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Safe container transport north of the Wadden Islands

Lessons learned following the loss of containers from MSC ZOE

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The Hague, June 2020

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The Dutch Safety Board

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Dutch Safety Board

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N.B. This report is published in the Dutch and English language. If there is a difference in interpretation between the Dutch and English version, the Dutch will prevail.

CONTENT

SUMMARY

In the night of 1 to 2 January 2019, the MSC ZOE lost 342 containers north of the Wadden Islands, while sailing towards Bremerhaven, Germany, in a stormy northwesterly wind in the Terschelling-German Bight traffic separation scheme (known as the southern shipping route) to the German port of Bremerhaven. The course of events of this very serious marine casualty was investigated by an international investigation team comprising the Panama Maritime Authority (PMA), the German Bundesstelle für Seeunfalluntersuchung (BSU) and the Dutch Safety Board. The report of this investigation considers the causes of the accident and the potential lessons learned.

The accident also led the Dutch Safety Board to launch an additional investigation into the route-specific risks on the shipping routes north of the Wadden Islands, which can lead to the loss of containers for large container ships like the MSC ZOE. This report describes the findings of that investigation. The findings from the two investigations into the accident with the MSC ZOE were exchanged and the reports (and recommendations) harmonized.

Modelling of the high-risk situation as experienced in the accident scenario of the MSC ZOE
The Dutch Safety Board requested the knowledge and research institutes Deltares and MARIN to contribute to the investigation based on their areas of expertise to gain a greater insight into the extent to which the environmental conditions on the shipping routes north of the Wadden Islands contribute to the risk of the loss of containers by large ships. Using measurement data and models, Deltares calculated the current, sea level, wind and wave conditions for reference positions on the southern and northern shipping routes at the moment of the accident with the MSC ZOE. A stormy northwesterly wind on the North Sea like that experienced during the occurrence on average occurs between one and several times a year in the area. In the event of such a northwesterly wind, the waves have both the time and the space to build in height and peak period before they reach the Dutch and German Wadden coastline. In these conditions, the wave direction is at right angles to the southern and northern shipping routes. MARIN made calculations and undertook basin tests with a ship model of a large container ship to gain a greater insight into the ship motions under these conditions. The basin tests revealed that in these conditions, with beam seas, large and wide container ships can be caused to make severe motions. Specifically these ships normally sail with high stability; they are in principle more difficult to upset from their steady state and as a result also return more rapidly to that steady state. This combined investigation has provided a new insight into the circumstances, ship motions and phenomena that occur in the area north of the Wadden Islands.

Route-specific risks of loss of containers on the southern shipping route
The German container ports can be reached via two routes on the North Sea: the southern route, close to the Wadden Islands and the northern route, which is situated further away from the coast. The investigation revealed that in both shipping routes specific risks can occur. These risks are the consequence of high beam seas, the limited depth of the shipping route and the high stability of large, wide container ships.

In the basin tests, four hydrodynamic phenomena were measured and observed which individually and in combination can lead to the loss of containers:

- extreme ship motions, resulting in large accelerations and forces on the lashing systems and containers;
- bottom contact due to a combination of the rolling motion of the ship and large vertical motions in the waves;
- green water, whereby solid masses of water from waves spray upward at high speed along the side of the ship, slamming on the containers;
- impulsive slamming against the ship hull.

The potential occurrence of extreme ship motions relates to the fact that container ships have gradually become larger and wider, and sail with high stability. The natural roll period of these ships closely approximates the wave period that can prevail on the North Sea. In the event of beam seas with a wave period close to the natural roll period of a ship, as a consequence of resonance, the ship responds significantly to the waves, resulting in violent rolling motions. This in turn leads to rapid accelerations on the ship, containers and lashing equipment. The occurrence of bottom contact, green water and slamming can even further amplify these accelerations and/or forces. The basin tests reveal that the accelerations can come close to the maximum design limits of the lashing systems and the containers. A large and wide container ship, that sails in the southern route under the given circumstances, will encounter these phenomena or a combination of these phenomena. As a consequence, large forces are acting on the vessel, the containers and the lashing equipment. If the design limits are exceeded, the lashing systems and/or containers can fail and containers can subsequently fall overboard.

During the course of the investigation, in October 2019 the Dutch Safety Board issued an interim warning relating to the risk that in specific wind and wave conditions, container ships dimensioned similar to those of the MSC ZOE sailing on the southern shipping route could experience contact or near contact with the seabed. The reason for issuing this warning was to ensure that users of the southern shipping route were informed as quickly as possible of previously unrecognized risks.

Comparison of route-specific risks on the southern and northern shipping routes
To a large extent, the northern and southern shipping routes are both subject to comparable route-specific risks for large container ships. The investigation into meteorological and maritime conditions at the time of the accident with the MSC ZOE revealed that the wave conditions on the northern shipping route were comparable with those on the southern route. The northern shipping route is deeper than the southern one, but waves typical for shallow water occur on both shipping routes. Moreover, in a stormy northwesterly

wind, vessels on both shipping routes will experience waves approaching abeam. This means that large, wide container ships on the northern shipping route can also experience extreme ship motions, green water and wave impacts (slamming). On the other hand, the basin tests do suggest that these two latter phenomena occur more commonly on the southern shipping route.

An essential difference is that on the northern shipping route, due to the additional metres of water depth as compared with the southern route, the risk of contact with the seabed is negligibly small and there is more room to manoeuvre and make course changes to reduce the risk of violent rolling motions. In a storm-force northwesterly wind, the northern route therefore is not a safe route, but a more favourable route in respect of the risk of loss of containers. In the other wind conditions, the southern shipping route can offer safer sailing conditions because of the screening effect of land on this shipping route located closer to the coastline.

It can be concluded that on both the southern and the northern shipping route, large and wide container ships like the MSC ZOE, in a storm-force northwesterly wind, do run the risk of failure of their lashing systems and containers, as a result of which they may lose containers. For both routes the loss of containers will result in pollution of the North Sea, and depending on the wind and current direction, of the vulnerable Wadden area.

Risk management by ships on the shipping routes
In the (container shipping) industry, no link so far has been established between the polluting consequences of container loss and the damage to the nature values of the Wadden area. For container ships there are no specific guidelines, restrictions or requirements when making use of the northern or southern shipping route above the Wadden Islands. The southern route is shorter and for that reason economic factors such as time and fuel consumption play a clear role in selecting the route.

Managing the risk of containers loss on the shipping routes in poor weather conditions, in the current situation, depends on the actions of the master and the crew. The master must act and make choices based on good seamanship, like timely changes to the course or shipping route. This situation is vulnerable, given the fact that at present, the crew has no insight into the forces and accelerations acting on the containers and the lashing equipment.

Protection of a vulnerable area of nature in the international context
The southern and northern shipping route have been set by the International Maritime Organisation (IMO, the United Nations organization for maritime affairs). The Netherlands has no independent authority to impose binding regulations on the use of these shipping routes or to adjust the location of these routes. Only decisions by the IMO can result in obligations or regulations for ships on these shipping routes.

The recognition of the Wadden Sea as a Particularly Sensitive Sea Area by the IMO does offer the affected Coastal States (the Netherlands, Germany and Denmark) some

opportunities for proposing associated (protective) measures for shipping to the IMO. Furthermore, because of the internationally recognized status of the area (UNESCO World Heritage, Natura 2000), the affected coastal states are required to prevent damage to the nature values. At present, no specific measures for the shipping routes north of the Wadden Islands have been taken aimed at protecting the Wadden area against pollution as a consequence of containers loss. The coastal states of the Wadden Sea therefore have to share the findings from the international investigation and this investigation with regard to the revealed risks with the IMO and have to develop a proposal for appropriate measures. Improvement measures via the IMO are procedures that take years and as a consequence will only have an effect on the risk management of container loss near the Wadden Sea in the long term.

Prospects for action by the Dutch government
Following the accident with the MSC ZOE, the Ministry of Infrastucture and Water Management launched a series of investigations, including an investigation into the possibilities for marking containers with electronic chips, an investigation by the ILT into the lashing of containers, and additional basin tests also involving other vessel types. Earlier expressed concerns, among others, by the Wadden municipalities, haven't led to a targeted approach to manage the risks of container loss or to execute a specific risk analysis for the shipping routes north of the Dutch Wadden Islands.

The Netherlands Coastguard has, at this moment, no formal role in determining routes that must be taken by container ships north of the Wadden Islands. On the other hand, the Coastguard can advise ships sailing in an easterly direction on the choice of either the southern or northern shipping route. Since the interim warning was published by the Dutch Safety Board, the Netherlands Coastguard has responded actively by pointing out the risk of bottom contact in the event of high waves on the southern shipping route, but this is only one of the route-specific risks. Ships sailing in a westerly direction from German waters on the northern or southern shipping route do not, at present, receive any warning; the German authorities are awaiting the final results of the international investigation by PMA, BSU and the Dutch Safety Board.

CONSIDERATION

A loss of containers on the shipping routes north of the Wadden Islands may result in damage to a unique and vulnerable area of nature. The accident with the MSC ZOE on 1 and 2 January 2019 and the subsequent large-scale plastic pollution forcefully emphasized this conclusion.

