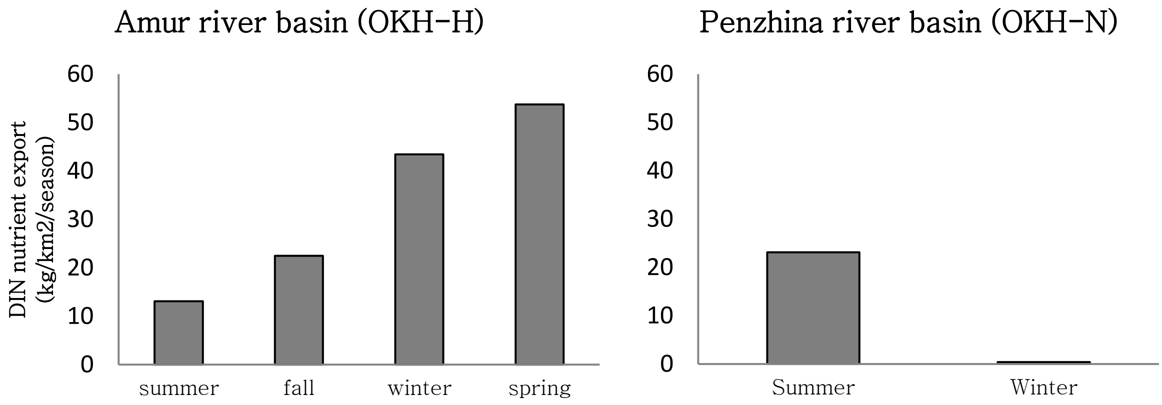


Figure 19. Seasonal DIN river nutrient export (kg/km2/season) for the Amur river basin (Russia), and for the Penzhina river basin (Russia). OKH-H = Okhotsk Sea - Human activity basin group (four seasons), OKH-N = Okhotsk sea - Non human activity basin group. OKH-N (two season: summer and winter). Source: see Section 3.2. for the model description.

The Amur river basin is by far the largest river basin in the Okhotsk sea region. It is also the dominant source of DIN to the Okhotsk sea, providing 99% of the yearly yield (141 kg/km^2/year from Amur, out of 142 kg/km^2/year for the total basin group). The seasonal DIN export pattern of the Amur river and Okhotsk sea are therefore very similar (see Figure 18 and Figure 19). Also, when adding the four seasons for the Amur river (140 kg/km^2/yr) and compare it to the annual river DIN export for Amur from the Global NEWS-2 model (77 kg/km^2/yr) it is higher. This overestimation is caused by several seasons having less retention and higher nutrient inputs. An overview of the different inputs to land and river, as well as export to river for the Amur river see Appendix 3. An overview of the seasonal DIN river export per river basin is made visual in Figure 20 for the OKH-H basin group and Figure 21 for the OKH-N basin group. The seasonal variation is clearly visible for the individual river basins in Okhotsk river basin groups.

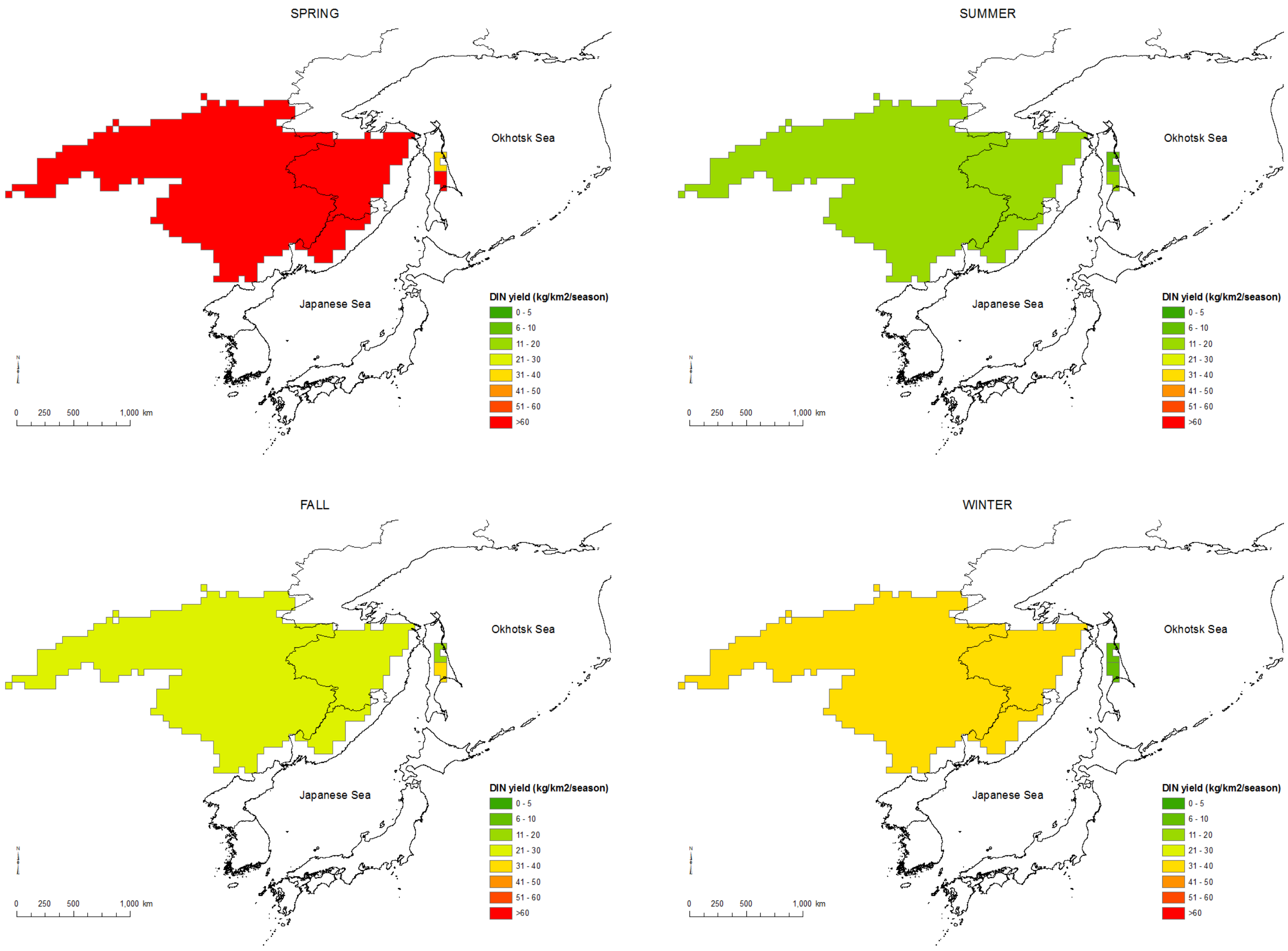


Figure 20. Seasonal DIN river nutrient export (kg/km2/season) for the Okhotsk-Human activity (OKH-H) basin group. Source: see Section 3.2. for the model description.

