Erasmus Centre for Urban, Port and Transport Economics

The economic effects of a ballast water management SRA

UPT ERASMUS CENTRE FOR URBAN PORT AND TRANSPORT ECONOMICS

TPR Department of Transport and Regional Economics University of Antwerp

The economic effects of ballast water management SRA

Martijn Streng and Bart Kuipers *(Erasmus UPT)*
Edwin van Hassel, Mohseni Seyed Abolfazl, Thierry Vanelslander and Christa Sys
(University of Antwerp | Department of Transport and Regional Economics)

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List of abrreviations and terms:
BWM convention: Ballastwater management convention
SRA: Same risk area
IMO: International maritime organisation
Ecologic study: Assessing the ecological support for installing an SRA with Belgian and Dutch ports: a pilot study by Royal Belgian Institute of Natural Sciences
NPV: Net present value
BW: Ballast water

Summary

This study analyses the economic effects of a possible exemption within the ballast water management convention, i.e. a same risk area between The Netherlands and Belgium. Parallel to this economic study, an ecologic study is carried out. It is however not the aim of the researches to analyse the confrontation between economy and ecology. Purpose of this economic study is the determination of the economic effects and the determination of the viability of an SRA in the North Sea between the Netherlands and Belgium from an economic perspective. There has been cooperation with the ecologic study and some assumptions and input is shared within the two studies.

An SRA as an exemption to the ballast water management convention that provides economic benefits to ship owners and operators. Three types of vessels have been identified related to the SRA:

- Vessels sailing from outside the SRA to a port in the SRA
- Vessels sailing from an SRA port to another SRA port but the previous port of call was outside the SRA.
- Vessels sailing from an SRA port to another SRA port but the vessel is always operational in a SRA.

Since it is necessary to treat ballastwater if the ship is coming from outside the SRA and since a ballast water system should be operational at all time to guarantee meeting the standards, even if part of the trip is within the SRA, only vessels that are strictly active within the SRA – they do not leave the SRA – will benefit from an SRA. These vessels do not have to buy an on-board system or they do not have to use a shore based system; these avoided costs are the economic benefits of the SRA.

Combining the ballast water volumes used by these ships, with the other variables, provides the benefits of implementing an SRA. In total the benefits range between €2,4 and €4,8 million per year, of which the majority (about 50%) is achieved in relation to the port of Rotterdam. Several sensitivity analyses have been carried out in order to validate the results and to provide a bandwith for the input variables and the results. The operational costs per m^3 of treated ballast water has been analysed for €5 and €10 as well, in order to account for multiple price scenarios. The implementation – and operational costs have been changed and the deviations because of a change in volume of ballast water handled have been tested and analysed. This last analysis provides more insight and validation from two perspectives:

- A tipping point of 70.000 tonnes ballast water is taken from literature as the trade off point between a shore based and ship based system. With a change in treated ballast water volumes, this tipping point is (indirectly) varied, providing more reliable bandwiths. For full explanation see page 21.
- Second aspect is the capacity to treat ballast water with shore based systems. By varying with the volumes of ballast water, this is (indirectly) taken into account; if there is not enough capacity avaialable for ships, these ships have to invest in a ship based system, causing the total volumes that will be treated to decrease. Full for explanation, see page 21 as well.

These sensitivity analyses further validate the results and put them into a broader perspective. The analyses show that even with a decrease of 70% of the ballast water volume in 2017, still a net benefit can be obtained for the SRA. Overall conclusion therefore is that there is an economic base for an SRA and that from an economic perspective an SRA is beneficial.

Introduction

In February 2004, the International Maritime Organization (from now on: IMO) adopted by consensus the International Convention for the Control and Management of Ships' Ballast Water and Sediments (from now on: BWM Convention). The BWM convention requires all ships to implement a ballast water management plan. All ships have to carry a ballast water record book and are required to carry out ballast water management procedures to a given standard.

Ballast Water	"International Convention for the Control and Management of Ships' Ballast Water and Sediments" (IMO)	Aims to prevent the transfer of invasive aquatic organisms and pathogens through the control and management of ships' ballast water and sediments	Adpoted in 2004, the convention will enter into force 12 months after ratification by 30 states representing 35% of global GT. **Status:** 50 signatories (34.9% of global GT)
	"Final Discharge Standard' (Under the National Invasive Species Act, US Coast Guard)"	These regulations aim to prevent the transfer of invasive aquatic organisms and pathogens through the control and management of ships' ballast water and sediments in ***US waters only***	Adopted in June 2012. Existing vessels with a ballast water capacity between 1,600 and 5,000 cu.m. must implement an approved ballast water management method by the first scheduled drydocking after 1st January 2014. New builds delivered on/after 1st December 2013 must comply on delivery. Ballast water management systems must be USCG "Type-Approved"
	"Vessel General Permit" (Under the Clean Water Act, US Environmental Protection Agency)		Vessels ≥ 300 GT or with a ballast water capacity >8 cu.m. must implement an approved ballast water management method according to the same schedule as the USCG's Final Discharge Standard

Source: Clarkson Research

Parties to the convention are given the option to take additional measures which are subject to criteria set out in the convention and to IMO guidelines. The BWM convention entered into force on 8 September 2017. This means that within the next 7 years, so at the latest 2024, all ships that sail in international waters should have a ballast water management system.

In order to anticipate on - and react to - this future situation, several governments around the world have started analyses to determine the viability of a so-called Same risk area (from now on: SRA). An SRA is an exemption area within the ballast water management convention; in this SRA, it is not necessary to treat the ballast water and it can be loaded and unloaded anywhere within the SRA. Ministries within the Netherlands and Belgium have taken the initiative to analyse the viability of a SRA. This analysis takes an economic perspective and analyses the economic effects of a ballast water management SRA.

Part 1. Problem statement

It is important to first define the BWM convention and its operational side. What are the characteristics and what does the implementation and enforcement of the convention mean? The BWM convention requires all ships to carry out ballast water management procedures to clean ballast water, before the ballast water can be unloaded elsewhere. The main reason for implementing the BWM convention is ecological; the distribution of species of animals and plants via maritime transportation to other locations where the 'invaders' could be a threat to the existing eco system. The BWM convention is relevant for cross border transport; only international maritime transportation is applicable for the BWM convention. National shipping (inland or short sea within a country) is usually exempted; besides this there are also port to port exemptions; an SRA in another possible example of an exemption.

Due to the entry into force of the BWM convention in September 2017, all ships for which the BWM convention is relevant should be equipped with one or more ballast water treatment systems. New ships that are delivered now will be equipped with a ballast water treatment system. Existing ships need to be equipped as well, according to an implementation schedule that will end in 2024. In order to analyse the economic consequences of installing and utilising such a ballast water treatment system, it is important to first identify which kind of ballast water treatment sytsems are available.

Ballast water systems: types and operational/capital costs

There are two main methods to treat the ballast water. These are onboard systems or shore based systems. For the first group, there are several different techniques possible each with their own pros and cons. The main decisive factor if a vessels will have either an onboard or shore based ballast water system is dependent on the yearly volume of ballast (King et al, 2010). King et al (2010) found that if a vessel is processing less than 70.000 metric tonnes of ballast water per year, then a shore-based system is better to use. For vessels handling more ballast water per year an onboard system is better to use. Since this is an important element within the study, some additional elaboration on why this study assumes 70.000 tonnes is the tipping point. The expectation is that both on shore and ship based systems did substantially evolve since 2010; the investment costs for ship owners in a ship based system did decrease substantially, but also the shore based systems have developed since then, causing the operational costs and thus price for using such a shore based system to decrease as well. The assumption is that the development did proceed with a similar pace and therefore the ratios between the different systems did not change since the study. To the knowledge of the researchers, there aren't more recent studies available assessing this issue. The tipping point is dependent upon the treatment rate per m^3; a higher treatment rate will lead to a lower quantity of ballast water as a tipping point. Therefore later on within the study, various price scenarios will be elaborated to account for these price differences. To also, though indirectly, vary with the tipping point, sensitivity analyses will be carried out with the total volumes of treated ballast water. This way, the results are validated within a changing perspective and provide an accurate estimation of the costs and benefits of an SRA.

For onboard systems, there are different types of ballast water treatment systems available. These systems differ in different characteristics such as capacity, costs, methodology; the corresponding investment necessary for such a system differs as well. The different systems can be divided into three main categories and several sub-categories (Source: DNV GL, 2018 and Marine Insight, 2017):

I. UV systems
   a. Ultra-violet treatment
   b. Filtration Systems (physical)[1]
II. Electrolytical systems
   a. Acoustic (cavitation treatment)
   b. Electric pulse/pulse plasma systems
   c. Magnetic Field Treatment
   d. Heat (thermal treatment)
III. Chemical injection systems
   a. Chemical Disinfection (oxidizing and non-oxidizing biocides)
   b. Deoxygenation treatment

[1] Not only UV system, but could be categorised within multiple categories.