The lessons to be learned from this accident must result in a better risk management of container transport on the shipping routes on the North Sea north of the Wadden area. The findings from the international investigation into the circumstances of the MSC ZOE accident and the present investigation into the risks on the shipping routes, form the basis for arriving at an approach for preventing the loss of containers close to the Wadden area, in the short and long term.

Precaution to protect nature in the Wadden area
On the shipping routes north of the Wadden Islands, the loss of containers is a realistic risk that – despite the precise content – leads to pollution of the North Sea. Depending on the direction of wind and current, a container and its content will pollute the Wadden area. The seriousness of such pollution should not be underestimated. Apart from potential long term damage to organisms, for example through spreading of hardly degradable microplastics, lost containers directly degrade the natural value of the Wadden area with its unique variety of flora and fauna. The accident with the MSC ZOE is a pivotal point in the attitude towards container losses on the shipping routes are perceived, and should lead all stakeholders involved to realise that every container lost in this area is one too many, and that container loss should therefore be prevented.

Container loss prevention requires knowledge of the risks of the loss of containers on the shipping routes north of the Wadden Islands. This investigation has brought to light risks of container loss for large, wide container ships during specific weather conditions, i.e. a stormy northwesterly wind, on the shipping routes above the Wadden Islands. Further research is needed to, for the shipping routes near the Wadden Islands, also map the risks for different circumstances and/or other sizes and types of ships. The Dutch Ministry of Infrastructure and Water Management has already taken an important first step by commissioning additional research.

The new insights into the risks and the recognition of the undesirability of the degradation of the natural value of the Wadden area as a consequence of container loss should be cause for the container shipping industry, the Dutch government and the International Maritime Organization (IMO, the United Nations organisation for maritime affairs) to take measures to prevent container loss at this location. The status of the Wadden Sea as a UNESCO World Heritage area and an IMO Particularly Sensitive Sea Area (PSSA) reinforces the necessity of these actions and offers further opportunities to take up this responsibility.

International approach to prevent container loss

The two shipping routes north of the Wadden Islands have been established internationally by the IMO. At this moment, on neither of the shipping routes routing measures for container ships apply with the aim to prevent the loss of containers. Any route alteration or other measures for (a specific category of) container ships on these routes can only be established through the IMO at the initiative of one or more member states.

It is now up to the Netherlands – together with fellow Wadden States Germany and Denmark – to translate the knowledge of route-specific risks that have emerged from this study, and possibly other still to be identified hazardous scenarios on the two shipping routes, to a detailed proposal for measures in an IMO context. The aim of this proposal should be to minimise the loss of containers north of the Wadden Islands and to protect the Wadden area. This may include measures for (a specific category of) container ships, and if necessary alteration of the two shipping routes north of the Wadden Islands. Within that framework it may also be considered to further extend the area of the PSSA Wadden Sea, for example to include the southern shipping route.

The coalition of Wadden States will be further strengthened if the state of Panama is involved as well. As the flag state of the MSC ZOE, Panama was in charge of the international investigation into the course of events. Moreover, around one quarter of the world's merchant fleet sails under Panamanian flag. In addition, the Netherlands can exercise additional influence through its seat in the IMO's Council; this seat was extended for a further two years at the end of 2019. At the IMO conference in November 2019, the Dutch Minister of Infrastructure and Water Management stated that the Netherlands intended to keep safety high on the IMO agenda and was looking to reach sound agreements on safety issues worldwide. She emphasised the Dutch interest in this process referring to the loss of containers off the Wadden coast in January 2019. It is now up to the Netherlands to live up to this ambition and take action. The present investigations and the resultant insights into the risks of loss of containers in the Wadden area offer a sound basis.

Short-term approach

The process of improving risk management by means of measures implemented through the IMO will take at least several years. For that reason it is important that the Dutch government also examines what can be done immediately to minimise container loss on the shipping routes north of the Wadden Islands. One good possibility lies in expanding the advisory role of the Dutch Coast Guard beyond the risk of seabed contact which already takes place. The Coast Guard could be given the authority to provide container ships with relevant information and concrete advice about the shipping route or required manoeuvring, so that these vessels can sail safely past the Wadden Islands in all wave and weather conditions. In doing so, it is important that the Netherlands works closely with Germany and Denmark in order to arrive at a uniform cross-border approach.

No less important is that the container shipping industry itself learns lessons from the occurrence involving the MSC ZOE. Preventing the loss of containers is in the first place the responsibility of shipping companies and container ship masters. For the fulfilment of this responsibility it is important that, when sailing on either the northern or the southern shipping route north of the Wadden Islands, they are aware of the complex relationships between environmental conditions, ship motion, ship stability and the limits of lashing systems and containers.

With immediate effect, in their voyage preparation and during the voyage, both shipping companies and container ship masters can and must anticipate the route-specific risks of the shipping routes above the Wadden Islands. This means that masters have information and knowledge of all route-specific weather and wave conditions, and of the interaction thereof with the characteristics and design criteria of their ship and its cargo. Moreover, the conclusions and recommendations from the international investigation offer starting points for shipping companies and masters for the fulfilment of their responsibility. A significant example is the development and use of instruments for measuring accelerations while sailing.

Give the degradation of natural value, the uncertainties about the ecological damage and the vulnerability of the Wadden area, precaution is necessary. This means that in this area the loss of containers should be prevented. The Dutch government can and must, both independently and in collaboration with the governments of Germany, Denmark and Panama, take the lead to achieve this goal. For that, the container and shipping industries can and must take steps as well. The Dutch container and shipping industries can play a role – as both a binding force and a driving force – by taking the lead in initiating improvements in the international world of container transport.

RECOMMENDATIONS

Minimizing the risks of container loss on the two shipping routes north of the Wadden Islands requires an integrated approach by the parties involved: the container shipping sector, the IMO and the Dutch government. In the international investigation into the course of events of the accident with the MSC ZOE and this investigation into the risks on the shipping routes north of the Wadden Islands, recommendations are made to prevent container loss near the Wadden area. The recommendations of both studies must be considered in conjunction.

Recommendations from the international investigation
The international report[1] makes recommendations to the Panamanian, German and Dutch governments to review the technical requirements imposed on container ships in an IMO context. More specifically, this concerns:

1. the design requirements for lashing systems and containers,
2. the requirements for loading and stability of container ships,
3. obligations with regard to instruments providing insight into roll motions and accelerations, and
4. the technical possibilities for detecting container loss.

Recommendations are also made to the German and Dutch governments to investigate, in cooperation with Denmark, the need for additional measures on these shipping routes or adjustments to the routes and to submit a proposal to the IMO on the basis thereof. In addition, the shipping company of the MSC ZOE is instructed to explicitly draw the attention of crews sailing in this area to the route-specific risks, and to equip and load their ships in such a way that the loss of containers is prevented. Finally, through the World Shipping Council and the International Chamber of Shipping, the international maritime sector is called upon to actively communicate the safety lessons from the investigation and to take the lead in drafting safety requirements and in the innovation of ship design and container transport in order to minimize the risk of container loss, also in conditions such as near the Wadden area.

The recommendations that emerge from the investigation into the shipping routes are aimed specifically at Dutch parties and are listed below.

1 The recommendations are presented in the international investigation report. The full report is available on the website of the DSB and BSU.

Initiative for an international approach to prevent container loss
In the area north of the Wadden area, there are at present no restrictions for international container shipping with regard to the two internationally specified shipping routes: the southern and the northern shipping route. Additional routing measures for (a specific category of) container ships can only be adopted by IMO, on the initiative of one or more member states.

To the Minister of Infrastructure and Water Management

1. In collaboration with the Wadden states Germany and Denmark, take the initiative for a specific proposal to the IMO with measures for international container shipping to prevent the loss of containers on both shipping routes north of the Wadden Islands. This can for example take the form of a review of technical standards, the introduction of restrictions, recommended routes, precautionary areas, traffic control and/or information provision. Make particular use of the status of the Wadden Sea as a Particularly Sensitive Sea Area (PSSA) and the possibilities within the IMO standards for taking measures to protect a PSSA. Make use of the outcomes of this investigation and other investigations into route-specific risks (also see recommendation 5).

Short-term approach
Decision-making by the IMO is a lengthy process. Therefore, out of precaution to protect the Wadden Sea, the Netherlands itself must take immediate measures parallel to that process within the existing legal framework to minimize the risks of loss of containers. Above all, the container shipping sector itself has a social responsibility to prevent the loss of containers, certainly in the vicinity of the Wadden Islands, but also elsewhere.

To the Minister of Infrastructure and Water Management

2. Inform shipping companies and masters of large container ships in a structural manner about the four hydrodynamic phenomena that emerged from this investigation, which can occur in the event of high beam seas on both shipping routes north of the Wadden Islands. In providing this information, also make it clear that these phenomena and combinations of these phenomena can generate forces on large, wide and stable container ships which can result in the loss of containers. If further route-specific risks emerge from other investigations, shipping companies and masters should also be immediately informed of those outcomes.