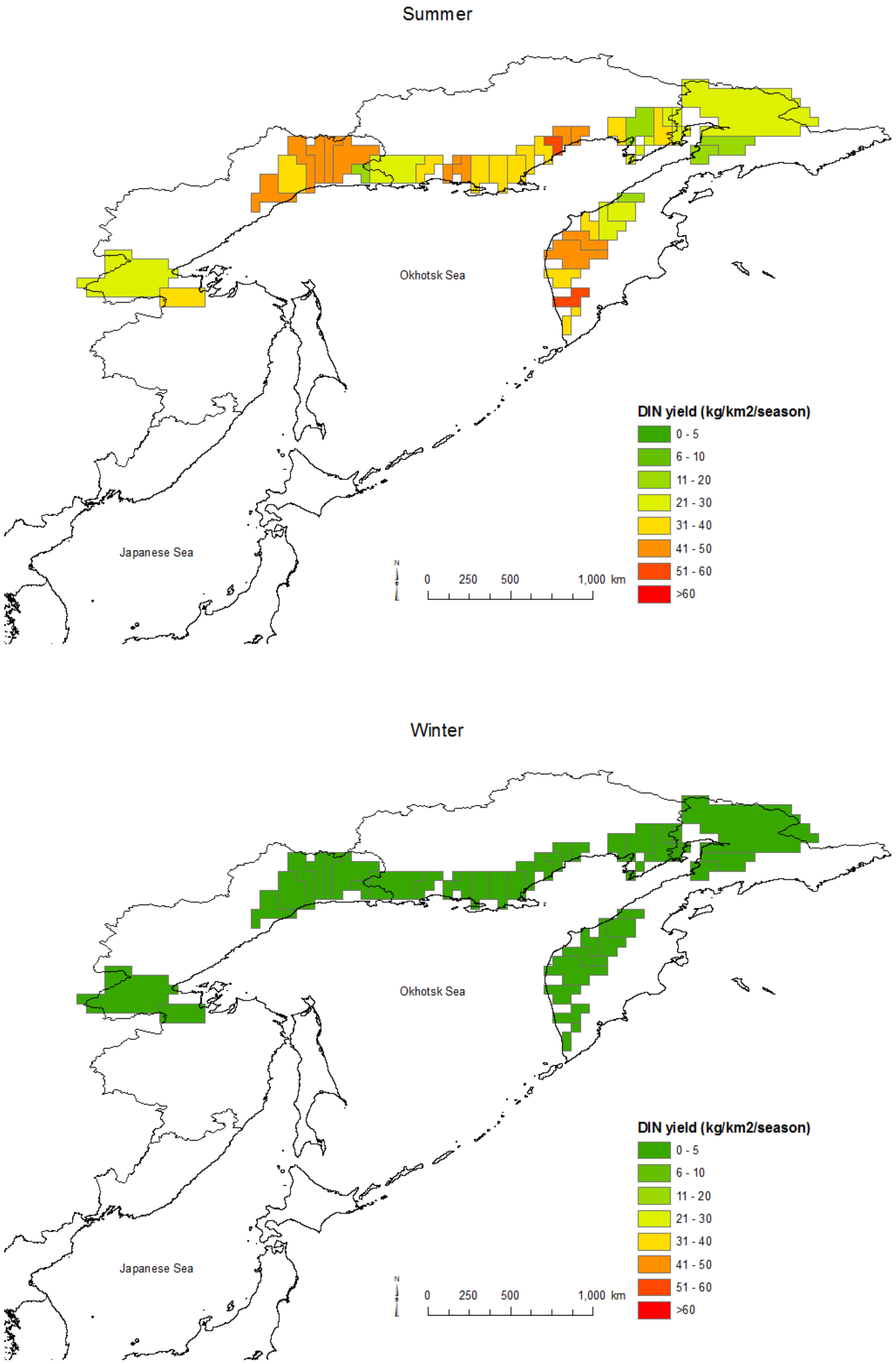


Figure 21. Seasonal DIN river nutrient export for the Okhotsk sea – Non human activity (OKH-N) basin group. OKH-N has two effective seasons: winter and summer. Source: see Section 3.2. for the model description.

3.4 CONCLUSION

In this chapter I answer the following research question: "**What is the effect of seasonality on the modelled river dissolved inorganic nitrogen export into the Japanese and Okhotsk seas?**". The answer is found by applying the Dissolved Inorganic Nitrogen Seasonal model (DIN-S) of McCrackin et. al. [37].

Alterations have been made to the DIN-S model in hydrology, nitrogen-budget and temperature to make it specifically applicable for the Japanese and Okhotsk seas. The study area is separated in 1) two and four seasons according to temperature, and 2) low and high human activity according to population density. This separation created four basin groups: Japanese Sea – High human activity (JPN-H), Japanese Sea – Low human activity (JPN-L), Okhotsk Sea – Human activity (OKH-H) all with four seasons and Okhotsk Sea – Non human activity (OKH-N) with two seasons (winter and summer).

For JPN-H the DIN nutrient export is high in winter and spring, each season exports a third of the yearly DIN. Winter is crop land preparation time and spring planting season. Therefor the high DIN export in winter and spring are explained by the manure and fertilizer usage in crop production. In the JPN-L basin group half of the yearly DIN export happens in spring, which concurs with planting season. Here there are two crop seasons: summer and winter crops. Therefore a second DIN export peak is found for fall, exporting a third of the yearly DIN when preparing the land and sowing winter crops. For the Okhotsk sea the OKH-H basin group shows a clear peak in DIN river export in spring, exporting almost half of the yearly DIN. A third of the DIN is exported in winter, showing a similar pattern to that of the JPN-H basin group, but with much lower DIN fluxes. The OKH-N basin group has only two seasons, through-out winter the region is completely frozen. In that time river export is minimal. The DIN export therefor happens for 96% in summer.

The effect of seasonality on the modelled DIN river export for both the Japanese and Okhotsk seas is strong variations among seasons. A clear pattern of high DIN export in spring and low DIN export in summer is found in case of four seasons. When dealing with two seasons, river DIN export happens mainly in summer and is close to zero in winter. Insights into the modelling results for seasonal variation of DIN river export to the seas can help to manage seasonal eutrophication problems more effective in the future.

CHAPTER 4. DISCUSSION AND CONCLUSION

4.1 DISCUSSION

4.1.1 INTRODUCTION

The main objective of my MSc thesis research is to analyse nutrient inflow into the Japanese and Okhotsk seas by updating the Global NEWS-2 model with specific reference to seasonality. To reach this objective I have analysed the Global NEWS-2 outputs for the Japanese and Okhotsk seas, studied the missing sources for this region in the Global NEWS-2 model and modified the McCrackin et. al. [37] model (DIN-S) for quantifying seasonal export to the seas. In this chapter I will explain the strengths and weaknesses of my research in Section 4.1.2. I compare my work to that of other studies in Section 4.1.3 and then provide recommendations for further research in Section 4.1.4

4.1.2 STRENGTHS AND WEAKNESSES OF THIS RESEARCH

Strengths of this research:

- Locating gaps in Global NEWS-2 for a specific region

Studying the Global NEWS-2 sources and gaps in sources for the Japanese and Okhotsk seas has not been done before. As nutrient sources change over time, finding these gaps may offer knowledge on how to more accurately model the river nutrient export throughout the coming years.