For a complete description of the different types of ballast water treatment systems, we refer to appendix 1. A typical ballast water treatment system onboard ships uses two or more technologies together to ensure that the treated ballast water is of IMO standards. It is not the aim of the study to assess the choice of ballastwater treatment system; there is no discusion within this study whether an onboard system is better than a on shore system, or what kind of onboard system is preferred. The investment decision whether to use an onboard system or a shore based system could also be influenced by the amount of ports within and outside of the SRA; a small percentage of ports outside the SRA could lead to using a shore based system outside of the SRA and vice versa, a big percentage outside, might lead to using an onboard system. Again, this analysis is however not the scope of this research.

Objective of the study and framing

These described systems are only necessary if the ships sail internationally and if there is no SRA defined, in which ballast water treatment is not necessary; it can be loaded and unloaded anywhere within the SRA. It is an area in which ballast water would naturally distribute anyway, due to the currents and other natural circumstances. There is a lower, or none, ecologic risk that species that potentially could be a threat to 'native' species are transported to the other area; these species already naturally distribute due to the natural circumstances. The SRA could function as one of the solutions to the ballast water management convention. Such an SRA has not only ecological effects, but also economic consequences. Aim of this study is to determine these economic consequences for a possible SRA in (part of) Netherlands and Belgium waters.

In order to determine the viability of the SRA, two studies are carried out: an economic (this study) and an ecologic study. Often when discussing the viability, there is a confrontation between ecologic incentives and economic incentives. Does the ecologic risk increase exponentially when a SRA would be implemented or is there a natural distribution of species anyway? How many ships would be affected by an SRA and what would the potential costs and benefits be of an SRA? Are these benefits the additional ecological costs and risks worth? It is however not the aim of this research to analyse the confrontation between economy and ecology, but its purpose is the determination of the economic effects and the determination of the viability of an SRA in the North Sea between the Netherlands and Belgium from an economic perspective. For this economic study, there has been cooperation with the ecologic study and some assumptions and input is shared within the two studies.

In order to analyse the economic viability, it is important to first identify the main maritime locations and their characteristics within the possible SRA. In this initial phase of the study, the SRA would include five different Dutch and Belgian ports:

I. Rotterdam
II. Antwerp
III. Zeebrugge
IV. Zeeland Seaports (North Sea Port)
V. Ostend

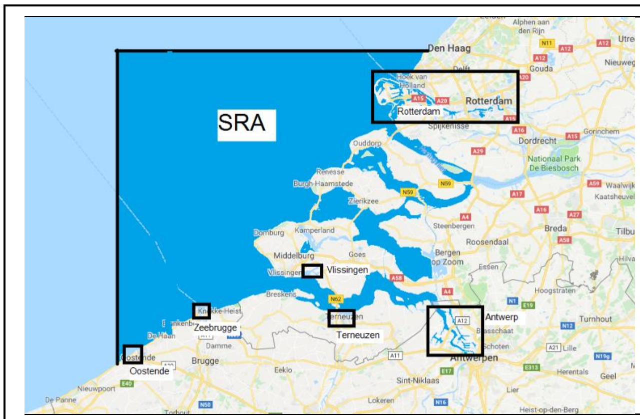


Figure 1: possible SRA area and ports

These five ports are some of the most important ports within this geographic region. For a short description per port, we refer to the appendix 2. The maritime network within this geographic region is a diverse network. On the one hand, the biggest seagoing vessels (both tankers as well as containerships) come to ports within this geographic area; on the other hand, there is a large number of smaller inland vessels that operate within the port and towards the hinterland. These vessels transport large amounts of cargo, both import and export cargo. The direction of these cargo flows does differ for the various ports; Rotterdam and Zeeland Seaports are 'importing' ports, but Antwerpen and Zeebrugge are 'exporting' ports; i.e. the outgoing flows are more than or almost the same as the ingoing flows. This research does not make a comparison between different ports in this geographic range, but it could be important to keep into mind when analysing the economic effects of the ballast water management and an SRA. It needs to be mentioned that for vessel movements between two ports from the same country, ballast water doesn't need to be treated. Therefore only the vessel movements between either Rotterdam or Zeeland Seaport on the one hand, and Antwerp, Zeebrugge and Ostend on the other hand, and vice versa is relevant. The ecologic study with its current information and data gives insufficient reason to expand the research area to the ports in the United Kingdom and/or France; there seems to be a very weak two-directional natural distribution of species within the current assumptions, if at all. Therefore none of the UK or French ports are taken into account in this study. Later on within the analysis (P19) a qualitative estimation for the economic effect if the UK would have been included is elaborated, to provide an indication for the effect, however, this is only an estimation.

Proposal analysis ecnomic effects

Taking into account the characteristics of the BWM convention, of an SRA and of the maritime locations within the possible geographic area of a SRA, we propose the following methodology. First, an overview is given of maritime transportation within the geographical area; origins, destinations, characteristics of the fleet etc. The second part gives the qantification of the economic effects for various scenarios, including sensitivity analyses to validate the results in a broader perspective. This methodology will be elaborated more extensively in the next step of the research.

Part 2: Methodology economic effects: costs and benefits

In order to quantify the cost and benefits of installing an SRA, a method is needed. Firstly, the potential benefits will be quantified and secondly the cost. Based on the cost and benefits, the total cost benefit ratio can be quantified.

Benefits of the SRA

The main benefits of having an SRA are the saved cost for the vessel owners not to having the treat their ballast water. In order to calculate these benefits, first a definition of the vessels operation in the SRA is needed. Secondly, the two main options to treat the ballast water needs to be taken into account. Based on this a typology of vessels in the SRA and, the main calculation method of the benefits can be determined. The determination of the 'target group' for the SRA, i.e. the relevant, influenced vessels by an SRA is a result of this initial analysis.

Definition of the vessel operations

The main benefits of installing an SRA are the saved cost for vessel owners for not having to treat their ballast water. If a vessel is having a complete trip in a SRA then the ballast water for that trip doesn't need to be treated[2]. This means that, from the perspective of an SRA port, three different types of vessel operations are possible:

1. Vessels sailing from outside the SRA to a port in the SRA
2. Vessels sailing from an SRA port to another SRA port but the previous port of call was outside the SRA. An example here could be a container vessel calling firstly in Hamburg, secondly in Rotterdam and finally in Antwerp.
3. Vessels sailing from an SRA port to another SRA port but the vessel is always operational in a SRA. These are on the one hand small vessels such as service vessels, fishing and offshore vessels and on the other hand relatively small cargo vessels.

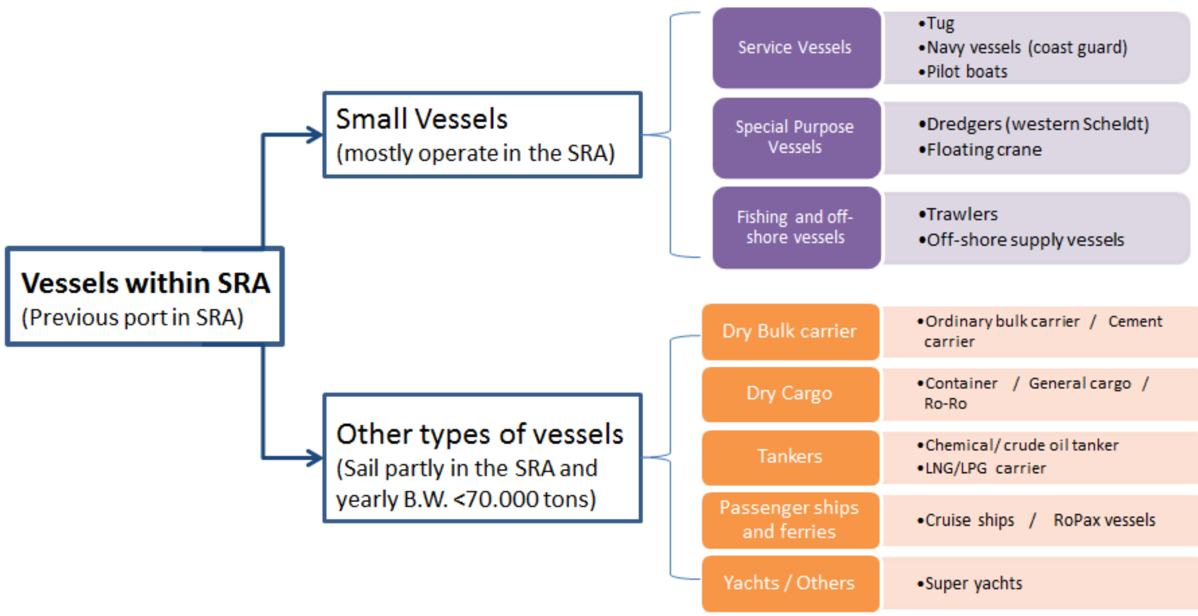
First type of ships need to treat their ballast water at all time, since they are coming from outside the SRA. For the second type of ships, it seems possible to obtain a benefit for the part of the trip within the SRA. However, when it comes to the potential benefit of installing an SRA, it needs to be mentioned that based on information obtained from the interviews, it was not possible to switch off onboard ballast water systems (Damen, 2018). It is technically possible to switch off a treatment system for the voyage within the SRA, but the untreated water inside the ballast tanks will cause the tanks to be contaminated. The next ballast water discharge outside of the SRA will likely not comply with the D-2 standard since the water was treated only once (for UV systems, upon discharge) or not at all (for chlorination systems that treat only on intake). All of the manufacturers of type-approved systems recommend to operate the system at all times to prevent contamination. Therefore, the operational cost of treating the ballast water for an SRA trip cannot be saved. This means that for the second type of vessels, sailing only partly in the SRA and having an onboard ballast water system, there is no benefit of having an SRA.