3. Grant the Netherlands Coastguard the tasks, authorities and resources it needs to monitor container ships so that ships can sail safely past the Wadden Islands in all wave and weather conditions. With this in mind, investigate the possibilities for traffic control of container ships, such as establishing a VTS area, actively disseminating warnings to shipping about prevailing weather and wave conditions in the Dutch part of the North Sea and innovating the way such information is provided. Involve the Netherlands Coastguard and Rijkswaterstaat in defining this role and responsibility. Also seek cooperation and/or harmonization with Germany on the intended tasks.

To Maritime by Holland and the Royal Association of Netherlands Ship Owners (KVNR)

4. Actively communicate the lessons learned from this investigation and the international investigation into the course of events and in your national and international networks, take up a pioneering role in reaching agreement on and disseminating the principles and industry standards that promote the safety of container transport close to the Wadden area.

Insight into route-specific risks north of the Wadden Islands

The risks revealed by this investigation relate to a scenario for large, wide and stable container ships. Further investigation is necessary to also chart out these risks in other conditions and for other types of (container) ships besides Ultra Large Container Ships like the MSC ZOE. The first steps for this follow-up investigation have already been taken by the Ministry of Infrastructure and Water Management. These must be followed up further.

To the Minister of Infrastructure and Water Management

5. Investigate the extent to which the route-specific risks of loss of containers on the shipping routes near the Wadden Islands as referred to in this report can occur on different types of container ships and in different meteorological and maritime conditions. In this investigation, include all incidents and other signals which could suggest other as yet unrecognized risks of loss of containers on the specific shipping routes.

6. Make a periodic risk analysis of the route-specific risks that can lead to container loss on the shipping routes close to the Wadden Islands, with a view to the safety of shipping and protection of the North Sea and the Wadden area, and include this analysis as a fixed element of North Sea policy. Under all circumstances, make use of a system of monitoring and analysis of shipping incidents and near misses on these shipping routes. Also include developments in shipping such as economies of scale, changes in the picture of shipping traffic and (future) changes to infrastructure and area activities on the North Sea.

J.R.V.A. Dijsselbloem
Chairman Dutch Safety Board

C.A.J.F. Verheij
Secretary Director

ABBREVIATIONS

BSU	*Bundesstelle für Seeunfalluntersuchung*, maritime casualty investigation authority of Germany
EEZ	Exclusive Economic Zone
IDON	Interdepartmental Directors' Consultation on the North Sea (Dutch: Interdepartementaal Directeuren Overleg Noordzee)
IMO	International Maritime Organization, the United Nations organization for maritime affairs
MARIN	Maritime Research Institute Netherlands
MSC	*Mediterranean Shipping Company*, shipping company of the MSC ZOE
NIOZ	Royal Netherlands Institute for Sea Research (Dutch: Nederlands Instituut voor Onderzoek der Zee)
PMA	Panama Maritime Authority, maritime casualty investigation authority of Panama
PSSA	Particularly Sensitive Sea Area
SOLAS	Safety of Life at Sea
TEU	Twenty Foot Equivalent Unit, is used to designate container dimensions. 1 TEU is a container of 20 feet long.
TUHH	Technical University of Hamburg (German: Technische Universität Hamburg)
ULCS	Ultra Large Container Ship, a commonly employed name for very large container ships. In this report, it is taken to refer to a container ship with a capacity of more than 10,000 TEU.
UNESCO	United Nations Educational, Scientific and Cultural Organisation
VDR	Voyage Data Recorder
WUR	Wageningen University & Research

1 INTRODUCTION

1.1 Background

The North Sea is one of the busiest shipping areas in the world.[2] To successfully control shipping traffic, a series of routeing measures apply on the North Sea. Above the Wadden Islands, one traffic separation scheme passes close to the Dutch coast, with a second more northerly traffic separation scheme also available. The so-called southern and northern shipping routes are often used by vessels sailing to destinations including Bremerhaven, Hamburg or the Kiel Canal, and in the opposite direction by vessels heading for Rotterdam, Antwerp and locations further to the south.

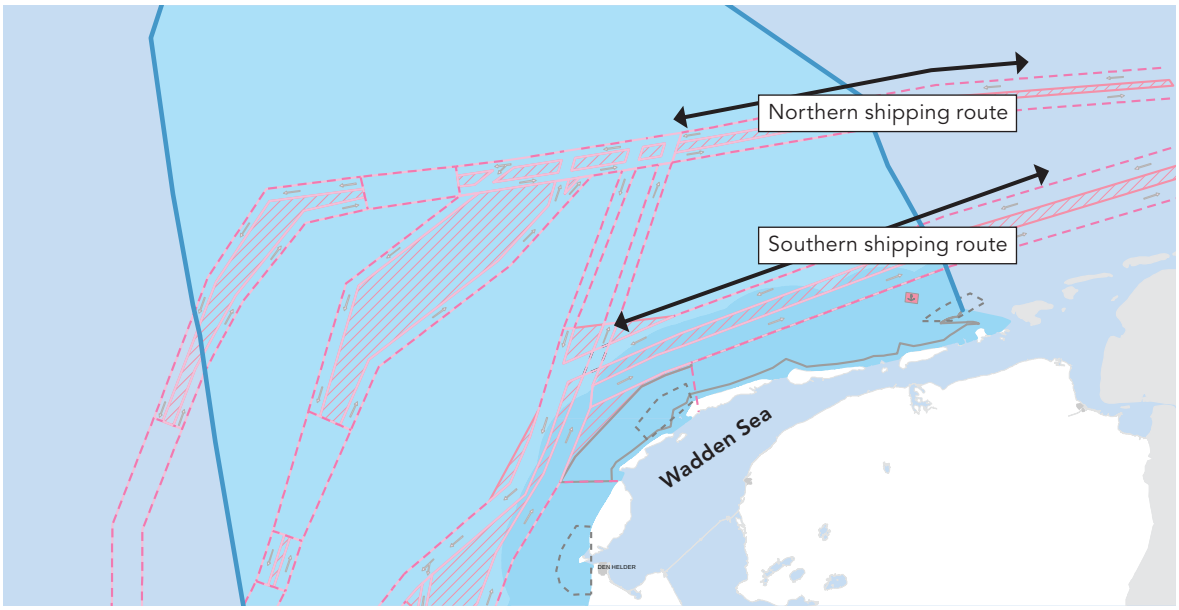


Figure 1: Location of northern and southern shipping routes north of the Wadden Islands.

The Wadden Sea, the sea area between the Wadden Islands and the Dutch mainland, is a unique nature area and is featured on the UNESCO World Heritage List.[3] In addition, the Wadden Sea has been designated as a Particularly Sensitive Sea Area by the International Maritime Organization (IMO), the maritime organization of the United Nations. On the initiative of the United Kingdom, Germany and the Netherlands, the IMO had taken additional protection measures at an earlier stage by requiring oil tankers to make use of the northern route.[4] This is not because the northern route is inherently

2 Ministry of Infrastructure and Environment, Ministry of Economic Affairs, North Sea Policy Document 2016-2021, December 2015.
3 The Wadden Sea is the inland sea between the Wadden Islands and the North Sea on the one hand and the mainland of the Netherlands, Germany and Denmark on the other.
4 [Netherlands] parliamentary papers II, 2002-2203, 28 816, nr.1.

safer than the southern route, but because in the event of a disaster, there is still time to recover the lost oil before it reaches the Wadden Sea and the coast of the Wadden Islands.

The Wadden Sea is connected directly to the North Sea. As a consequence, the Wadden area is also vulnerable to pollution occurring on the North Sea. If container ships lose their cargo, it can wash up on the beaches. In addition to potential long-term damage to organisms, pollution in and of itself represents a damage to the natural value. This clearly became visible when the MSC ZOE lost 342 containers in the night of 1 to 2 January 2019. The beaches of the German and Dutch Wadden Islands and along the coastline of Friesland and Groningen were polluted with the content of the containers. Months after the accident, MSC ZOE cargo still washed ashore.[5]

The MSC ZOE, built in 2014, has a capacity of 19,224 20-foot containers (TEU)[6] and at the time of the accident had 2,659 20-foot containers and 5,403 40-foot containers (together amounting to 13,465 TEU) on board. The size of the MSC ZOE is typical for the huge upscaling which have taken place over the past few decades in the container shipping sector. Whereas in 2005 the largest container ship carried around 10,000 TEU, the largest vessel launched in 2019 can carry 23,756 TEU.[7] Container ships continue to become ever larger.

Because of its impact on the environment, the accident involving the MSC ZOE has been classified as a '*very serious marine casualty*'.[8] The course of events that led up to the accident with the MSC ZOE was investigated by an international investigation team. In accordance with the Casualty Investigation Code of the IMO[9], the Panama Maritime Authority (PMA) was placed in charge of the investigation because Panama is the flag state of the vessel in question. The Netherlands and Germany were involved in the investigation as states with a substantial interest, due to the location and impact of the accident. The PMA, the German Bundesstelle für Seeunfalluntersuchung (BSU) and the Dutch Safety Board jointly investigated this accident. The final report with the conclusions regarding this investigation are published separately.