- Improve modelling by applying seasonal scale to specific region

I have presented the first local application of the DIN-S model. I introduce a two season possibility in the model's application. Refining the DIN-S model for the Japanese and Okhotsk sea proved the importance of having four and two seasons for the study area. The DIN-S application has provided insight in the seasonal variation of coastal nutrients which can help to more accurately model eutrophication and algal bloom predictions.

Weaknesses of this research:

- Validation and calibration

I did not compare observed values of N concentrations with modelled values. This is because I did not have enough time to select observations. However, HABs are observed mainly in summer and fall. These are the seasons that I calculate the higher river export of N. This comparison give trust in using the seasonal model for the study area. But farther validation is required (see recommendations). I used the calibrated model parameters from the global seasonal model of McCrackin et. al. [37]. I realise that these are model parameters calibrated on a global scale that may need recalibration for local application. However, this needs a lot of observations which are not available for me at present time. Further collection of observations as needed to re-calibrate the model for the study area.

- Seasonal ICEP values

To better understand the seasonal variation of nutrients, it would be beneficial to calculated the ICEP per season and test if the seasonal variation in nutrient export will make alterations in seasonal eutrophication potential of the coastal waters. Such alterations could be implemented when the seasonal calculations are done for the whole set of river nutrients present in Global NEWS-2 and therefore could not be done for this research yet.

- Including missing sources in DIN-S

The most accurate seasonal variations in river nutrient export can be modelled by included the found missing sources for the Japanese and Okhotsk seas in the local application of the DIN-S model. Doing so requires insight in the amounts and type of nutrients these missing sources provide. Such knowledge was not yet available and could therefore not yet be implemented in the DIN-S model. This is an important step for future river nutrient export modelling to keep the model up to date and accurate.

- Seasons are defined by temperature only

In this research the seasons dynamics are defined by temperature only. There is literature available suggesting that storms and precipitation effect eutrophication and algal bloom as well [81]. Though temperature is an important factor in eutrophication and algal bloom, wet or dry seasons and storms may have an equal influence. To create a more complete view on the influence of seasons on eutrophication, the definition of season should be elaborated with other variables then only temperature.

- Spatial resolution for local watersheds

Due to the spatial resolution of the Global NEWS-2 model, the small watersheds (<3 grids) are not included. These smaller watersheds are of high importance in this region compiled of local watersheds and therefor may be a source of nutrients not included in my calculations. Refining the grid of Global NEWS-2 may thus be beneficial to seas depending on local watersheds.

4.1.3 COMPARISON WITH OTHER STUDIES

I compare my method to four other models that also calculate nutrient river export: Global NEWS-2 [4], the MARINA model [82], McCrackin DIN-S model [37], IMAGE-GNM [83].

- Global NEWS-2

Global NEWS-2 forms the basis of this research. As explained in Section 2.2 the model is a global river nutrient export model providing yearly averages in nitrogen, phosphorus and silicon values per river basin. The annual output of the Global NEWS-2 model for the Japanese and Okhotsk sea are discussed in Section 2.3. The model is not equipped with seasonal calculations, which I have now offered through my research. I modified the DIN-S model of McCrackin et. al. [37] for my study area. The original DIN-S model was developed based on the Global NEWS-2 model.

- MARINA

The MARINA model is a sub-basin model based on Global NEWS-2 focussing on China. Larger basins are divided into sub-basins and so analysed in more details. Also missing sources such as direct discharge of animal manure are included and found to be of strong influence on the river nutrient export. MARINA is focussed and applicable only for large basins, of which there is only one in the Japanese and Okhotsk seas (Amur river). For the Japanese and Okhotsk seas this model would not be applicable, as both regions are depending on smaller river basins. Also I have provided seasonal calculations, which are not included in the MARINA model.

- McCrackin DIN-S

My seasonal model is an application of the McCrackin DIN-S model. DIN-S is a global model, looking at seasonal river export of DIN which I have made locally applicable for the Japanese and Okhotsk rivers. McCrackin et. al. [37]found similar seasonal variation in nutrient export as that I have found when looking at four seasons. The model does not include the two season option that I have added to the local DIN-S model. Also I have applied more detailed hydrology dynamics and N-budget seasonal division calculations.

- IMAGE-GNM

IMAGE-GNM is a global model that calculates N and P delivery to freshwater systems on a yearly timescale. The model is grid based, and in that way thus more detailed then Global NEWS-2 or DIN-S which merges grid cells to the size of the river basins. The grids size in all these models are equal (0.5 by 0.5 degrees). IMAGE-GNM takes into account freshwater aquaculture and a specific natural area N budget, were Global NEWS-2 defines agricultural and non-agricultural land only. The model does not take direct discharge of human waste or animal manure into account, nor does it provide seasonal calculations as I have done in my research.

4.1.4 RECOMMENDATIONS FOR FURTHER RESEARCH

The important recommendations are summarized below.

Recommendation 1: Validation
It is important to compare the model output with observations. I have done a general comparison of the timing of HABs in the region and the seasons that my model calculates the higher nutrient export to the seas, which match well. I was unable, due to lack of time, to find the records of observation and perform a complete validation.

Recommendation 2: Model other nutrient forms in the seasonal model.
DIN-S is a first step towards a seasonal river nutrient export model. The other nutrient forms such as Dissolved Organic Nitrogen (DON), Dissolved Inorganic Phosphorus (DIP) and Dissolved Organic Phosphorus (DOP) should also be seasonalized to create a comprehensive analysis of seasonal river nutrient export to the Japanese and Okhotsk seas.

Recommendation 3: Include missing sources
Several missing sources of nutrients have been found throughout this research. To create a better modelled output for the river nutrient export to the Japanese and Okhotsk seas, these nutrient sources should be included in the model.

Recommendation 4: Included seasonal ICEP
To create a full overview of the seasonal dynamics of the river nutrient export, it would be good to include seasonal ICEP value calculations. It offers a more directly understandable output on the effect of seasonality on eutrophication, and possible algal bloom in the studied seas. ICEP values are also easier to understand for lay people who are in need of understanding the eutrophication issue.

Recommendation 5: Monthly analysis
It might be beneficial to calculated river nutrient export per month, not per season. Even within seasons there are large variations in N-budget, hydrology and climatological factors which are lost if grouped to seasonal calculations. A monthly model will help in finding the nutrient export and eutrophication dynamics in the Japanese and Okhotsk seas.