[2] If a trip is between two ports in the same country, then also no ballast water need to be treated, due to the definition of the ballast water convention (the US is an exemption on this rule).

Further typology of vessels in an SRA

For the third type of ships, a further typology of vessels is made. In this study area, the ports of Antwerp and Rotterdam are included. These two are the largest ports in Europe and they will accommodate vessels types such as: very large containers vessels, bulkers, oil tankers, tug boats, etc. Based on the insights obtained in the previous sections, the main typology of vessels calling at an SRA port which could benefit from the SRA can be defined, illustrated in figure 2.

Figure 2: Typology of vessels that could benefit from the SRA



The vessels that are sailing only in the SRA are relatively small vessels. These vessel types include tug boats, pilot vessels, etc. Tug boats and pilot boats, which are the vast majority of the vessels permanently sailing in the SRA, do have a very limited amount of ballast water. For fishing vessels / trawlers also only a limited amount of ballast water is present. Therefore, the benefits of not having to treat the ballast water for these vessels are very low. In order to make an assessment of the total benefits of the SRA, these benefits are estimated at zero.

For vessels that have a yearly ballast water consumption less than 70.000 tonnes an additional calculation need to be made[3]. For a complete explanation about the tipping point of 70.000 tonnes which is used within the analyses, see earlier in the problem statement (P5). There are no vessels within the data that use more than 70.000 tonnes of ballast water and sail only within the SRA. The choice has been made to estimate an average ballast water consumption based on the statistics of the world fleet and the total worldwide seaborne trade. Based on the total worldwide trade volume, the total ballast water consumption can be estimated. David (2015) estimated that, taking different ballast factors into account, roughly 33% of the total worldwide trade volume in tonnes is used as ballast water. From Unctad (2017), it is found that in 2016 10.287.000.000 tonnes of cargo were transported. This means that in total,

[3] Because no data is available at port level about the ballast water consumption per vessel type, some calculations are needed to estimate the average ballast water consumption.

3.394.710.000 tonnes of ballast water were consumed in 2016. In order to determine the ballast water consumption per vessel group, the shares of each vessel group are multiplied with the total ballast water consumption. The fleet data, along with the calculated ballast water consumption, can be seen in table 1. It is assumed that all the used ballast water will have to be cleaned or exchanged, to comply with all IMO regulations and standards.

Table 1: Statistics of the world fleet and ballast consumption per vessel group (Source: Data from Unctad (2017) and own calculations)

Vessel type [-]	Share [%]	Total capacity [dwt]	BW consumption [tonne/year]
Tankers	28,7%	534.855.000	974.281.770
Bulkers	42,8%	796.581.000	1.452.935.880
General cargo	4,0%	74.823.000	135.788.400
Container vessels	13,2%	245.609.000	448.101.720
Other:			
Gas carriers	3,2%	59.819.000	108.630.720
Chemical	2,3%	43.225.000	78.078.330
Offshore	4,2%	77.490.000	142.577.820
Ferries	0,3%	5.896.000	10.184.130
Other	1,3%	23.554.000	44.131.230
	100%	1.861.852.000	3.394.710.000

From table 1, it can be seen that, in 2017, 85% of the total world merchant fleet consisted of oil tankers, bulkers and container vessels. These three vessel groups are also responsible for 85% of the total ballast water consumption. In order to calculate the average ballast consumption per vessel type, more detailed vessel data is needed. From van Hassel (2017) detailed fleet data is available for tankers, bulkers and container vessels. For each vessel group, different vessel types are available along with the number of vessels (columns 1 to 3 in table 2). From the weighted share of each vessel type (column 4), it is possible to calculate the ballast water consumption for each of the sub groups of vessels[4]. If the total ballast water consumption per vessel type is known, it is possible to calculate the average yearly ballast water consumption per year (table 5). Table 2 shows the results of the calculations.

From table 2, it can be seen that there are five vessel types which have, on average, a yearly ballast water consumption less than 70.000 tonnes per year. These vessel types are:

- Product tankers (dwt < 60.000 tonnes)
- Handymax bulkers (dwt < 35.000 tonnes)
- Small feeder, feeder and feedermax container vessels (all container vessels smaller than 3.000 TEU capacity)

[4] The total ballast water consumption for containers, bulkers and tankers are known from table 1. If we apply the weighted share of each vessel sub group, then the total ballast water consumption for each of these sub groups can be calculated.

For the other vessel groups, we lack the detailed data. However the total number of general cargo vessels (16.957), gas carriers (1.850) and chemical tankers (5.418) for 2017 are found from Statista (2018). Based on this, it can be calculated that the yearly average ballast water consumption for these vessel types is:

- 8.000 tonnes for general cargo vessels
- 58.720 tonnes for gas carriers
- 14.410 tonnes for chemical tankers

So also these vessels can be considered as vessels that could, according to King et al. (2010), be using shore based ballast water systems.

Table 2: Yearly ballast water consumption per vessel type (Source: Vessel data from van Hassel (2017) and own calculations)

TANKERS	DWT (1)	Average capacity (dwt) (2)	Number of vessels (3)	Weighted share (4)	BW per vessel (tonne/year) (5)
Product tanker	10.000-60.000	30.000	1.315	8,7%	64.680*
Panamax	60.000-80.000	70.000	546	8,5%	150.921
Aframax	80.000-120.000	100.000	1.113	24,6%	215.602
Suezmax	120.000-200000	160.000	528	18,7%	344.962
VLCC	200.000-320000	260.000	606	34,9%	560.564
ULCC	320.000-550000	435.000	48	4,6%	937.867
BULKERS	DWT				
Handysize	10.000-35.000	22.500	2.070	9,1%	63.543*
Handymax	35.000-60.000	41.500	3.243	26,2%	117.202
Panamax	60.000-80.000	70.000	1.773	24,1%	197.690
Capesize	80.000	80.000	2.615	40,7%	225.932
CONTAINERS	TEU				
Small Feeder	1.000	1.000	948	4,6%	21.921*
Feeder	1.000-2.000	1.500	1.283	9,4%	32.881*
Feedermax	2.000-3.000	2.500	673	8,2%	54.802*
Panamax	3.000-5.000	4.000	920	18,0%	87.684
Post Pananmax	5.000-10.000	7.500	1.071	39,3%	164.407
New Panamax	10.000-14.500	12.250	265	15,9%	268.531
Ultra large	14.500	14.500	64	4,5%	317.853

The vessel types that consume less than 70.000 tonnes of ballast water per year are given in table 3, along with their average yearly ballast water consumption (column 2). In order to quantify the benefits for not using the shore based ballast water treatment systems, also the average ballast water consumption for a trip between two SRA ports needs to be known.

* Further used in the analyses

This ballast water consumption is estimated based on the following formula:

$$BW_{j,X} = \frac{YBWC}{250} \quad (1)$$

The ballast water consumption per trip between two SRA ports ($BW_{j,x}$) can be calculated by dividing the yearly ballast water consumption (YBWC) by average number of operational days per year for the different vessel types[6]. This can be done because the average time needed for such a trip is more or less one day (column 3).