There was no Dutch involvement in the accident with the MSC ZOE besides the fact that at the time when the containers fell overboard, the vessel was located in the Dutch sector of the North Sea. Together with Germany, the Netherlands had to deal with the consequences of this accident, namely the pollution of the Wadden area. The question is what the Netherlands can do to prevent accidents of this kind occurring, and if they do take place, to limit the harmful consequences as far as possible. This question is urgent given the growing potential damage as a result of the ever increasing size of container ships.

5 Source: https://www.trouw.nl/nieuws/onderhandelen-de-reder-van-de-msc-zoe-moet-gewoon-betalen~b27901a8/ (accessed on April 16 2020).

6 TEU (also teu). The abbreviation TEU stands for Twenty Foot Equivalent Unit and is used to designate container dimensions. 1 TEU is a container of 20 feet long, 8 feet wide and generally 8.6 feet high (in metres: 6.10 x 2.44 x 2.62). A 40-foot long container counts for 2 TEU.

7 Source: https://www.maritiemnederland.com/nieuws/rotterdam-ontvangt-grootste-containerschip-te-wereld.

8 Classification according to the Casualty Investigation Code (CI-CODE) of the IMO. These are international standards for the safety investigations of marine casualties and incidents.

9 Casualty Investigation Code (CI-CODE) of the IMO.

With that in mind, the Dutch Safety Board carried out an additional investigation focusing on the shipping routes above the Dutch Wadden Islands.

In the framework of this investigation, the Dutch Safety Board further investigated the risks of loss of containers along the southern shipping route. One of the outcomes of this investigation is that wide, large container ships in severe weather conditions run the risk on the southern shipping route above the Wadden Islands of coming into contact with the seabed, which could lead to high forces acting on the vessel and the cargo. For that reason, in October 2019, the Dutch Safety Board issued an interim warning. This warning related to the risk to vessels of comparable size to the MSC ZOE making contact or near contact with the seabed along the southern shipping route, in specific wind and wave conditions.[10]

At the moment of the interim warning, the investigation was still fully underway. This report makes public the results of the entire investigation. The findings relevant for the investigation into the course of events surrounding the accident with the MSC ZOE were contributed to the international investigation, in accordance with international agreements.

1.2 Focus of the investigation

The investigation by the Dutch Safety Board focused on the risks of the loss of large numbers of containers from large container ships sailing on the shipping routes north of the Wadden Islands. The aim of the investigation by the Dutch Safety Board is to contribute to improved risk management for container transport along the shipping routes in the North Sea north of the Wadden area. This requires consideration of the route-specific risks of loss of containers from large container ships. The focus has been placed on the circumstances that could potentially lead to unsafe situations involving large container ships on the shipping routes above the Wadden Islands. In this process, the circumstances at the time of the accident involving the MSC ZOE were taken as the starting point, since this has emerged as a proven high-risk situation for large container ships.

The following key questions are the central focus of the investigation:

What are the route-specific risks of loss of containers for large container ships such as the MSC ZOE in the southern shipping route north of the Wadden Islands?

To what extent are these route-specific risks also applicable to the northern shipping route?

How are the route-specific risks of the shipping routes above the Wadden Islands taken into account in respect of maritime container transport?

10 See Appendix C for the complete text of the interim warning.

Demarcation
The immediate reason for carrying out this investigation was the accident involving the MSC ZOE, an Ultra Large Container Ship.[11] The course of events surrounding the accident involving the MSC ZOE is the subject of an international investigation under the responsibility of the PMA. The Dutch Safety Board participated in this investigation and relevant information from the investigation by the Board has been integrated in the international investigation. See Section 1.3 for a further explanation of the international investigation.

This investigation by the Dutch Safety Board focuses on route-specific risks of the loss of containers on the shipping routes in the North Sea to the north of the Wadden Islands for ultra large container ships such as the MSC ZOE. Due to the focus on the shipping routes, the investigation does not focus on the technical design criteria and certification of container ships, containers and fastening mechanisms / lashing materials. Because of the focus on ultra large container ships such as the MSC ZOE, this investigation will provide useful but not a precise insight into the risk of the loss of containers from other types of (container) vessels.

Ship movements also engender risks to the crew, but this subject is beyond the scope of this particular investigation with emphasis on the risk of container loss. The following subjects regarding the effects of container loss are also beyond the scope of the investigation:

- Implementation of incident management and crisis management immediately following the accident involving the MSC ZOE.[12]
- Effects (either short term or long term) of plastic pollution in marine and coastal areas around the Wadden Islands as a consequence of the accident with the MSC ZOE.

The Dutch Safety Board has taken note of investigations into the effects of plastic pollution in order to gain a clearer picture of the seriousness of the loss of containers in general, with plastic (products) in particular. The Board has also consulted experts in the field of marine ecology and (micro)plastic pollution.

Appendix A contains a detailed explanation of the design and implementation of this investigation.

1.3 Other investigations

International investigation into the course of events
The accident involving the MSC ZOE was classified according to the Casualty Investigation Code of the (IMO) and the European Directive 2009/18/EC as a 'very serious marine casualty'. This classification requires the flag state of the MSC ZOE to carry out an accident investigation.

11 Ultra Large Container Ship (ULCS) is a commonly employed name for very large container ships. In this report, it is taken to refer to a container ship with a capacity of more than 10,000 TEU.
12 The Institute for Safety carried out an investigation into these aspects. See Section 1.3 for further explanatory notes to this investigation.

The maritime investigation bodies of the flag state Panama and States with a substantial interest (Germany and the Netherlands) reached agreement on the cooperation procedure for carrying out the investigation. The Panama Maritime Authority (PMA) as investigating body of the flag state took the lead in the investigation into the course of events leading up to the loss of containers from the MSC ZOE. On behalf of Germany and the Netherlands, the investigation bodies *Bundesstelle für Seeunfalluntersuchung* (BSU) and the Dutch Safety Board respectively participated in the investigation.

On 6 January 2019, the safety investigators of the PMA, the BSU and the Dutch Safety Board boarded the MSC ZOE in Bremerhaven and launched the accident investigation. During the on-site investigation, the relevant data and information were secured, including statements from the crew members, data from the Voyage Data Recorder (VDR), data from the loading computer and the lashing programme, the stowage plan for containers, the stability manual and extracts from the logbook. The damage was also assessed.[13]

To harmonize the (interim) results and to determine follow-up steps, the PMA, the BSU and the Dutch Safety Board organized joint meetings in Hamburg, Naples and The Hague.

Both the BSU and the Dutch Safety Board consulted experts on the behaviour of vessels in sea conditions and circumstances along the shipping route to the north of the Wadden Islands. The BSU commissioned the Technical University of Hamburg (TUHH) to carry out calculations of the movements of the vessel MSC ZOE and the resulting accelerations. The Dutch Safety Board requested the research institutes Deltares and the Maritime Research Institute Netherlands (MARIN) to determine the meteorological and wave conditions along the shipping route during the storm of 1 and 2 January 2019 and the effect of these conditions on ultra large container ships like the MSC ZOE. The studies by Deltares and MARIN were initiated within the investigation by the Dutch Safety Board and focus specifically on the shipping routes above the Wadden Islands. The results were also used in the international investigation into the course of events.

Criminal investigation (Netherlands)
Under the authority of the Dutch Public Prosecution Service, a criminal investigation was launched into the accident. The investigation is being carried out by the Maritime Police and the Human Environment and Transport Inspectorate (ILT) of the Ministry of Infrastructure and Water Management.

Crisis management investigation
At the request of the Safety Regions of Fryslân, Groningen and Noord-Holland Noord and the Ministry of Infrastructure and Water Management, the Institute for Safety evaluated the crisis management following the accident involving the MSC ZOE.[14]

13 Prior to the start of the international investigation, on January 3 a Port State Control inspection took place in Bremerhaven. This inspection is mandatory based on European Directive 2009/16/EG for ships where unexpected factors have occurred, such as problems with the cargo. Further details on this inspection can be found in the international investigation.

14 Institute for Safety, *Container disaster in the North: the approach and impact. An evaluation for the Ministry of Infrastructure and Water Management*, 13 June 2019 and *Container disaster: crisis management in the Wadden area. An evaluation commissioned by the Fryslân, Groningen and Noord-Holland Noord security regions*, 18 June 2019.

On behalf of the Ministry of Infrastructure and Water Management, the Netherlands Organisation for Applied Scientific Research (TNO) also made an inventory of the technological possibilities involved in localizing and determining the content of the containers.[15]

Investigation into environmental consequences
The Minister of Agriculture, Nature and Food Quality commissioned two investigations:

- Wageningen University & Research (WUR) carried out a quick scan into the potential ecological consequences.[16]
- WUR and the University of Utrecht investigated the cause of death and the origin of the guillemots that washed up in huge numbers on the Dutch coastline in January and February 2019.[17]

In addition, subject to the coordination of the Wadden Academy, Rijkswaterstaat commissioned a multiyear research and monitoring plan focused on investigating the consequences in the short term (one to five years) and the long term (more than five years) of the loss of the containers and their content - specifically the effects of (micro) plastics - on the ecosystem of the North Sea coastal zone and the Wadden Sea. Participants in this programme include Wageningen Marine Research and the Royal Netherlands Institute for Sea Research (NIOZ).[18] In October 2020, the final report including all results of the analyses, conclusions and if applicable a sketch of the further 'finger on the pulse' monitoring, is expected to be published.[19]

The University of Groningen, in collaboration with the NIOZ, WUR and the Radboud University in Nijmegen, is charting the scope and spread of plastics following the accident with the MSC ZOE. As part of this monitoring programme, the website www.waddenplastic.nl and a web application were launched. By these means, volunteers are helping to count the plastic granules in the area; via the app they can pass on their counts together with the finding location.