Recommendation 6: Elaborate definition of seasons
In this research the seasons are defined by temperature, as effective summer is the three months that have the highest average temperature. This is an incomplete definition of seasons. Besides temperature, precipitation and wind have an influence on eutrophication and algal bloom. Thus, In the future the definition of season should be elaborated with other variables such as precipitation and storms.

Recommendation 7: Refine the grid scale
To make the Global NEWS-2 and DIN-S model more accurate for regional application, it could be very much beneficial to refine the grid scale. Also the grids in each river basins are merged, meaning that the larger basins are a merge of a large number of grid points. It might be beneficial to update Global NEWS-2 for a complete gridded version, retaining a higher level of accuracy and insight in details inside a river shed.

4.2 CONCLUSION

In this section I summarize the main conclusions of my research.

Conclusion 1: In the past there was an increasing trend in dissolved N and P river export for both the Japanese and Okhotsk Seas.
River export of dissolved N and P to the Japanese and Okhotsk Seas increased by a factor of 1.2-2.5 between 1970 and 2000 (range for nutrient forms and seas). River export of dissolved inorganic N and P increased faster than of organic and particulate forms, which can be explained by urbanisation and increased agricultural activities. In the Japanese Sea there is an overall increase of nutrient sources, but largest increase is found in sewage by a factor of 4.7 and manure by a factor 2.2. For the Okhotsk sea increases nutrient export is mainly due to fertilizer and manure which increased by a factor of 5.3 and 2.3 respectively, concurring with an increase in agricultural activities.

Conclusion 2: Future river export of nutrients may decrease for the Japanese Sea, but increase for the Okhotsk Sea.
Future river export of DIN and DIP to the Japanese Sea may decrease by 20% and river export of DON and DOP may stay at the level of 2000 between 2000 and 2050 in both the Global Orchestration and Order from Strengths scenarios. These decreases can be explained by a reduction in agricultural activities. In contrast, river export of DIP to the Okhotsk Sea is projected to triple between 2000 and 2050 (GO). For DIN this increase is as much as 250%. The main reason for these increases is sewage for DIP and agriculture for DIN. DON and DOP export to the Okhotsk Sea may increase with 5-12% and 13-18% respectively due to increased sewage (DON) and fertilizer usage (DOP).

Conclusion 3: The coastal eutrophication potential is high for rivers draining into the Japanese Sea. In the Okhotsk Sea there is medium to no eutrophication potential.
In the past, the coastal eutrophication potential (ICEP>0 C-eq/km^2/day^{-1}) was especially high for the rivers draining into the Japanese Sea. Ten of the river basins draining in the Japanese Sea are hotspots for eutrophication with ICEP values of >10 C-eq/km^2/day^{-1}.

Conclusion 4: The following sources are missing in the Global NEWS-2 model: local land use, direct discharge of animal manure, aquaculture and atmospheric N deposition over sea.
The land use maps of Global NEWS-2 need to be updated as they underestimate the local agricultural activities which are highly important for the Japanese and Okhotsk Seas. Direct discharge of animal manure is important to include in the model due to intensive animal production farms directly discharge manure into the Amur river which provides 90% of the river

nutrients export to the Okhotsk sea. Aquaculture is considered an important local source of nutrients in the studied rivers and coast lines. Finally, Atmospheric N deposition over sea can bring much N input downwind from larger cities and should therefore also be included in the model. Including the missing sources in the Global NEWS-2 model may alter the future projections of nutrients and eutrophication potential. Where I found a decrease in future nutrient inflow to the Japanese Sea, there might be an increase of nutrients when including the missing sources in the calculations.

Conclusion 5: Modelled DIN river export shows a considerable seasonal variation for both the Japanese and Okhotsk Seas.

In the study region there are areas with four seasons, and areas with two seasons. In both cases, the modelled DIN river export varied considerably over seasons. A clear pattern of high DIN export in spring and low DIN export in summer is found in case of four seasons. When dealing with two seasons, river nutrient export happens mainly in summer and close to nothing in winter. Therefore, modelling with seasons provides seasonal variation of DIN river export to coastal waters. For a comprehensive assessment of coastal eutrophication potential, it is therefore important to account for seasonality.

REFERENCES

1. Smith, V.H., *Eutrophication of freshwater and coastal marine ecosystems a global problem.* Environmental Science and Pollution Research, 2003. **10**(2): p. 126-139.

2. Sutton, M.A., O. Oenema, J.W. Erisman, A. Leip, H. van Grinsven, and W. Winiwarter, *Too much of a good thing.* 2011. **472**(7342): p. 159-161.

3. Vörösmarty, C.J., P.B. McIntyre, M.O. Gessner, D. Dudgeon, A. Prusevich, P. Green, S. Glidden, S.E. Bunn, C.A. Sullivan, and C. Reidy Liermann, *Global threats to human water security and river biodiversity.* nature, 2010. **467**(7315): p. 555.

4. Mayorga, E., S.P. Seitzinger, J.A. Harrison, E. Dumont, A.H.W. Beusen, A.F. Bouwman, B.M. Fekete, C. Kroeze, and G. Van Drecht, *Global Nutrient Export from WaterSheds 2 (NEWS 2): Model development and implementation.* Environmental Modelling & Software, 2010. **25**(7): p. 837-853.

5. Seitzinger, S.P., E. Mayorga, A.F. Bouwman, C. Kroeze, A.H.W. Beusen, G. Billen, G. Van Drecht, E. Dumont, B.M. Fekete, J. Garnier, and J.A.C.G.A. Harrison, *Global river nutrient export: A scenario analysis of past and future trends.* Global Biogeochemical Cycles, 2010. **24**(4): GB0A08 p. 1-16.

6. Morée, A.L., A.H.W. Beusen, A.F. Bouwman, and W.J. Willems, *Exploring global nitrogen and phosphorus flows in urban wastes during the twentieth century.* Global Biogeochemical Cycles, 2013. **27**(3): p. 836-846.

7. Ahn, Y.-H., P. Shanmugam, J.-H. Ryu, and J.-C. Jeong, *Satellite detection of harmful algal bloom occurrences in Korean waters.* Harmful Algae, 2006. **5**(2): p. 213-231.

8. Van Drecht, G., A.F. Bouwman, J. Harrison, and J.M. Knoop, *Global nitrogen and phosphate in urban wastewater for the period 1970 to 2050.* Global Biogeochemical Cycles, 2009. **23**(3) GB0A03 p. 1-19.

9. Billen, G. and J. Garnier, *River basin nutrient delivery to the coastal sea: Assessing its potential to sustain new production of non-siliceous algae.* Marine Chemistry, 2007. **106**(1-2): p. 148-160.

10. Tang, D., B. Di, G. Wei, I.-H. Ni, I.S. Oh, and S. Wang, *Spatial, seasonal and species variations of harmful algal blooms in the South Yellow Sea and East China Sea.* Hydrobiologia, 2006. **568**(1): p. 245-253.