Table 3: Overview of vessel types which could make use of shore-based ballast water systems

Vessel group	**Size of the vessel (1)**	**Yearly Ballast water consumption (2)** [tonnes/year]	**Ballast water consumption in port X (3)** [tonnes/SRA trip]
Product tanker	< 60.000 dwt	64.680	258,72
Handysize	< 35.000 dwt	63.543	254,17
Small Feeder	< 1.000 TEU	21.921	87,68
Feeder	< 2.000 TEU	32.881	131,53
Feedermax	< 3.000 TEU	54.802	219,21
General cargo	All types	8.008	32,03
Gas carriers	All types	58.719	234,88
Chemical tankers	All types	14.411	57,64

There is some ballast water discharging data available via a port survey by in amongst the port of Antwerp (2014). In table 8 the results of our study are compared to the values of the study of the port of Antwerp.

Table 8: Total yearly benefit of the SRA

	Calculations	PoA (2014)
Chemical tankers	3.622	140.000
Bulkers	3.050	40.000
Container vessel	48.000	120.000
General cargo	7.239	20.000
Gas carriers	235	-
Chemical	28.361	40.000

From table 8 can be seen that in Antwerp yearly around 120.000 tonnes of ballast water is imported (discharged) by container vessels. In this data all the container vessels are taken into account, while in this study we only took those container vessels into account that will potentially make use of shore based ballast water treatment systems. If we compare the two values it can be concluded that due to the fact

[6] We lack more detailed data for the actual operational days of the different vessels. Therefore, an estimation of 250 days per year is used for all vessel types.

that the calculated ballast water volume is smaller (50.000 tonnes) then the total ballast water discharge in Antwerp for container vessels, the calculate volume is not overestimated. The same conclusion can be drawn for the other vessel types.

Quantification of the benefits

Based on the developed typology, it is possible to calculate the benefits for each vessel calling at an SRA port. These benefits come from the saved cost for the vessel owners not having to treat their ballast water. Because vessels that operate mostly in the SRA are relatively small, most of these vessels will have a yearly ballast water consumption less than 70.000 tonnes. Therefore, for the small vessels, the main benefit will come from the saved operational cost of not having to use a shore-based system. These yearly benefits can be quantified as follows:

$$Benefit_{Small,X} = \sum_{j=i}^{3} (\sum_{i=i}^{n} (BW_{j,X} .OC_j)_i) \tag{2}$$

$Benefit_{small,X}$ = the yearly benefit of not needing to treat their ballast water for small vessels, calling at port *x*, sailing continuously in the SRA in EUR/year.
j = the number of the small vessel types (from tugs to offshore supply vessels) that sail between either a Dutch and a Belgian port or vice versa[7].
N = the number of ships of each small vessel type that is sailing in the SRA.
BW_k = the ballast water consumption for vessel type j in port *x*.
OC_J = the operational cost for ballast water handling for vessel type *J*. These costs are estimated at €7,5 /ton[8].

The benefits of the other types of vessels can be quantified as follows:

$$Benefit_{Other,X} = \sum_{k=1}^{5} (\sum_{j=1}^{m} (BW_{j,X} .OC_k)_l) \tag{3}$$

$Benefit_{Other}$ = the yearly benefit for vessels sailing only partly in the SRA.
k = the number main other vessel types (bulk carriers, dry cargo vessels, etc.).
M <u>= the number of ships of each vessel type with a yearly ballast water consumption less than 70.000 tonnes (i.e., </u>tankers < 60.000 dwt, bulkers < 35.000 dwt, container vessels < 3.000 TEU, all general cargo vessels, gas carriers and chemical tankers).

Cost of the SRA

Besides the benefits of the SRA, there are also costs which are linked to installing and possibly also maintaining the SRA. The cost of installing the SRA is determined by the cost of applying for a SRA exemption at the IMO, while the cost of maintaining the SRA includes the cost of checks by persons who are controlling the vessels if the comply the SRA rules. These checks include the validation if a certain

[7] As mentioned before, vessels sailing between two ports of the same country, the ballast water convention doesn't apply
[8] Based on interview with Damen (2018).

vessel has a previous port of call inside the SRA. These cost are estimated at €200.000 per year for maintaining the SRA ($C_{SRA,yearly}$) and €2.000.000 to install and set up the SRA. The setup cost of the SRA is the cost for arranging the SRA at the IMO and the local governments. This estimation includes all the costs for the preparatory meetings, papers, regulations, monitoring of invasive species according to Ospar Helcom protocol, reporting and emergencies, including the then required personnel. On average 1 FTE per year per country (€75.000 per year x 2 countries) + port survey (€50.000 per year). These costs for the SRA have been discussed with the 'Inspectie Leefomgeving en Transport' for the Dutch situation. It is the assumption that the costs within Belgium are similar to the costs in the Netherlands.

Total net benefit of the SRA

The total net benefit per year of the SRA can be determined with the following formulae 4 and 5:

$$Benefit_{year} = \sum_{x=1}^{5} B_{SRA,X} - C_{SRA,yearly} \tag{4}$$

$$\mathrm{NPV} = \sum_{t=0}^{n} \left[\frac{Benefit_{year}(\mathrm{t})}{(1+\mathrm{r})^{\mathrm{t}}} \right] \tag{5}$$

$Benefit_{YEAR}$ (t) = the yearly net benefit per year in year t in [EUR],
B_{SRA} = the total benefit (saved cost per year) in Euro,
$C_{SRA,Yearly}$ = the yearly maintenance cost of the SRA in EUR,
t = year,
r = the discounting factor (4%),
n = the maximum life span of the investment in the SRA (10 years in this case).
NPV = net present value

If the benefits of the SRA are larger than the cost of the maintaining the SRA, a positive total net benefit can be obtained. If there is a positive total net benefit, than we can conclude that it economically possible to set up an SRA. Also, a sensitivity analysis can be made to research to which level the SRA cost can increase until the total benefits are just zero. This cost level is the maximum cost for which the SRA is still economically viable.

Part 3: Data analysis and results

The method described in part two shows that it is necessary to have data for the five considered ports about their vessels calls. In this section, the data is described and presented that was collected from the five different ports. The benefits of an SRA are calculated, as well as the costs, resulting in the calculation of the net effect of an SRA. Various sensitivity analyses are carried out, to further validate the results found and provide a bandwidth in various input variables as well as the results.

Data collection

The five considered SRA ports provided data with respect to the number of vessels calling at their ports. For each of these vessels, the previous port is known, as well as the type and size of vessel. If a size of the vessel was not directly given in GT or dwt, these values were obtained via either estimations of the length of the vessel or, if only the name was known, the GT and dwt values were collected by making use of MarineTraffic.

Vessel selection

Based on the typology made in part two (figure 2), the numbers of vessels are counted which are calling at an SRA port, with a previous call in a foreign SRA port. It can be seen that there are only a few vessels which sail purely in the SRA and are very small, i.e. consume very little ballast water, if at all. Most of these vessels sailing in the SRA and which are coming from a foreign port are pilot vessels and tugboats. This is especially the case for the port of Ostend and Zeeland Seaports. Also with respect to the total number of vessels calling at the five ports, the relative share is very small. This is an indication that also the total share of ballast water consumed for these vessels is small. Therefore, as indicated before, these really small vessels without ballast water consumption are not taken into account.

Based on the same data sources, the vessels are counted that could make use of shore-based systems to treat the ballast water. These vessel counts are given in table 5. Based on the collected data it is possible to calculate the net benefit of the SRA. This will be done in the next section.

Table 5: Number of vessel calls, which would make use of a shore-based ballast water system, calling at an SRA port with a previous port call in another country within SRA.

		Rotterdam	Zeeland seaports	Antwerp	Zeebruges	Ostend
Product tanker	< 60000 dwt	698	538	14	282	0
Handysize	<35000 dwt	8	15	12	0	0
Small Feeder	< 1000 TEU	63	18	51	0	0
Feeder	< 2000 TEU	97	1	31	0	0
Feedermax	< 3000 TEU	102	4	181	3	0
General cargo	All types	146	164	226	51	6
Gas carriers	All types	0	75	1	20	0
Chemical	All types	13	169	492	3	6

Results: Benefits

For the vessels sailing between foreign SRA ports, and which will use shore-based ballast water systems, the benefits (saved cost of not having to use the shore based system) are calculated in table 6 and 7. Table 6 shows the results for Dutch ports, while table 7 shows the results for the Belgian ports. For this calculation we assume that the total port time of vessel, using a shore based ballast water system, is not effected. The benefits for installing an SRA are obtained by the vessel owners, which are not all per se registered in either the Netherlands or Belgium. The benefits obtained by those vessels registered in another country then the Netherlands or Belgium could be interpreted as a leakage of benefits to other countries. However, installing the SRA in both Dutch and Belgian ports, is likely to make these ports more attractive to call at. The potential benefits for this increase in port calls will be a benefit for both the Netherlands and Belgium[9].