15 TNO Traffic & Transport, *Inventory of technologies for monitoring, tracking and identification of maritime containers and their cargo*, 25 September 2019.
16 M.J. Baptist et al., *Potential ecological consequences of container disaster MSC Zoe for the Wadden Sea and North Sea: a quick scan*, Wageningen University & Research | Wageningen Marine Research, March 2019.
17 M.F. Leopold et al., *The Zoe and the guillemot - an investigation into the cause of death and the origin of the guillemots that washed up in huge numbers on the Dutch coastline in January and February 2019*, Wageningen Marine Research, University of Utrecht and Wageningen Bioveterinary Research, commissioned and financed by the Ministry of Agriculture, Nature and Food Quality, in the framework of the policy-support investigation, March 2019.
18 K. Philippart, L. Hanssen & J. van Dijk (2019), *What are the consequences of the lost cargo from the MSC Zoe for the North Sea coastal zone and the Wadden Sea? Investigation and monitoring plan for the short and long-term consequences of microplastics for the Wadden area and its residents*. Position Paper 2019-01. Wadden Academy, Leeuwarden.
19 NIOZ WUR, *Memorandum on the status of the investigation into the ecological effects of the MSC ZOE incident focusing on microplastics*, 30 January 2020.

1.4 Structure of the report

Chapter 2 contains the reference framework, which the Dutch Safety Board used in this investigation. Chapter 3 contains factual information about container transport, the shipping routes above the Wadden Islands and the use of space in the North Sea. This information is essential for providing a clear overview of the route-specific risks that are discussed in Chapter 4. This is followed by an analysis of risk management in container transport on shipping routes to the north of the Wadden Islands in Chapter 5. The report closes with conclusions and recommendations.

2 REFERENCE FRAMEWORK

The Dutch Safety Board carries out accident investigations aimed at improving safety in the Netherlands, focusing specifically on situations in which personal safety is dependent on other parties such as the government, companies or institutions. Against this background, in response to the accident involving the MSC ZOE, the Board has investigated the risks of loss of containers from large container ships as a consequence of local conditions on the shipping routes north of the Wadden Islands. The investigations of the Board do not address issues of blame or liability. The aim of the investigation is to determine lessons learned in order to reduce the risks of a recurrence of occurrences such as that involving the MSC ZOE, or reducing the consequences of such occurrences.

For each investigation, the Board determines a reference framework. This framework describes the principles and standards the parties involved must comply with in order to manage the safety risks in a certain domain. By identifying discrepancies in respect of the reference framework, the Board is able to determine those aspects in respect of which safety gains can be achieved.

The reference framework for the current investigation is based on the relevant laws and regulations, general principles and standards and the status of the Wadden area nationally and internationally. The framework consists of the following elements:

- Loss of containers in nature,
- Safety management by the companies involved,
- Responsibilities of the master and crew, and
- The role of the Dutch government.

2.1 Loss of containers in nature

In the light of the total number of containers transported every day, the number of containers lost at sea is relatively small. Every container that ends up in the sea, however, is an example of pollution, in absolute terms. This applies all the more for loss of containers on shipping routes through and close to nature areas.

The content of containers can be very diverse, ranging from consumer goods through to chemicals. Logically, the severity of the impact of container loss for nature areas depends on the content of the containers. At the same time, these items from containers do not belong in nature areas and negatively influence the nature value, irrespective of the damage to organisms. In many cases it is a huge or even impossible task to thoroughly clean up a polluted nature area. Moreover, the content can continue to wash ashore and spread further through the sea, long after the containers actually fell overboard.

The way in which nature and the environment suffer damage from the pollution as a consequence of loss of containers cannot be unequivocally determined based on current knowledge (see Appendix E). It is, however, clear that plastic products degrade very slowly in nature. As a consequence, plastic contamination is both cumulative and irreversible. It is therefore essential to strive to prevent pollution as a result of loss of containers close to or in nature areas in advance.

2.2 Safety management by the companies involved

Container transport by sea is a vital form of transport in our society. This mode of transport has inherent risks. Although the risk of a container falling overboard is relatively small, the (environmental) consequences of an accident can be very considerable. This means that all parties involved in transport by ship are responsible for adequately managing the risks of loss of containers.

As its starting point, the Dutch Safety Board argues that companies themselves have primary responsibility for the safety and risk management of their own business processes. An shipping company that transports containers is primarily responsible for the safety of its activities. As a rule of thumb, the more these parties stand to gain from an activity, the more the Dutch Safety Board expects of them. The Board's expectations also rise as the scale of the risk increases, the parties' capacity to manage the risk increases, or the capacity of citizens to protect themselves decreases. This also applies to companies working with substances or goods (such as containers and their contents), as a consequence of which their employees, local residents and the environment run increased safety risks.

The Board assumes that companies and organizations that undertake and/or facilitate high-risk activities apply a systematic approach to safety management in order to identify and assess risks as well as possible and that they subsequently take appropriate measures to avoid or limit these risks as far as reasonably practicable. In other words, they must at all times take all available measures to exclude or mitigate the identified risks, unless risk reduction involves unreasonable costs or other negative consequences.[20] These measures can focus on precaution, risk management or limitation or mitigation of the consequences, if such undesirable events do occur.

With regard to shipping, via the 'International Convention on the Safety of Life at Sea' (SOLAS convention), a requirement has been imposed that on board any vessel, a safety management system is operated that satisfies the requirements laid down in the International Safety Management Code (ISM Code) developed specifically for that purpose. The responsibility for the implementation of the safety and environmental protection policy from the ISM-code lies with the owner of a ship or in practice the ship

20 This principle is derived from the so-called ALARP principle (As Low as Reasonably Practicable), which demands of the parties involved that they consciously and transparently balance the risks against the effort, time and investments needed to mitigate and/or remove the risk.

manager if the owner is not involved in the operation. The ship manager is often the shipping company.

The structure and layout of the safety management system play a crucial role in the demonstrable management and continuous improvement of safety. Complying with legislation and regulations and (international) guidelines represents a minimum requirement for managing safety risks. Based on international and national legislation and regulations and a large number of widely accepted standards, the Dutch Safety Board has defined a number of relevant focal points, as outlined in Appendix D.

The way in which the persons on board a vessel respond to the loss of cargo and its consequences for safety and the environment must be laid down in the safety management system drawn up and implemented subject to the responsibility of the ship manager. This includes developing, implementing and maintaining procedures, plans and work instructions aimed at guaranteeing the safety of personnel, the vessel and the environment and ensuring that tasks are allocated to qualified personnel.[21]

2.3 Responsibilities of the master and crew of a vessel

In the shipping world, the master bears final responsibility for the safety of his vessel, the crew and the cargo. In that connection, he has the authority to take all decisions he considers necessary to achieve and maintain that safety. The shipping company can be expected to grant the master this freedom of action. The master of the vessel may not be subject to any prohibition or restriction in taking certain decisions which in the professional judgement of the master are necessary for the safety of human life at sea and the protection of the marine environment.

The crew and in particular the master of a vessel are expected to demonstrate good seamanship. Good seamanship is an open standard that relates to all aspects relevant to the way in which a vessel is operated safely. This includes safe navigation, loading and unloading, manoeuvring, making the vessel ready for sea and carrying out safety exercises. According to Rule 2 of the Convention of the International Regulations for Preventing Collisions at Sea[22], this responsibility includes the obligation to take account of all dangers to navigation and of special circumstances that make it necessary to deviate from the COLREG regulations in order to avoid danger.

When preparing for any journey or choosing a sailing route in severe weather conditions, a number of different regulations and codes apply. The preparations for the journey are made subject to the applicable regulations and guidelines as laid down in SOLAS (International Convention for the Safety of Life at Sea). These include regulations for safe

21 The definition of qualified personnel is described in an international IMO Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW).

22 The Convention on the International Regulations for Preventing Collisions at Sea, COLREG Convention, was drawn up by the IMO. The convention includes international traffic rules at sea, including the rules governing the way in which vessels avoid collisions and give one another right of way.

navigation (up-to-date charts, navigation equipment, certified and trained crew members,

keeping of a logbook). Prior to departure, the master must also ensure that the proposed journey is planned using the correct nautical charts and nautical publications for the area in question, taking account of the guidelines and recommendations laid down by the IMO. In planning the journey, a route must be selected which:

- takes account of any applicable routeing systems for shipping;
- guarantees that throughout the journey, there is sufficient space in the shipping route for the safe passage of the vessel;
- anticipates known hazards to navigation and poor weather conditions; and
- takes account of current measures for protection of the marine environment, and as far as possible prevents tasks and activities which could harm the environment.