11. Kim, T.-W., K. Lee, C.-K. Lee, H.-D. Jeong, Y.-S. Suh, W.-A. Lim, K.Y. Kim, and H.-J. Jeong, *Interannual nutrient dynamics in Korean coastal waters.* Harmful Algae, 2013. **30**: p. S15-S27.

12. Lee, J.-Y., D.-J. Kang, I.-N. Kim, T. Rho, T. Lee, C.-K. Kang, and K.-R. Kim, *Spatial and temporal variability in the pelagic ecosystem of the East Sea (Sea of Japan): A review.* Journal of Marine Systems, 2009. **78**(2): p. 288-300.

13. FAOSTAT. *Country Indicators*. 2015 20-07-2017].

14. DeWind, J., E.M. Kim, R. Skeldon, and I.-J. Yoon, *Korean Development and Migration.* Journal of Ethnic and Migration Studies, 2012. **38**(3): p. 371-388.

15. Witherick, M., *Recent population changes in Japan and their spatial implications.* Geography, 1983: p. 97-114.

16. FSSS, *Cities of the Primorsk Territory*, in *Regions of Russia: The main socio-economic indiactors of cities*. 2010, Russian Federal Service of State Statistics: Moscow.

17. Karim, M.R., M. Sekine, and M. Ukita, *Simulation of eutrophication and associated occurrence of hypoxic and anoxic condition in a coastal bay in Japan.* Marine Pollution Bulletin, 2002. **45**(1): p. 280-285.

18. Lee, C.-K., T.-G. Park, Y.-T. Park, and W.-A. Lim, *Monitoring and trends in harmful algal blooms and red tides in Korean coastal waters, with emphasis on Cochlodinium polykrikoides.* Harmful Algae, 2013. **30**: p. S3-S14.

19. Yu, C.-S., *The New History of Korean Civilization*. 2012, Bloomington: iUniverse. pp. 352.

20. Jo, C.O., S. Park, Y.H. Kim, K.-A. Park, J.J. Park, M.-K. Park, S. Li, J.-Y. Kim, J.-E. Park, J.-Y. Kim, and K.-R. Kim, *Spatial distribution of seasonality of SeaWiFS chlorophyll-a concentrations in the East/Japan Sea.* Journal of Marine Systems, 2014. **139**: p. 288-298.

21. Yamada, K., J. Ishizaka, S. Yoo, H.-c. Kim, and S. Chiba, *Seasonal and interannual variability of sea surface chlorophyll a concentration in the Japan/East Sea (JES).* Progress in Oceanography, 2004. **61**(2): p. 193-211.

22. Lee, Y.S. and S.Y. Lee, *Factors affecting outbreaks of Cochlodinium polykrikoides blooms in coastal areas of Korea.* Marine Pollution Bulletin, 2006. **52**(6): p. 626-634.

23. Tkalin, A.V., T.A. Belan, and E.N. Shapovalov, *The state of the marine environment near Vladivostok, Russia.* Marine Pollution Bulletin, 1993. **26**(8): p. 418-422.

24. Stonik, I. and T.Y. Orlova, *Spatial and long-term changes in the phytoplankton of the coastal waters off Vladivostok (Peter the Great Bay, Sea of Japan), 1991–2000.* Climate Variability and Human Activities in Relation to Northeast Asia Land-Ocean Interactions and their Implications for Coastal Zone Management: p. 4-8.

25. Alekseev, A.V., P.J. Baklanov, I.S. Arzamastsev, Y.G. Blinov, A.S. Fedorovskii, A.N. Kachur, F.F. Khrapchenkov, I.A. Medvedeva, P.A. Minakir, G.D. Titova, A.V. Vlasov, B.A. Voronov, and H. Ishitobi, *Sea of Okhotsk - GIWA Regional assessment 30*, in *Global International Waters Assessment*. 2006, UNEP.

26. Seki, O., Y. Mikami, S. Nagao, J.A. Bendle, T. Nakatsuka, V.I. Kim, V.P. Shesterkin, A.N. Makinov, M. Fukushima, H.M. Moossen, and S. Schouten, *Lignin phenols and BIT index distributions in the Amur River and the Sea of Okhotsk: Implications for the source and transport of particulate terrestrial organic matter to the ocean.* Progress in Oceanography, 2014. **126**: p. 146-154.

27. Yoshikawa, C., T. Nakatsuka, and M. Wakatsuchi, *Distribution of N^* in the Sea of Okhotsk and its use as a biogeochemical tracer of the Okhotsk Sea Intermediate Water formation process.* Journal of Marine Systems, 2006. **63**(1): p. 49-62.

28. Ohshima, K.I. and S.C.C.S. Martin, *Introduction to special section: Oceanography of the Okhotsk Sea.* Journal of Geophysical Research: Oceans, 2004. **109**(C9): C09S01 p. 1-3.

29. Martin, S. and M. Kawase, *The southern flux of sea ice in the Tatarskiy Strait, Japan Sea and the generation of the Liman Current.* Journal of Marine Research, 1998. **56**(1): p. 141-155.

30. Sorokin, Y.I., *Dynamics of inorganic phosphorus in pelagic communities of the Sea of Okhotsk.* Journal of Plankton Research, 2002. **24**(12): p. 1253-1263.

31. Jiang, R., R. Hatano, Y. Zhao, K. Kuramochi, A. Hayakawa, K.P. Woli, and M. Shimizu, *Factors controlling nitrogen and dissolved organic carbon exports across timescales in two watersheds with different land uses.* Hydrological Processes, 2014. **28**(19): p. 5105-5121.

32. Shevchenko, O.G., M.S. Selina, T.Y. Orlova, T.V. Morozova, I.V. Stonik, V.I. Zvalinsky, and P.Y. Tishchenko, *Phytoplankton of the Amur River Estuary (Sea of Okhotsk) during the summer periods of 2005–2007.* Russian Journal of Marine Biology, 2013. **39**(2): p. 92-106.

33. Isada, T., T. Iida, H. Liu, S.-I. Saitoh, J. Nishioka, T. Nakatsuka, and K. Suzuki, *Influence of Amur River discharge on phytoplankton photophysiology in the Sea of Okhotsk during late summer.* Journal of Geophysical Research: Oceans, 2013. **118**(4): p. 1995-2013.

34. Fekete, B.M., D. Wisser, C. Kroeze, E. Mayorga, L. Bouwman, W.M. Wollheim, and C.C.G.B.A. Vörösmarty, *Millennium Ecosystem Assessment scenario drivers (1970–2050): Climate and hydrological alterations.* Global Biogeochemical Cycles, 2010. **24**(4): GB0A12 p. 1-12.

35. Suwarno, D., A. Löhr, C. Kroeze, and B. Widianarko, *Past and future trends in nutrient export by 19 rivers to the coastal waters of Indonesia.* Journal of Integrative Environmental Sciences, 2013. **10**(1): p. 55-71.