Table 6: Benefits for vessels calling at the Dutch SRA ports

Port of Rotterdam		BW consumption per call	Number of calls	Total ballast water not handled	Saved cost
		[tonnes/call]	[-]	[tonnes/year]	[EUR]
Product tanker	< 60000 dwt	258,72	698	180.588	1.354.409
Handysize	<35000 dwt	254,17	8	2.033	15.250
Small Feeder	< 1000 TEU	87,68	63	5.524	41.431
Feeder	< 2000 TEU	131,53	97	12.758	95.685
Feedermax	< 3000 TEU	219,21	102	22.359	167.695
General cargo	All types	32,03	146	4.677	35.074
Gas carriers	All types	234,88	0	-	-
Chemical	All types	57,64	13	749	5.620
		Total	1.127	228.689	1.715.164
Zeeland Seaports		BW consumption per call	Number of calls	Total ballast water not handled	Saved cost
		[tonnes/call]	[-]	[tonnes/year]	[EUR]
Product tanker	< 60000 dwt	258,72	169	43.724	327.930
Handysize	<35000 dwt	254,17	41	10.421	78.158
Small Feeder	< 1000 TEU	87,68	18	1.578	11.837
Feeder	< 2000 TEU	131,53	1	132	986
Feedermax	< 3000 TEU	219,21	4	877	6.576
General cargo	All types	32,03	108	3.459	25.945
Gas carriers	All types	234,88	31	7.281	54.609
Chemical	All types	57,64	169	9.742	73.063
		Total	541	77.214	579.106

[9] The calculation of these benefits are outside the scope of this research.

Table 7: Benefits for vessels calling at the Belgian SRA ports

Port of Antwerp		BW consumption per call	Number of calls	Total ballast water not handled	Saved cost
		[tonnes/call]	[-]	[tonnes/year]	[EUR]
Product tanker	< 60000 dwt	258,72	14	3.622	27.166
Handysize	<35000 dwt	254,17	12	3.050	22.876
Small Feeder	< 1000 TEU	87,68	51	4.472	33.539
Feeder	< 2000 TEU	131,53	31	4.077	30.580
Feedermax	< 3000 TEU	219,21	181	39.677	297.576
General cargo	All types	32,03	226	7.239	54.293
Gas carriers	All types	234,88	1	235	1.762
Chemical	All types	57,64	492	28.361	212.705
		Total	1.008	90.733	680.496
Port of Zeebruges		BW consumption per call	Number of calls	Total ballast water not handled	Saved cost
		[tonnes/call]	[-]	[tonnes/year]	[EUR]
Product tanker	< 60000 dwt	258,72	282	72.960	547.197
Handysize	<35000 dwt	254,17	0	-	-
Small Feeder	< 1000 TEU	87,68	0	-	-
Feeder	< 2000 TEU	131,53	0	-	-
Feedermax	< 3000 TEU	219,21	3	658	4.932
General cargo	All types	32,03	51	1.634	12.252
Gas carriers	All types	234,88	20	4.698	35.232
Chemical	All types	57,64	3	173	1.297
		Total	359	80.121	600.909
Port of Ostend		BW consumption per call	Number of calls	Total ballast water not handled	Saved cost
		[tonnes/call]	[-]	[tonnes/year]	[EUR]
Product tanker	< 60000 dwt	258,72	0	-	-
Handysize	<35000 dwt	254,17	0	-	-
Small Feeder	< 1000 TEU	87,68	0	-	-
Feeder	< 2000 TEU	131,53	0	-	-
Feedermax	< 3000 TEU	219,21	0	-	-
General cargo	All types	32,03	6	192,19	1.441,41
Gas carriers	All types	234,88	0	-	-
Chemical	All types	57,64	6	345,86	2.593,96
		Total	12	538,05	4.035,37

Results: Total net benefit of the SRA

The total net benefit of the SRA can be calculated with formula 4. Table 9 gives the total benefits per year for a range of shore based ballast water handling costs per m^3. This variation in treatment costs per m3 for on shore systems is done to account for various price scenario's and indirectly account for different ballast water treatment tipping points; i.e. the 70.000 tonnes. This latter element is also taken into account via the sensitivity analyses later on in this analysis (P21) and a reduction in the treatment volumes.

Table 9: Total yearly benefit of the SRA

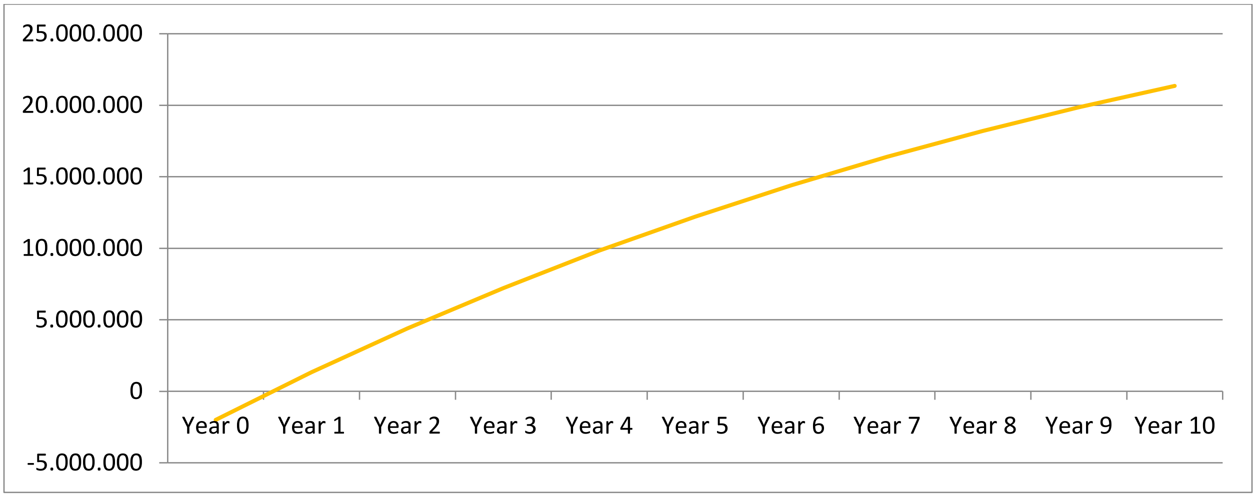
	Rotterdam	Zeeland Seaports	Antwerp	Zeebrugges	Ostend	Total
€5	€1.143.443	€386.070	€453.664	€400.606	€2.690	€2.386.474
€7,50	€1.715.164	€579.106	€680.496	€600.909	€4.035	€3.579.710
€10	€2.286.885	€772.141	€907.328	€801.213	€5.380	€4.772.947

The benefits are determined by the cost savings for vessel owners not needing to use the shore based systems in the respective ports. The biggest part of these cost savings are obtained by vessel owners calling in Rotterdam. This means that there are more vessel, which most likely will be making use if shore based systems, sailing from a Belgian port to the port of Rotterdam then in the other direction. The benefits for the vessel owners at the ports of Zeeland Seaports, Antwerp and Zeebrugges are, roughly the same. The potential benefits obtained in the port of Ostend are negligible. The total benefits of the SRA range between €2.380.000 and €4.770.000 per year. For the cost of the SRA, there is an initial installment cost of €2.000.000 at year 0 for the total SRA. The yearly maintenance cost of the total SRA is €200.000 per year as explained in the methodology in part two.

In the rest of the calculations the yearly cost are indexed by 2% a year to cover for inflation. The yearly benefits are taken as constant[10]. The total estimated benefit of in the base case (€7,50 per m^3) the SRA is €3.579.710 per year. This means that the for the given cost of installing the SRA and the given cost saving per ton ballast, there is an economic benefit of installing the SRA. The yearly discounted net benefits of the SRA are given in figure 3. Ports in the UK were not taken into account in the current costs and benefits, see earlier in the analysis for the argumentation (P7). It is the estimation of the researchers that the benefit-cost ratio would increase if some of the UK ports would be taken into account; i.e. the benefits would increase faster than the costs, assuming the costs do not increase exponentially when increasing the SRA size.

[10] Due to the fact that no forecasts are available for the number of vessels calling at the different SRA ports, the yearly benefits are assumed to be constant.