Also relevant to the crew of a vessel is Circular 1228 of the Maritime Safety Committee.[23] This is a guideline for the master for avoiding hazardous situations in poor weather and sea conditions. This circular recommends the master to follow the specified procedures for navigation in poor weather conditions so as to avoid hazardous situations. Specific attention is paid to certain combinations of wave length and wave height that result in hazardous situations for shipping. Without prejudice to the above, also in less severe weather conditions, the master must take all reasonable measures he considers necessary. Good seamanship on the part of the master means that in all situations account is taken of specific characteristics and the condition of the vessel, crew and cargo.

Finally, the Code of Safe Practice for Cargo Stowage and Securing (CSS) of the IMO offers guidelines for the correct lashing and securing of cargo. The code among other things deals with:

- the principles of safe loading and securing;
- severe weather conditions;
- shifting cargoes.

It is of absolutely vital importance that the master and the crew of a vessel pay close attention to planning and supervising the lashing and securing of cargoes to prevent cargoes falling overboard.

23 The Maritime Safety Committee (MSC) is a committee of the International Maritime Organization (IMO) which is responsible for all matters relating to maritime safety subject to the frameworks of the IMO. This includes regulations for navigation, construction and equipment of vessels, and requirements on crew members from the point of view of safety. The MSC also prepares rules for preventing collisions, managing hazardous cargoes and the standardization of hydrographic information, logbooks and navigation records.

2.4 The role of the Dutch government

The Dutch government has a responsibility for the protection of the Wadden area, which is an internationally recognized unique and vulnerable nature area. In that context, the Dutch government has a responsibility in safeguarding safety on the shipping routes north of the Wadden islands. The government should actively implement a policy to manage the risks of container transport on the shipping routes above the Wadden islands.

The standards of the International Maritime Organization (IMO) are decisive for ship routeing at sea and the safety of sea shipping. Member states, including the Netherlands, constitute the IMO. In order to satisfy the responsibility referred to above, it is the responsibility of the Dutch government to submit to the IMO any problems relating to the management of environmental and safety risks on the shipping routes above the Wadden Islands.

The Dutch Safety Board has identified another important element of the role of government, namely the responsibility for identifying risks at an early stage and wherever possible taking measures to manage these risks. In that context, uncertainty is a given. This means that governments must be constantly alert and must remain open to signals that may suggest reduced safety or new, unknown risks. That in turn calls for an open mind to developments and risks and the willingness to express doubt as to standard and/or previously made assumptions.

Finally, it should be noted that container transport on and around Dutch waters impacts on various interests in respect of the economy, safety and the environment. All relevant government parties - and indeed private parties - may therefore be expected to approach these interests individually and jointly with the greatest possible care. The organization of adequate (counter)force is essential for ensuring that weaker interests are also represented and protected. The Dutch government has the task of organizing a cautious approach to the various interests and to constantly reflect on these interests in a critical manner.

3 CONTAINER TRANSPORT ON THE NORTH SEA

3.1 Container transport

3.1.1 Container ships

The shipping industry is a global industry. Approximately 80% of the total volume of trade goods is transported by ship.[24] Sea shipping thereby acts as a vital link in the logistic chain. International sea trade is broadly determined by developments in the global economy. Today, the majority of goods are transported by container. A container is a metal box with standard dimensions to allow them to be transported efficiently and easily by road, water and rail. The standard size for a container is known as a TEU (Twenty Foot Equivalent Unit). In 2018, around 152 million TEU were transported by container ships over sea around the world. Maritime trade forecasts predict an average annual growth of worldwide shipping trade of 3.4% for the period 2019-2024.[25]

Figure 2: Photograph of a container ship. (Source: https://www.mvovlaanderen.be/inspiratie/hoe-milieuvriendelijk-zeevaart)

The majority of container ships secure their containers by placing them in guide rails below deck. Containers can also be placed on deck, and stacked on top of each other. There are attachment points at each corner of a container (corner castings), via which the containers can be connected to the underlying container using a system known as twistlocks. Twistlock foundations are placed on the deck hatches to secure the first tier of containers so these can not slide. A series of steel structures are placed on the deck between the bays known as lashing bridges. Using lashing rods, the stacked containers are attached to the lashing bridge or to the deck, starting from the bottom layer.

24 United Nations Conference on Trade and Development, *Review of Maritime Transport 2019 https://unctad.org/en/PublicationsLibrary/rmt2019_en.pdf.*

25 United Nations Conference on Trade and Development, *Review of Maritime Transport 2019 https://unctad.org/en/PublicationsLibrary/rmt2019_en.pdf.*

Depending on the ship, the first three, four or five layers of containers can be secured to a lashing bridge or the deck using lashing rods. Lashing equipment such as twistlocks and lashing rods must be certified.

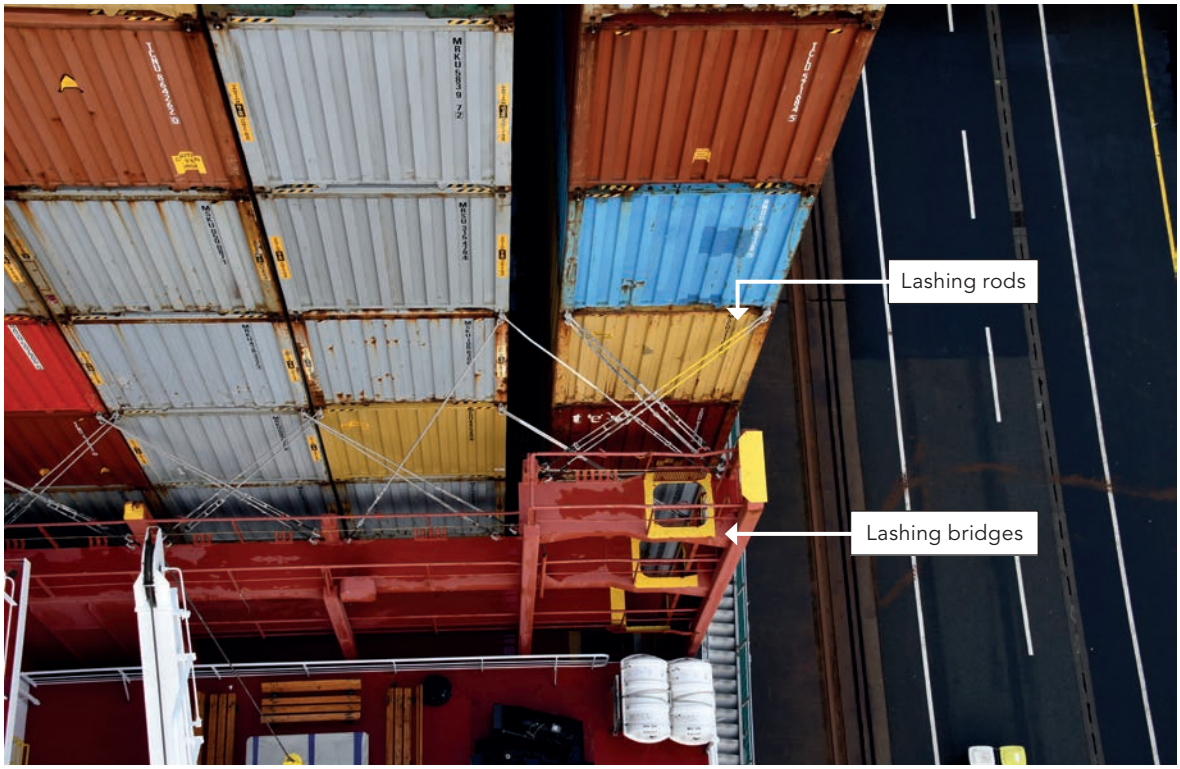


Figure 3: Photograph of part of the lashing bridge, stacked containers with lashing rods on the bottom layers on board the MSC ZOE. (Source: Dutch Maritime Police)

3.1.2 Economies of scale

The container as a means of transport first appeared in the nineteen fifties. The first container ship that entered the port of Rotterdam (1966) was carrying 226 containers.[26] Since that time, ship capacity has grown exponentially. In 2019, the vessel MSC Gülsün was launched, with a capacity of 23,756 TEU, making it the largest container ship currently in use.[27] The growth in world trade contacts is resulting in ever larger ships, increased operational efficiency and an increasing pressure on sailing schedules including planned time in ports. Over the past fifteen years, the capacity of individual ships has doubled, see Figure 4.

In the last 15 years, a doubling has been observed of the capacity of individual ships, see Figure 4. Among other developments, increases in length and beam, the raising of the bridge height and the shifting of the bridge position towards the fore part have led to an increase in the capacity of the number of containers on deck. The loading configuration for the MSC ZOE for example - depending on the weights of the loaded containers - provides for a stack of 11 containers on deck (approximately a height of 26 metres).