36. Lüftner, K., *Coastal Eutrophication caused by oil palm plantations in Indonesia and Malaysia*, in *Environmental Systems Analysis group*. 2016, Wageningen University and Research Center.

37. McCrackin, M.L., J.A. Harrison, and J.E. Compton, *Factors influencing export of dissolved inorganic nitrogen by major rivers: A new, seasonal, spatially explicit, global model.* Global Biogeochemical Cycles, 2014. **28**(3): p. 269-285.

38. Bouwman, A.F., M. Pawłowski, C. Liu, A.H.W. Beusen, S.E. Shumway, P.M. Glibert, and C.C. Overbeek, *Global Hindcasts and Future Projections of Coastal Nitrogen and Phosphorus Loads Due to Shellfish and Seaweed Aquaculture.* Reviews in Fisheries Science, 2011. **19**(4): p. 331-357.

39. Garnier, J., A. Beusen, V. Thieu, G. Billen, and L.C.G.B.A. Bouwman, *N:P:Si nutrient export ratios and ecological consequences in coastal seas evaluated by the ICEP approach.* Global Biogeochemical Cycles, 2010. **24**(4): GB0A05 p. 1-12.

40. Amin, M.N., C. Kroeze, and M. Strokal, *Human waste: An underestimated source of nutrient pollution in coastal seas of Bangladesh, India and Pakistan.* Marine Pollution Bulletin, 2017. **118**(1-2): p. 131-140.

41. Strokal, M., H. Yang, Y. Zhang, C. Kroeze, L. Li, S. Luan, H. Wang, S. Yang, and Y. Zhang, *Increasing eutrophication in the coastal seas of China from 1970 to 2050.* Marine Pollution Bulletin, 2014. **85**(1): p. 123-140.

42. Bouwman, A.F., A.H.W. Beusen, and G.C.G.A. Billen, *Human alteration of the global nitrogen and phosphorus soil balances for the period 1970–2050.* Global Biogeochemical Cycles, 2009. **23**(4): GB0A04 p. 1-16.

43. FAO, *Land Use Systems of the World- East Asia and Pacific, version 1.1*. 2010, Food and Agricultural Organization of the United Nations: Rome.

44. Strokal, M., L. Ma, Z. Bai, S. Luan, C. Kroeze, O. Oenema, G. Velthof, and F. Zhang, *Alarming nutrient pollution of Chinese rivers as a result of agricultural transitions.* Environmental Research Letters, 2016. **11**(2): p. 024014.

45. Wang, M., M. Strokal, W. Ma, X. Liu, Z. Liu, and C. Kroeze, *Low nutrient use efficiencies in Chinese agriculture call for region-specific nutrien management.* in preperation.

46. Ma, L., G.L. Velthof, F.H. Wang, W. Qin, W.F. Zhang, Z. Liu, Y. Zhang, J. Wei, J.P. Lesschen, W.Q. Ma, O. Oenema, and F.S. Zhang, *Nitrogen and phosphorus use efficiencies and losses in the food chain in China at regional scales in 1980 and 2005.* Sci Total Environ, 2012. **434**: p. 51-61.

47. Strokal, M., C. Kroeze, M. Wang, Z. Bai, and L. Ma, *The MARINA model (Model to Assess River Inputs of Nutrients to seAs): Model description and results for China.* Science of The Total Environment, 2016. **562**: p. 869-888.

48. KOSIS, *Sewerage Supply Status*, M.o.E. Korea, Editor. 2016, Korean Statistic Information Services: Seoul.

49. SBJ, *Japan Statistical Yearbook*, S.B.M.o.I.A.a.C. Japan, Editor. 2014, Statistics Bureau Japan: Tokyo.

50. Amurstat, *Amur Statistical Yearbook 2014*, Amurstat, Editor. 2014, Amurstat.

51. FSSS, *Russian Statistical Yearbook - 2014*, F.S.S. Service, Editor. 2014, Federal State Statistics Service.

52. Habstat, *Central Statistics Database*, Habstat, Editor. 2017, Federal State Statistics Service: Russia.

53. Sakhalinstat, *Sakhalin Statistic Yearbook 2014*, F.S.S. Service, Editor. 2014, Sakhalinstat.

54. FAO, *An Overview of Recently Published Global Aquacultural Statistics*, X. Zhou, Editor. 2017, FAO Fisheries and Aquaculture: Rome.

55. Beusen, A.H.W., A.F. Bouwman, L.P.H. Van Beek, J.M. Mogollón, and J.J. Middelburg, *Global riverine N and P transport to ocean increased during the 20th century despite increased retention along the aquatic continuum.* Biogeosciences, 2016. **13**(8): p. 2441-2451.

56. Lim, J. and M. Choi, *Assessment of water quality based on Landsat 8 operational land imager associated with human activities in Korea.* Environmental Monitoring and Assessment, 2015. **187**(6).: p. 384-401.

57. Zhuang, P., B. Kynard, L. Zhang, T. Zhang, Z. Zhang, and D. Li, *Overview of biology and aquaculture of Amur sturgeon (Acipenser schrenckii) in China.* Journal of Applied Ichthyology, 2002. **18**(4-6): p. 659-664.

58. FAO, *FAO yearbook Fishery and Aquaculture Statistics 2012*. 2014, Food and Agriculture Organization of the United Nations: Rome.

59. Liu, X., L. Duan, J. Mo, E. Du, J. Shen, X. Lu, Y. Zhang, X. Zhou, C. He, and F. Zhang, *Nitrogen deposition and its ecological impact in China: An overview.* Environmental Pollution, 2011. **159**(10): p. 2251-2264.

60. Vitousek, P.M., J.D. Aber, R.W. Howarth, G.E. Likens, P.A. Matson, D.W. Schindler, W.H. Schlesinger, and D.G. Tilman, *Human alterations of the global nitrogen cycle: sources and consequences.* Ecological Applications, 1997. **7**(3): p. 737-750.

61. Kim, T.-W., K. Lee, R.G. Najjar, H.-D. Jeong, and H.J. Jeong, *Increasing N Abundance in the Northwestern Pacific Ocean Due to Atmospheric Nitrogen Deposition.* Science, 2011. **334**(6055): p. 505-509.

62. Phoenix, G.K., W.K. Hicks, S. Cinderby, J.C.I. Kuylenstierna, W.D. Stock, F.J. Dentener, K.E. Giller, A.T. Austin, R.D.B. Lefroy, B.S. Gimeno, M.R. Ashmore, and P. Ineson, *Atmospheric nitrogen deposition in world biodiversity hotspots: the need for a greater global perspective in assessing N deposition impacts.* Global Change Biology, 2006. **12**(3): p. 470-476.

63. Liu, X., Y. Zhang, W. Han, A. Tang, J. Shen, Z. Cui, P. Vitousek, J.W. Erisman, K. Goulding, P. Christie, A. Fangmeier, and F. Zhang, *Enhanced nitrogen deposition over China.* Nature, 2013. **494**(7438): p. 459-462.