Figure 3: Yearly discounted net benefits

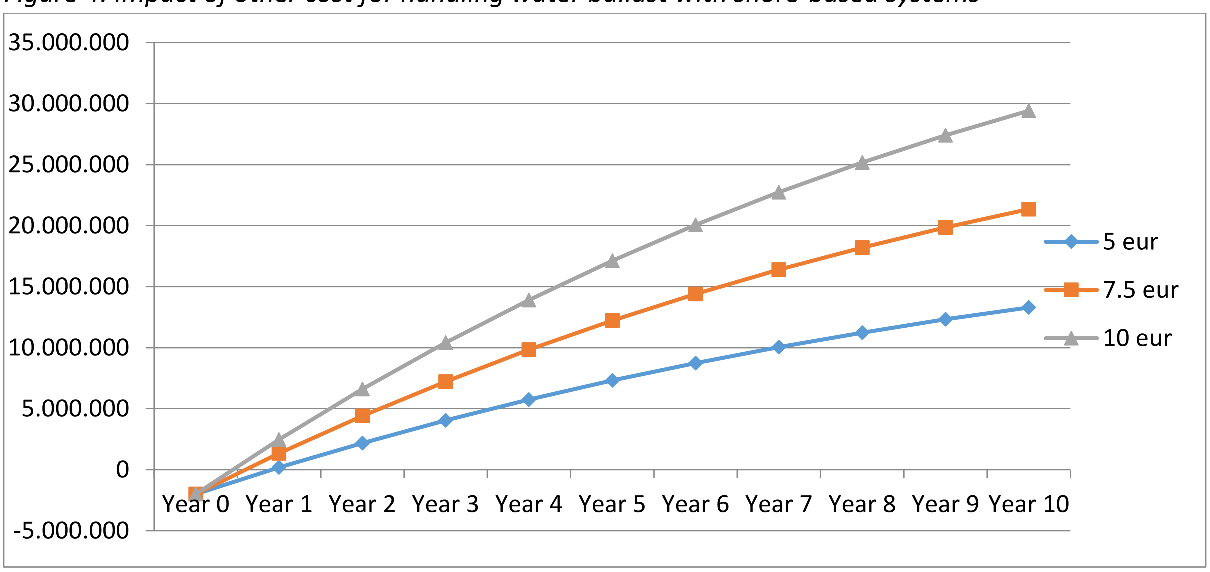


The total net benefit after 10 years is €21.350.000. This means that based on the assumed cost, it is economically worthwhile to install the SRA.

Sensitivity analyses and further validation of bandwidth in results

In figure 4, the impact of using a different cost to treat ballast water with a shore-based system is researched. The costs are varied from €5 to €10 per tonne.

Figure 4: Impact of other cost for handling water ballast with shore-based systems



From figure 4, it can be observed that a lower cost for treating the ballast water with a shore-based system will lead to a lower net benefit after 10 years (€13.200.000). For a higher cost, the net benefits will be higher (€29.400.000). In all scenarios, the net benefit remains positive. The next sensitivity analysis with respect to the cost of the SRA depends on both the investment cost and the yearly maintenance cost. In table 10, the net benefits are given for varying values of investment cost and yearly maintenance cost.

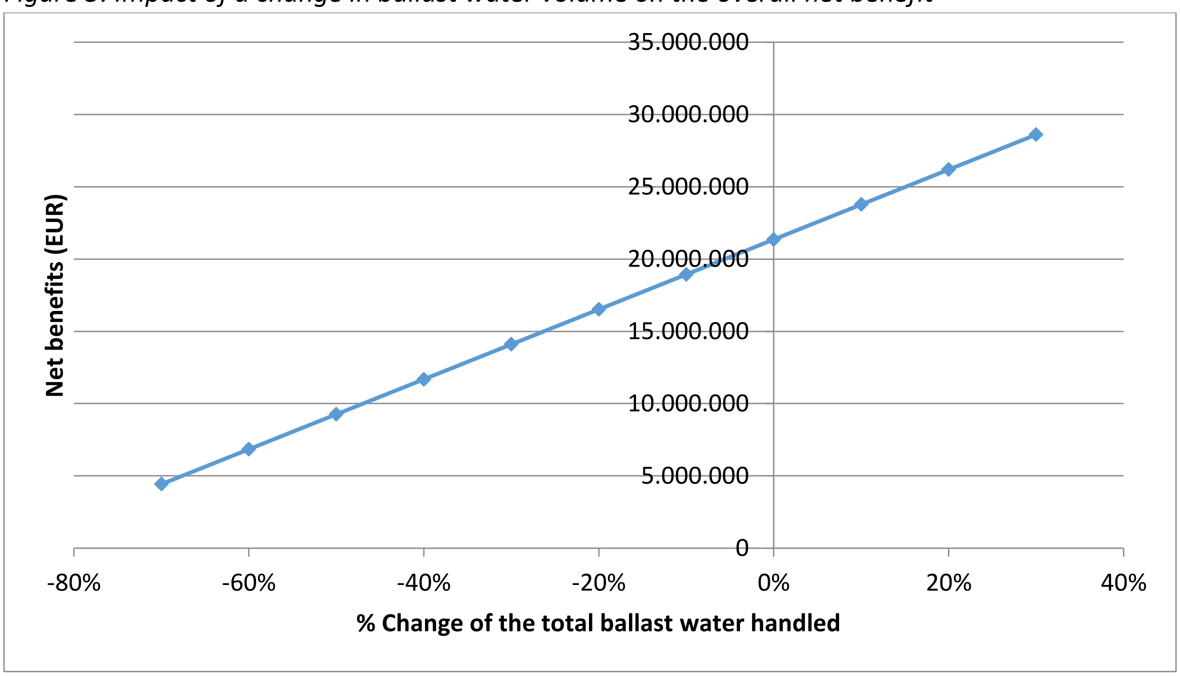
Table 10: Impact of SRA cost changes on net benefits

		Yearly maintenance cost (EUR)				
		200.000	500.000	2.000.000	2.500.000	3.000.000
Investment cost SRA (EUR)	500.000	22.028.228	19.809.056	8.713.198	1.315.959	-6.081.281
	1.000.000	21.352.664	19.133.492	8.037.634	640.394	-6.756.845
	2.000.000	20.001.536	17.782.364	6.686.505	-710.734	-8.107.973
	4.000.000	18.650.407	16.431.236	5.335.377	-2.061.862	-9.459.101
	6.000.000	17.299.279	15.080.107	3.984.249	-3.412.991	-10.810.230

From table 10, it can be concluded that the net benefits are above zero as the yearly maintenance cost is less than €3,000,000 per year and as the investment cost is less than €4,000,000. These two values can be interpreted as the maximum values which the establishment and yearly maintenance cost for the SRA can be.

The next variation the will be researched is the change in ballast water volume. This can either be caused by an increase or decrease in the number of vessels, which will make use of shore based systems to process ballast water, calling at the SRA ports or by a change in ballast water consumption of the considered vessels. This change in ballast water volume will impact the net benefit of the SRA. Figure 5 gives shows the impact of a percentage change in ballast volume handled in the considered SRA ports with a SRA investment cost of €2.000.000, a yearly maintenance cost of €200.000 and a ballast water treatment cost €7,5 per m^3 (base case situation).

Figure 5: Impact of a change in ballast water volume on the overall net benefit



If the total volume of ballast water to be handled increases, the net benefits are increasing from €21.350.000 in the base case scenario to €28.600.000 if the total ballast water volume increase with 30%.

For a decrease of 70% the net benefits will decrease to €4.400.000. On average can be concluded that 1% increase in handled ballast water volume the net benefits will increase with €240.000 (or vice versa).

The reason to calculate the benefits if the ballast water volume that could benefit from the SRA is reduced with 70% compared to the initial ballast water volume is due to two possible effects. The first effect is linked to the investment decision of a vessel owner to choice for an onboard system to opt for a shore based installation to handle the ballast water. This tipping point value was taken from literature and was found to be 70.000 tonnes ballast water per year. If due to technological progress the onboard BWS cost are reduced, this tipping point value will be less. This will result in a decrease in the number of vessel that will make use of shore based systems and thus in a decrease ballast water that does not need to be handled.

The second effect is linked to possible capacity problems at ports for vessels using shore based systems. For vessels sailing in the SRA, this problem will not occur because these vessels don't need to use these installations. But it could be that there are capacity problems at ports that are not part of the SRA. If that is the case then vessel owners will, because they need to fulfill the ballast water convention, make use of onboard systems. As a result of that, as in the previous case, a decrease in the ballast water that does not need to be handled is expected. Based on the results of figure 5 it can be concluded that even with a decrease of 70% of the ballast water volume in 2017 still a net benefit can be obtained and that the SRA is economical viable.

SRA without the port of Antwerp

Final sensitivity analyses is to consider an SRA without Antwerp, since the results of the ecological study seem to conclude that it might not be possible to include the port of Antwerp in the SRA. As a results of that an anlysis is done in which the port of Antwerp is not a part the SRA. In this situation the total amount of ballast water which not have to be handeled is reduced. This reduction is not only caused by the fact that the port of Antwerp is excluded, but also the total ballast water volume that do not need to be handled in the Dutch ports is redcued. This reduxtion is due to the fact that, in the case that Antwerp is excluded, only the vessels sailing between Ostend and Zeebrugges and the Dutch ports are to be taken into accont. In table 11 the number of vessel callings with and without the ports of Antwerp are given for the two Dutch SRA ports.