26 Source: https://www.portofrotterdam.com/nl/nieuws-en-persberichten/50-jaar-containeroverslag.
27 Source: https://www.transport-online.nl/site/106523/grootste-containerschip-msc-gulsun-onderweg-naar-rotterdam/

With a view to the efficient handling of container ships in port, above all the height of the stack of containers on deck and the draught, length and beam of the vessel are determining factors in the development of container ships.

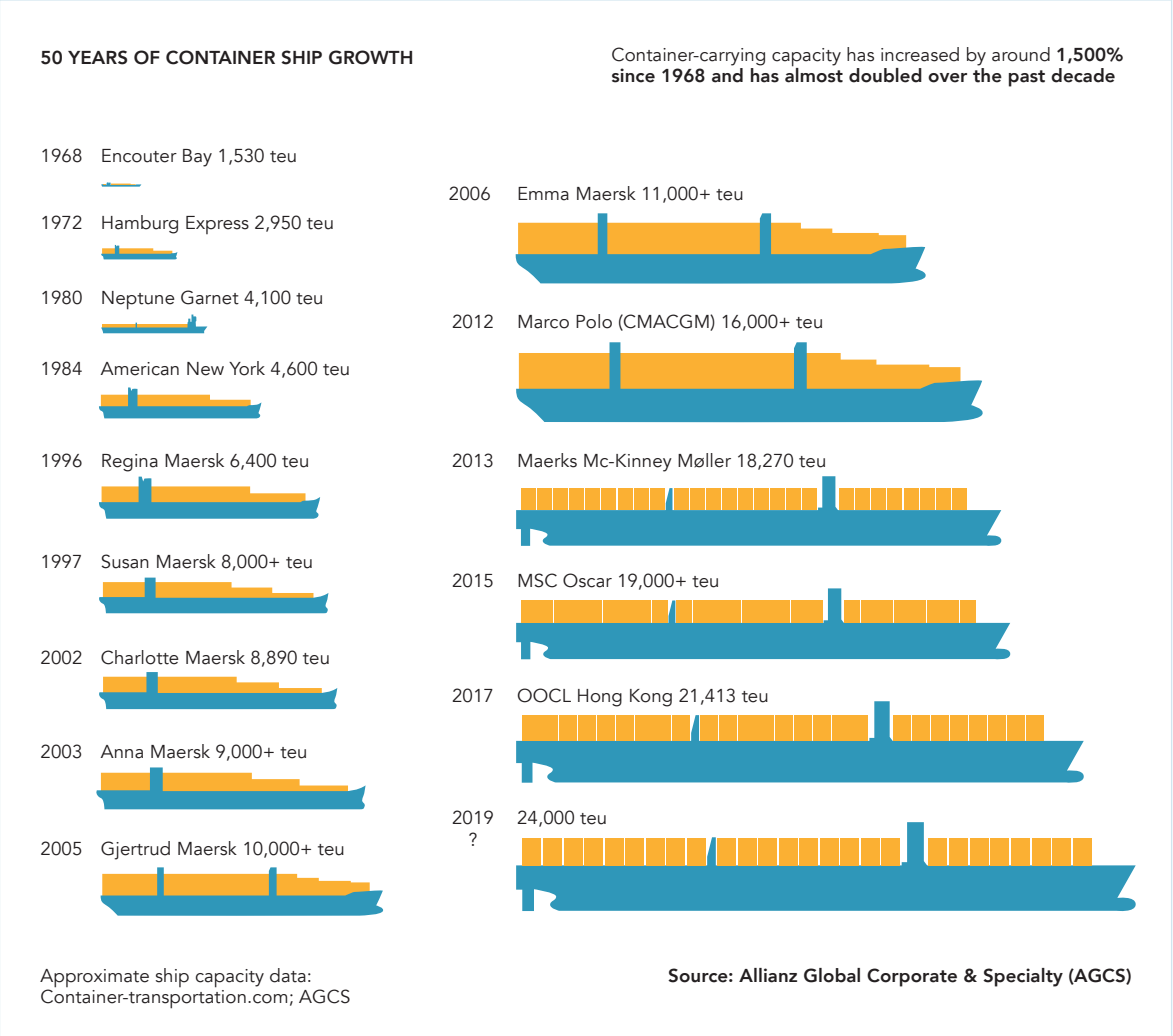


Figure 4: Overview of the growth of container ships over the years. (Source: Safety and Shipping Review 2019, Allianz)

3.1.3 Incidents in container shipping

Every year, a number of incidents involving ships occur. Over the past ten years, 1,036 incidents occurred worldwide, representing more than 100 each year, in which the ship was considered lost. 41 of these 1,036 incidents involved a container ship. The number of incidents is decreasing. In 2018, 46 total losses were reported - including one container ship - the lowest number since 2009.

Total losses by type of vessel: 2009-2018 Vessels over 100GT only											
	2009	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**Total**
Cargo	52	62	38	62	40	31	40	34	55	15	**429**
Fishery	29	21	14	12	13	15	16	10	8	11	**149**
Bulk	10	11	14	11	15	5	13	5	7	2	**93**
Passenger	5	3	7	7	8	10	7	11	6	3	**67**
Chemical/ Product	11	6	4	8	10	2	3	7	4	1	**56**
Tug	5	7	2	6	7	7	6	7	5	4	**56**
Container	4	5	3	7	4	4	5	5	3	1	**41**
Ro-ro	6	1	3	5	2	5	6	9		1	**38**
Supply/ Offshore	3	2	2	3	2	3	3	2	2	1	**23**
Tanker	2	4	4	1		1			2	3	**17**
Dredger		2	2	1		1	1	1	3	2	**13**
Barge		1			3	1		3	1	2	**11**
LPG		1	1	1				1	1		**5**
Unknown					1		2	1			**4**
Other	5	3	5	3	6	4	4	3	1		**34**
Total	**132**	**129**	**99**	**127**	**111**	**89**	**106**	**99**	**98**	**46**	**1,036**

Figure 5: Overview of the shipping losses worldwide. (Source: Safety and Shipping Review 2019, Allianz)

In addition to reported vessel losses, there are also numerous incidents involving lost cargoes. The World Shipping Council (WCS) has estimated the number of containers lost worldwide, based on a survey among carriers.[28] Based on this survey, it emerged that in the period 2008-2016 approximately 1,582 containers were lost at sea, each year, worldwide.

Figure 6 shows that the number of containers lost per year varies widely. The statistics are primarily influenced by a limited number of incidents whereby a large number of containers are lost, such as:

- the grounding and loss of the Rena close to New Zealand in 2011 (approx. 900 containers);
- the sinking of the MOL Comfort in the Indian Ocean in 2013 (loss of 4,293 containers);

28 World Shipping Council, *Containers Lost At Sea – 2017 Update*, 2017.

- extreme roll motions of the Svendborg Maersk in heavy weather circumstances in the Bay of Biscay (517 containers were lost) in 2014;[29]
- the sinking of the SS El Faro close to the Bahamas in 2015 (approx. 600 containers[30]).

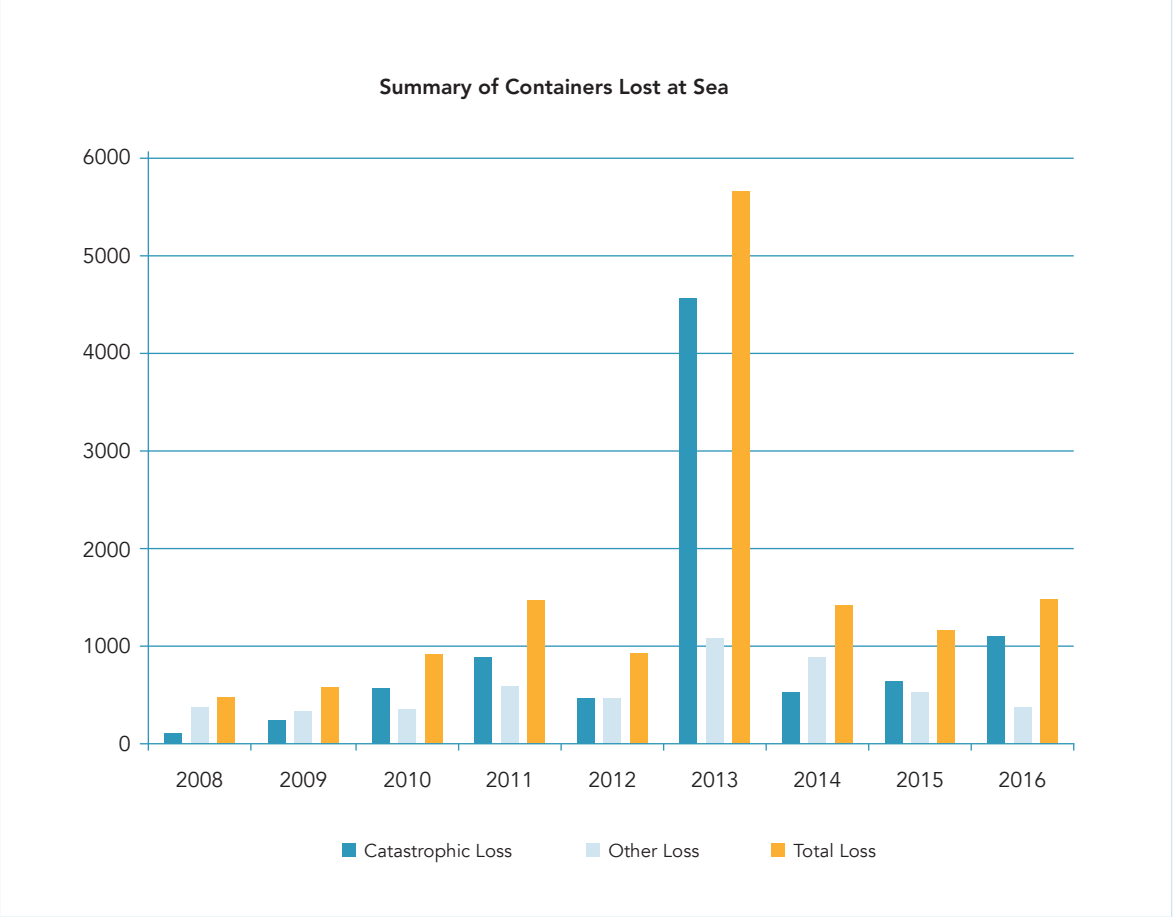


Figure 6: Lost containers worldwide. (Source: World Shipping Council)