64. Kim, T.-H. and G. Kim, *Changes in seawater N : P ratios in the northwestern Pacific Ocean in response to increasing atmospheric N deposition: Results from the East (Japan) Sea.* Limnology and Oceanography, 2013. **58**(6): p. 1907-1914.

65. Yoshikawa, C., Y. Yamanaka, and T. Nakatsuka, *An Ecosystem Model Including Nitrogen Isotopes: Perspectives on a Study of the Marine Nitrogen Cycle.* Journal of Oceanography, 2005. **61**(5): p. 921-942.

66. Lee, J.H.W., Y. Huang, M. Dickman, and A.W. Jayawardena, *Neural network modelling of coastal algal blooms.* Ecological Modelling, 2003. **159**(2): p. 179-201.

67. JSB, *Japan statistical yearbook 2013*. 2014, Japan Statistics Bureau: Tokyo.

68. KOSIS, *Agricultural Production*. 2016, Statistics Korea: Daejeon.

69. Rosstat, *Russia in figures 2016, statistical yearbook*. 2016, Federal State Statistics Service Russia: Moscow.

70. Alley, M.M., T.H. Pridgen, D.E. Brann, J.L. Hammons, and R.L. Mulford, *Nitrogen Fertilization of Winter Barley: Principles and Recommendations*. 2009, Virginia Tech: Petersburg. pp. 4.

71. Dasberg, S., *Nitrogen fertilization in citrus orchards.* Plant and Soil, 1987. **100**(1): p. 1-9.

72. Onitsuka, G., I. Uno, T. Yanagi, and J.-H. Yoon, *Modeling the effects of atmospheric nitrogen input on biological production in the Japan Sea.* Journal of Oceanography, 2009. **65**(3): p. 433-438.

73. Westermann, D.T., G.E. Kleinkopf, and L.K. Porter, *Nitrogen fertilizer efficiencies on potatoes.* American Potato Journal, 1988. **65**(7): p. 377.

74. Yamada, T., T. Inoue, K. Tsushima, M. Nagai, and Y. Kiso, *Nutrient Loss from a Tea Plantation Area in Japan.* Journal of Water and Environment Technology, 2009. **7**(4): p. 331-340.

75. Yoon, C.G., J.-H. Ham, and J.-H. Jeon, *Mass balance analysis in Korean paddy rice culture.* Paddy and Water Environment, 2003. **1**(2): p. 99-106.

76. Carroll, B.J., D.L. McNeil, and P.M. Gresshoff, *Isolation and properties of soybean [Glycine max (L.) Merr.] mutants that nodulate in the presence of high nitrate concentrations.* Proceedings of the National Academy of Sciences, 1985. **82**(12): p. 4162-4166.

77. Kondo, M. and M. Yasuda, *Seasonal Changes in N_2 Fixation Activity and N Enrichment in Paddy Soils as Affected by Soil Management in the Northern Area of Japan.* Japan Agricultural Research Quarterly: JARQ, 2003. **37**(2): p. 105-111.

78. Shanahan, J.F., N.R. Kitchen, W.R. Raun, and J.S. Schepers, *Responsive in-season nitrogen management for cereals.* Computers and Electronics in Agriculture, 2008. **61**(1): p. 51-62.

79. Tantowijoyo, W. and E.v.d. Fliert, *All about potatoes, a handbook to the ecology and integrated management of potato*. 2006, FAO regional Office for Asia and the Pacific: Bangkok.

80. Tripp, L.N., D.F. Bezdicek, and P.E. Heilman, *Seasonal and Diurnal Patterns and Rates of Nitrogen Fixation by Young Red Alder.* Forest Science, 1979. **25**(2): p. 371-380.

81. Lim, A.S., H.J. Jeong, T.Y. Jang, N.S. Kang, S.H. Jang, and M.J. Lee, *Differential effects of typhoons on ichthyotoxic Cochlodinium polykrikoides red tides in the South Sea of Korea during 2012–2014.* Harmful Algae, 2015. **45**: p. 26-32.

82. Strokal, M., *River export of nutrients to the coastal waters of China: the MARINA model to assess sources, effects and solutions*. 2016, Wageningen University.

83. Beusen, A., L. Van Beek, L. Bouwman, J. Mogollón, and J. Middelburg, *Coupling global models for hydrology and nutrient loading to simulate nitrogen and phosphorus retention in surface water–description of IMAGE–GNM and analysis of performance.* Geoscientific Model Development, 2015. **8**(12): p. 4045-4067.

Appendix 1 Overview of River export of dissolved nutrients into the Japanese and Okhotsk Seas

Table AP1.1. River export of dissolved nutrients for past (1970 and 2000) and two future projections (2050) in kg/km^2/yr. GO = Global Orchestration, OS = OS. NA = Non-agricultural Areas, AA = Agricultural Areas. Source: Global NEWS-2 [4]

Japanese Sea

DIN (kg/km^2/yr)	Sewage	Manure	Fertilizer	Fix & Dep (AA)	Fix & Dep (NA)
1970	8	75	113	40	423
2000	38	165	234	52	542
2050 GO	43	109	64	27	593
2050 OS	29	129	68	28	526

DIP (kg/km^2/yr)	Sewage	Manure	Fertilizer	P-Weathering (AA)	P-Weathering (NA)
1970	6	8	23	<1	7
2000	20	13	30	<1	8
2050 GO	25	12	20	<1	8
2050 OS	20	14	22	<1	8

DON (kg/km^2/yr)	Sewage	Manure	Fertilizer	Leaching (AA)	Leaching (NA)
1970	5	1	2	19	154
2000	18	3	4	16	171
2050 GO	25	3	2	11	178
2050 OS	19	3	3	14	174

DOP (kg/km^2/yr)	Sewage	Manure	Fertilizer	Leaching (AA)	Leaching (NA)
1970	<1	<1	1	1	8
2000	<1	<1	2	<1	9
2050 GO	<1	<1	1	<1	10
2050 OS	<1	<1	1	<1	9

Appendix 1 (Continuation):

Table AP1.2: as table AP1.1, but for the Okhotsk sea

Okhotsk Sea

DIN (kg/km^2/yr)	Sewage	Manure	Fertilizer	Fix & Dep AA	Fix &Dep NA
1970	1	4	3	4	35
2000	3	10	14	10	38
2050 GO	12	18	22	12	48
2050 OS	6	15	19	12	44

DIP (kg/km^2/yr)	Sewage	Manure	Fertilizer	P-weathering (AA)	P-weathering (NA)
1970	<1	<1	<1	<1	1
2000	3	<1	<1	<1	1
2050 GO	7	<1	2	<1	1
2050 OS	4	<1	<1	<1	1