Table 11: Reduction of vessels calling at Dutch SRA port with and without Antwerp

		Rotterdam		Zeeland seaports	
		With ANT	Without ANT	With ANT	Without ANT
Product tanker	< 60000 dwt	698	10	169	53
Handysize	<35000 dwt	8	0	41	4
Container vesselsFeeder	< 1000 TEU	63	1	18	0
Feeder	< 2000 TEU	97	20	1	0
Feedermax	< 3000 TEU	102	8	4	0
General cargo	All types	146	1	108	11
Gas carriers	All types	0	5	31	11
Chemical	All types	13	0	169	103

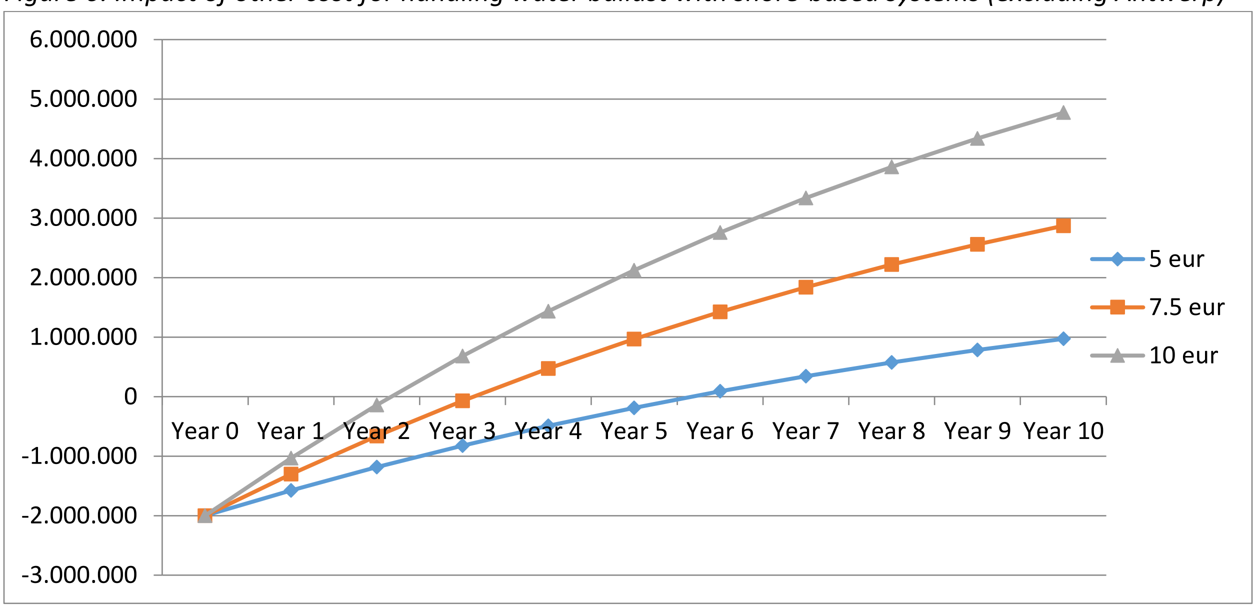
The total benefits, in the case that the port of Antwerp is excluded can be seen in table 12. From table 12 can be concluded that the total yearly benefits are reduced to a range of€ 560.000 to €1.125.000. This is a redcution of 76.4% compared to the situatiuon in which the port of Antwerp was included.

Table 12: Total yearly benefit of the SRA without Antwerp

	Rotterdam	Zeeland Seaports	Antwerp	Zeebrugges	Ostend	Total
5 eur	41,328	118,011	-	400,606	2,690	562,635
7.5 eur	61,991	177,017	-	600,909	4,035	843,953
10 eur	82,655	236,022	-	801,213	5,380	1,125,270

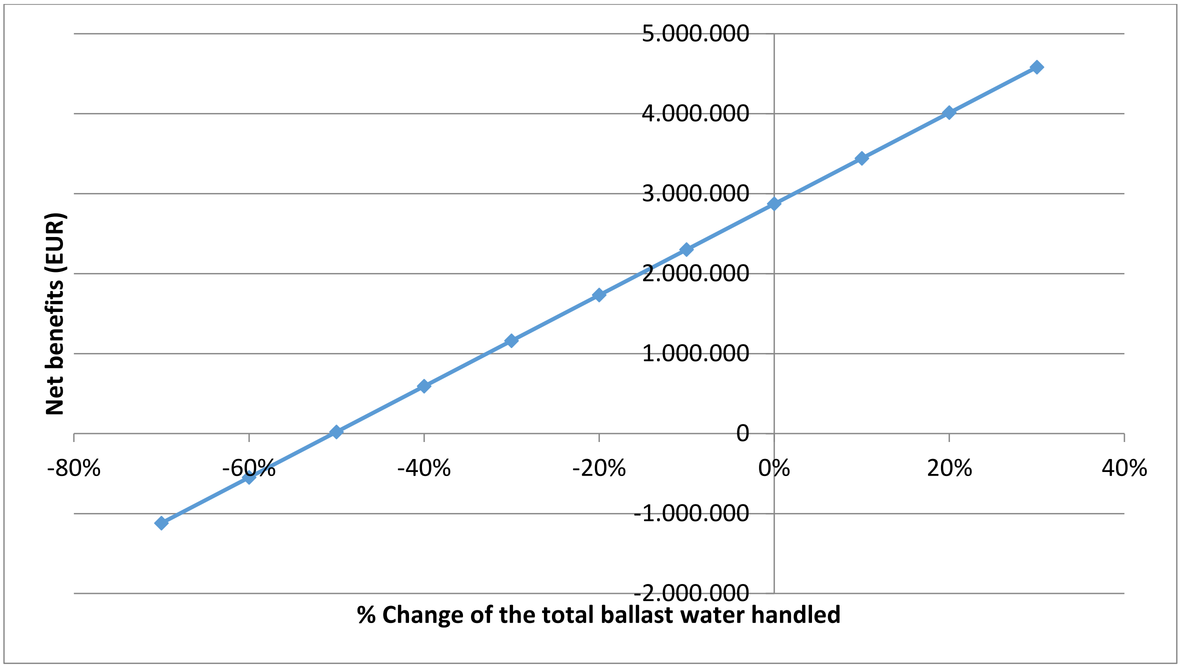
If net benefits are calculated of the SRA without the port of Antwerp, and with varying cost of handling ballast water with shore based systems, the net benefits reduce to €2.870.000 for the base case (€7.5 per tonne). This is a decrease of 87% compared to the SRA including Antwerp. In figure 6 the results of the net benefit calculation can be seen.

Figure 6: Impact of other cost for handling water ballast with shore-based systems (excluding Antwerp)



From figure 6 can be concluded that if Antwerp is exlcuded from the SRA the total net benefits will reduce much compared to the SRA in which the port of Antwerp is included. However, the net benefits are still positive (ranging between €1.000.000 and €4.800.000). This means that, given an initial investment cost of €2.000.000 and a yearly maintaince cost of €200.000 it is still economical viable to install a SRA even without the port of Antwerp. In figure 7 the variation of the ballast water volume is taken into account for the SRA without Antwerp.

Figure 7: Impact of a change in ballast water volume on the overall net benefit (excluding Antwerp)



From figure 7 can be concluded that the if the ballast water volume is decreased with 50% compared to the base values, the net benefits are just positive. If the ballast water volume is decreased even further, the net benefits will become negative. This means that the SRA, whitout Antwerp, is only economicly viable if the total ballast water volume that could benefit from the SRA is not reduced further then 50% of the base value.

Conclusions

Aim of this study was to provide an overview of the economic effects of an SRA exemption from the ballast water treaty. Various ballast water management systems are described and analysed within an SRA context. Main part of the analyses was to analyse the economic costs and benefits of an SRA surrounding five ports within The Netherlands and Belgium. Considering different types of ships and different components, the analyses show that there are economic benefits of an SRA. There are substantial volumes of ballast water, which would not have to be treated when an SRA would be implemented, via ships that sail only within the SRA and with relatively low volumes of ballast water. The total net benefit of an SRA ranges between €2,4 and €4,8 million per year. Various sensitivity analyses show the variation in the results due to its (in)dependancy upon the value of some variables. Overall conclusion remains in all scenarios that there are economic benefits of an SRA and there is an economic base for the implementation. It is important to analyse the SRA within a complete framework. Therefore this study will be combined with an ecologic study in order to provide a complete overview.