DON (kg/km^2/yr)	Sewage	Manure	Fertilizer	Leaching (AA)	Leaching (NA)
1970	<1	<1	<1	6	45
2000	3	<1	<1	9	51
2050 GO	8	<1	<1	8	54
2050 OS	5	<1	<1	8	53

DOP (kg/km^2/yr)	Sewage	Manure	Fertilizer	Leaching (AA)	Leaching (NA)
1970	<1	<1	<1	<1	2
2000	<1	<1	<1	<1	3
2050 GO	<1	<1	<1	<1	3
2050 OS	<1	<1	<1	<1	3

Appendix 2: Japanese Sea comparison of Seasonal and Annual output

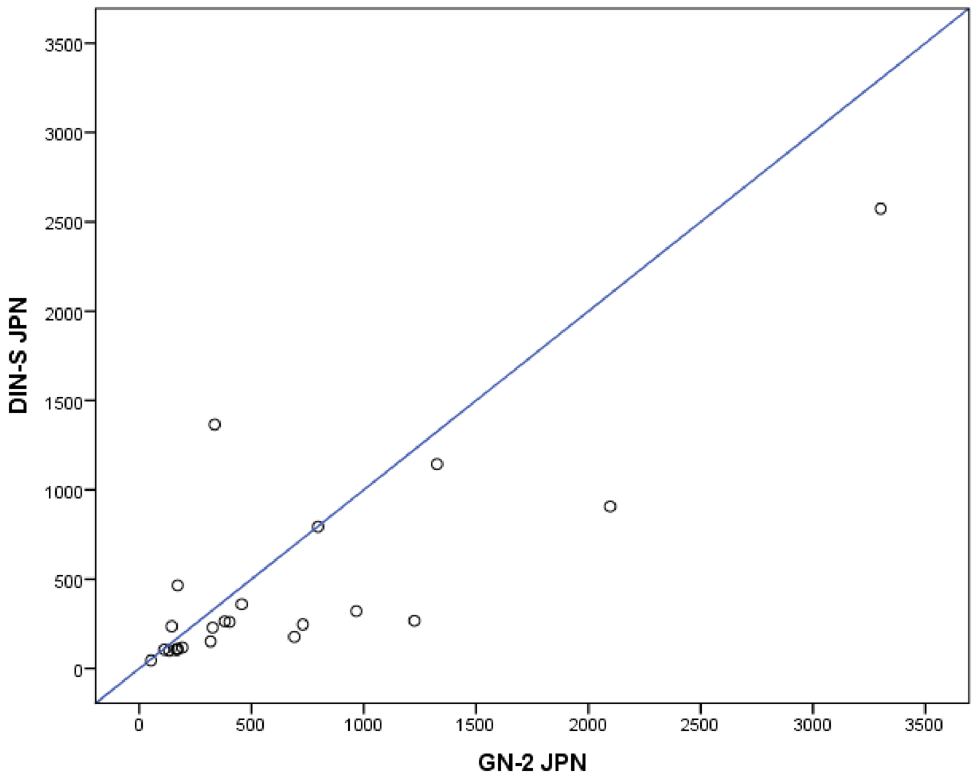


Figure AP2.1. Scatter Plot comparing the Seasonal total output from the DIN-S model and the Global NEWS-2 annual output for the Japanese sea river basins (combining the JPN-L and JPN-H river basins). Blue line: x = y. In general the seasonal model underestimates the total DIN yield compared to the Global NEWS-2 output due to temperature dependent denitrification. Some river basins have lower retention to rivers and higher nutrient inputs for seasons other than summer causing an overestimation of DIN-yield compared to the Global NEWS-2 output

Appendix 3: Amur river data and statistics.

The DIN-S model overestimates the Amur river basin DIN yield, while in general it should underestimate DIN yield based on temperature dependent denitrification. Figure AP2.1 shows the output of the seasonal model in comparison to the Global NEWS-2 model per river basin in the Okhotsk Sea. Table AP2.1 shows the sources, retention and DIN yield for the Amur river basin from both the seasonal and Global NEWS-2 models.

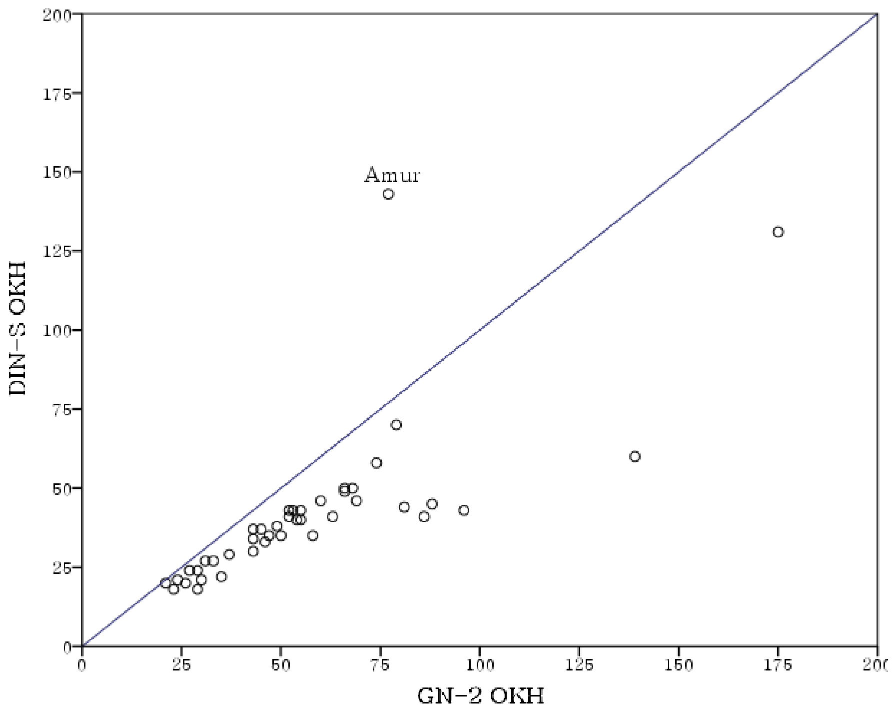


Figure AP2.1. Scatter Plot comparing the Seasonal total output from the DIN-S model to the annual output of the Global NEWS-2 model for the Okhotsk sea. Blue line: x = y. For all river basins the expected underestimation is found, except for the Amur river basin with overestimated output due to less retention and higher inputs in seasons outside of summer.

Table AP2.1. Amur river basin sources, export and DIN yield (kg/km^2). Due to less retention (higher export to river) in winter and spring, but higher input the DIN yield is overestimated in comparison the yearly Global NEWS-2 DIN yield.

	Sources (kg/km^2)			Export to river (fraction)	DIN yld (kg/km2)
	To land	To river			
		Point	Diffuse		
Summer	565	3.51	7.21	0.32	14
Fall	403	3.51	5.04	0.74	25
Winter	305	3.51	9.79	0.74	39
Spring	744	3.51	17.24	0.74	61
Annual (GN2)	2013	4.70	72.05	0.33	77