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Appendix

Appendix 1: Brief description different types of Ballast water treatment systems

I. UV systems

UV systems are the most used option at this moment. Usually they use a two-step process of filtration and uv to sterilise organisms and stop their reproduction. In amongst the developed shore based system by Damen uses these techniques (Damen, 2018). UV systems are suitable for any vessel in theory, but primarily for those which do not take in too much ballast water and have flow rates of up to around 1,000 cubic metres per hour. This includes ro-ro vessels, container ships, offshore supply vessels and ferries. UV systems are easy to install and retrofit, and have few safety concerns from a class point of view. They also operate independently, no matter what the water salinity and temperature are. However, they are dependent on the water transmittance (UV-T) and work less well in turbid water (DNV GL, 2018)

a. Ultra-Violet treatment

Ultraviolet ballast water treatment method consists of UV lamps which surround a chamber through which the ballast water is allowed to pass. The UV lamps produce ultraviolet rays which acts on the DNA of the organisms and make them harmless and prevent their reproduction. This method has been - successfully used globally for water filtration purpose and is effective against a broad range of organisms (Marine Insight, 2017).

b. Filtration Systems

Physical separation or filtrations systems are used to separate marine organisms and suspended solid materials from the ballast water using sedimentation or surface filtration systems. With various types of equipment the ballast water is filtered and the waste is gathered at the ship. The filtered solids and waste (backwashing) water from the filtration process is either discharged in the area from where the ballast is taken or further treated on board ships before discharging (Marine Insight, 2017). There are three types of equipment mainly used for physical filtration of ballast water: screens/discs, hydrocyclone, media filters. Usually the process of physical filtration is carried out after an initial phase of coagulation or flocculation, which is a method to join smaller particles together to increase their size. As the size of the particles increases, the efficiency during the filtration processes increases.

Screens (fixed or movable) or discs are used to effectively remove suspended solid particles from the ballast water with automatic backwashing. Screen filtration is effective for removing suspended solid particles of larger size but is not very handy in removing particles and organisms of smaller sizes. That why solely using screens or discs is not sufficient to treat ballast water according to IMO standards. The second type of equipment is an hydrocyclone, which uses high velocity centrifugal force to rotate the water to separate solids. Third type of filtration system are media filters, which is mainly used to filter out smaller-sized particles. These compressible media filters (crumb rubber) are more suited for onboard use because of their compact size and lower density, making it easier to transport and store (Marine Insight, 2017).

II. Electrolytic systems

The second method of cleaning ballast water water is by using electrolytical systems. By passing an electric current through a small side-stream of seawater, they use the salt and the water molecules in a chemical reaction to generate sodium hypochlorite, a disinfectant, which is then reinjected into the ballast water to kill all organisms (DNV GL, 2018). Electrolytic treatment systems are more suited for larger vessels such as tankers and bulk carriers, which have large ballast water volumes and high flow rates. As well as being able to handle large capacities, electrolysis-based systems are very efficient and the treatment of the water is done on the intake only (possible neutralization on discharge). Due to the (physical) characteristics of the installation and the processes carried out, electrolytical systems are more complex to install, control and maintain compared to UV filter systems (DNV GL, 2018).

Within electrolytical systems there are four main categories of treatment of ballast water: 1) cavitation or ultrasonic treatment, 2) eletric pulse/plasma treatment, 3) magnetic field treatment and 4)heat treatment.

In cavitation or ultrasonic treatment, ultrasonic energy is used to produce high energy ultrasound to kill the cells of the organisms in ballast water. The electric pulse /plasma for ballast water treatment uses short bursts of energy to kill the organisms in ballast water. In the pulse electric field technology, two metal electrodes are used to produce energy pulse in the ballast water at very high power density and pressure. This energy kills the organisms in the water. In electric plasma technology, high energy pulse is supplied to a mechanism placed in the ballast water, generating a plasma arc and thus killing the organisms (Marine Insight, 2017). This technique is still in development stage and is not widely applied yet. The magnetic field treatment uses the coagulation technology. Magnetic powder is mixed with the coagulants and added to the ballast water. This leads to the formation of magnetic flocs which includes marine organisms. With the help of magnetic discs these magnetic flocks are separated from the water. (Marine Insight, 2017). Last category of treatment within electrolytical systems is heat treatment. This treatment basically consists of heating the ballast water and 'boiling' the organisms, because of the higher water temperature.

III. Chemical injection systems

Chemical injection systems use a chemical solution, which is injected into the ballast water to ensure disinfection. These systems are often used in combination with filtration. There are regulations surrounding the use of chemicals; not every type of chemical is allowed to be used. Some of the active substances which are commonly used include sodium hypochlorite, peracetic acid and chlorine dioxide. The disinfectant may be liquid or granular and will sometimes require neutralization prior to discharge overboard (DNV GL, 2018). Chemical injection systems are deemed appropriate for most ballast flow capacities ranging up to 16,000 cubic metres per hour and are mostly used to treat ballast water on vessels with larger capacities and flow rates, such as tankers and bulkers. The technology is suitable for infrequent usage.Chemical injection systems are easier to install than other types of systems, since they require less space on board. In addition though, the chemicals must be stored on board – for example in closed containers - and may be hazardous. This uses space, plus the use use of chemicals requires implementation of strict safety provisions for storage and use as well as crew training (DNV GL, 2018 and Marine Insight, 2017). Two types of chemical injection systems will be discussed: chemical disinfection and deoxygenation.

a. Chemical Disinfection (Oxidizing and non-oxidizing biocides)

Oxidizing and non-oxidizing biocides are disinfectants which potentially remove invasive organisms from ballast water. On the basis of their functions, biocides are mainly divided into two types: oxidizing and non-oxidizing (DNV GL, 2018 and Marine Insight, 2017). Oxidizing biocides are general disinfectants such as chlorine, bromine and iodine used to inactivate organisms in the ballast water. This type of disinfectants act by destroying organic structures of the microorganisms such as cell membrane or nucleic acids. Some of the processes utilizing oxidizing biocides used on board ships are chlorination or ozonation. It is important to consider that these biocides should be readily degradable or removable to prevent discharge water from damaging to nature. Non-oxidizing biocides are a type of disinfectants which when used interfere with reproductive, neural or metabolic functions of the organisms. Though there are several non-oxidizing biocides available in the market, only a few such as Menadione/ Vitamin K are used in ballast water treatment system as they tend to produce toxic by-products (Marine Insight, 2017).

b. Deoxygenation

The deoxygenation ballast treatment method involves purging/removing of oxygen from the ballast water tanks to kill the organisms. This is usually done by injecting nitrogen or any other inert gas in the space above the water level in the ballast tanks. After a few days, the organisms are dead, so the method cannot be applied for ships with a really short transit time.

Appendix 2: Brief description per SRA port:

Rotterdam

Rotterdam is the biggest port of Europe with regards to throughput volumes. 461.2 million ton in 2016 have been transported through the port of Rotterdam; primarily consisting of liquid bulk (202.5 million ton) and containers (127.6 million ton). In 2016, almost 30,000 seagoing vessels and about 105,000 inland vessels came to the port of Rotterdam (Port of Rotterdam Authority, 2018).

Antwerp

Antwerp is the second port of Europe with 223.6 million tons of throughput. Antwerp has two main types of cargo: containers and liquid bulk. Unlike Rotterdam, which handles both crude oil and mineral oilproducts, the liquid bulk throughput in Antwerp mainly consists of mineral oil products. The number of seagoing vessels in Antwerp in 2016 was about 14,250 (Antwerp Port Authority, 2018).

Zeebrugge

Zeebrugge handled approximately 37.8 million ton in 2016. The majority of this cargo is containers and roll-on-roll-off throughput. Zeebrugge is often referred to as the automotive hub port in Europe (or even the world), since millions of (new) cars are shipped through Zeebrugge. About 8,500 seagoing vessels arrived in the port of Zeebrugge in 2016; next to that about 1,300 inland vessels arrived in Zeebrugge (Port of Zeebrugge Authority, 2018).

North Sea Port

Vlissingen and Terneuzen will be discussed together, since they work together within Zeeland Seaports (and since december 2017 with the port of Ghent as North Sea Port). In 2016, just over 33 million ton was transported through Zeeland Seaports. Both liquid – and dry bulk were the main categories of products; breakbulk is the third important category. Just over 5,500 seagoing vessels arrived in Zeeland Seaport, and about 22,500 inland vessels (Zeeland Seaports, 2018).

Ostend

Ostend is a relatively small port, Southwest of Zeebrugge. Compared to the other ports, Ostend handles relatively low volumes of thoughput. Ostend port is mainly focused on offshore wind and energy. Throughput in 2017 was about 1,4 million ton of general cargo, transported via about 4.000 calls; the vast majority being offshore related calls (Port of Oostende, 2018).