In the Safety and Shipping Review 2019, heavy weather and lashing failures were listed as general causes for the loss of cargo. The report also identified the risk of fire on board large container ships. Vessel design and the possibilities for fire fighting play a role, as well as the incorrect listing or packing of the cargo in the container. From an insurance perspective, insurers warn that the growing size of ships is leading to a greater accumulation of risks and insurance costs. It is also pointed out that there are growing concerns for the environment in respect of lost cargoes.[31]

29 The Danish Maritime Accident Investigation Board, *Marine accident report 'SVENDBORG MÆRSK - Heavy weather damage on 14 February 2014*, 5 September 2014.

30 The American National Transportation Safety Board stated in its accident report: "In his departure report, the captain detailed the cargo as follows: 238 electric reefers, 118 trailers, 149 autos, 15 not-in-container cargo, 391 containers, and 4 fructose tanks. He listed the total tonnage as 11,045.9 long tons."

31 Allianz, Safety and Shipping Review 2019, May 2019.

Shipping incidents in the North Sea

Rijkswaterstaat manages the National Shipping Accident Database (SOS database) that contains data about shipping accidents and all other events taking place in the waters within the area managed by the Netherlands. Since 2012, accidents have been classified according to the IMO standards and placed in the categories 'very serious', 'serious' or 'less serious' shipping accident (known in Dutch respectively as ZESO, ESO and MESO). Generally speaking, lost cargo is classified by Rijkswaterstaat as a very serious or serious shipping accident.

	2012	2013	2014	2015	2016	2017	2018
Very serious shipping accidents (ZESO)	4	2	0	0	2	2	1
Serious shipping accidents (ESO)	15	13	12	11	8	12	10
Other types of shipping accidents (MESO)	46	44	28	21	49	16	32
Total number of accidents	**65**	**59**	**40**	**32**	**59**	**30**	**43**
Number of fatalities (from the total number of accidents)	13	3	0	0	0	1	0
Number of injuries (from the total number of accidents)	6	2	0	2	3	3	0

Table 1: Number of shipping accidents registered in the Dutch sector of the North Sea (EEZ). (Source: Rijkswaterstaat[32])

On average, between 2012 and 2018 approximately thirteen shipping accidents were recorded each year on the North Sea in the SOS database and classified as very serious or serious. On average, four of these per year involved sea shipping.[33] In the period 2012-2018, ten classified occurrences involved the loss of containers.[34] In those occurrences, a total of 64 containers were lost overboard, of which 56 containers were lost in the vicinity of the Wadden area. The number of containers in each occurrence varies widely in the six years reviewed: from between 1 and 25 containers.

32 Rijkswaterstaat, reports for the budget report + Risk Analysis North Sea 2018.

33 There are four categories of shipping: sea shipping, fishing, recreational, and work and duty shipping. Container transport on the North Sea falls into the sea shipping category.

34 The SOS database was examined for incidents classified as very serious or serious. All ten registered occurrences are classified as serious shipping accident (ESO). Not all shipping accidents are registered in the SOS database. The database therefore represents a low estimate of the number of shipping accidents, in particular for less significant incidents. In the Risk Analysis North Sea 2018, Rijkswaterstaat reports that in a study carried out in 2014 the expectation was put forward that the level of registration of significant incidents amounted to 89%. To what extent this level of registration has improved over the past few years is uncertain.

Year	Number of occurrences	Number of containers lost	Details
2012	0	0	
2013	1	2	• *Container ship (333m); 10-2013 / 2 containers (empty) / off Terschelling / wind force 9 SW*
2014	2	13	• *Container ship (100m); 11-2014 / 3 containers / off IJmuiden / wind force 8 SSW* • *Container ship (214m); 10-2014 / 10 containers / off Terschelling / wind force 9 NW*
2015	1	2	• *Container ship (150m); 12-2015 / 2 containers (empty) / off Rotterdam / wind force 8 SW*
2016	0	0	
2017	4	43	• *Container ship (139m); 12-2017 / 25 containers / off Terschelling / wind force 5 NW* • *Container ship (203m); 10-2017 / 1 container / off Texel / wind force 8 NW* • *Container ship 8-2017 / 2 containers (empty) / off Rotterdam / wind force 8 SE* • *Container ship 1-2017 / 15 containers / off Texel / wind force 7 WNW*
2018	2	4	• *Container ship (237m); 2-2018 / 3 containers / 15NM W of Texel/wind force 7 W* • *Container ship (294m); 1-2018 / 1 container (empty) / S North Sea / wind force 10 W*

Table 2: Number of registered shipping accidents (ESO, serious shipping accidents) on the North Sea involving the loss of containers. (Source: Rijkswaterstaat, SOS database)

In a letter to the Dutch House of Representatives on 5 February 2019, the Minister of Infrastructure and Water Management reported that in the period 2010-2018 the Dutch Coastguard recorded 188 containers lost overboard in the Dutch sector of the North Sea.[35] In the Netherlands, if containers are lost overboard on an incidental basis on the North Sea, the causes are not structurally investigated. The loss of 342 containers by the MSC ZOE in 2019 represented an exceptional situation, and according to the standards of the SOS database, can be classified as a very serious shipping accident.

35 [Netherlands] parliamentary papers II, 2018/19, nr. 1430.

The case of the MSC ZOE
Late in the evening of 1 January 2019 and in the early morning of 2 January 2019, the container ship MSC ZOE sailing under Panamanian flag lost a total of 342 containers while en route to the German port of Bremerhaven. The containers were lost while the ship was sailing along the southern shipping route above the Wadden Islands.[36]

The consequences for the Dutch and German coastal area along the route were immediately visible the next day, above all on the Wadden Islands and along the coastline of Friesland and Groningen. The beaches of Vlieland, Terschelling, Schiermonnikoog and the German Wadden Island of Borkum, among others, suffered pollution. Dozens of containers, some of which broke open during their fall, washed ashore, and their contents were spread widely along the beaches or were blown further into the dunes. The contents consisted of a wide variety of (semi-) finished products such as electronics, car components, furniture, clothing and toys. Large quantities of small plastic particles also ended up in the Wadden area. Two of the containers lost overboard contained hazardous substances.

Following the accident, shipping traffic experienced considerable nuisance due to containers floating just below the surface of the water, representing hazardous obstacles in the shipping route. Fishing vessels experienced nuisance and damage while fishing. Nets may become caught on containers that have sunk to the seabed and material from the containers that ends up as by-catch in the fishing nets can damage the nets.

The accident involving the MSC ZOE led to considerable social unrest, above all in the Netherlands but also in Germany. This applies in particular to the residents of the Wadden Islands and the coastal municipalities of Friesland and Groningen. The huge volume of goods washed onto the beaches made abundantly clear the consequences of the loss of the 342 containers from the MSC ZOE. Illustrative for the intensive involvement of the population was the way in which, immediately following the accident, thousands of residents and other volunteers spent days clearing away washed up goods, alongside the emergency services.

The accident with the MSC ZOE is not the first occasion on which a large container ship has lost cargo close to the Wadden Islands. The container ship P&O Nedlloyd Mondriaan sailing under Liberian flag - at the time one of the largest container ships in the world - lost 58 containers in a storm, on 9 February 2006. Subsequently, various containers and a large volume of goods from those containers, such as polystyrene foam, toys and thousands of shoes washed onto the beaches of Terschelling.[37] The causes of this loss of

36 For a further explanation of the location of the southern shipping route, see Section 3.2.
37 Sources: *Centre of Documentation, Research and Experimentation on Accidental Water Pollution* (http://wwz.cedre.fr/en/Resources/Spills/Spills/P-O-Nedlloyd-Mondriaan), Noordzeeloket: *Nieuwsbrief Integraal Beheer Noordzee*, June 2006, number 3 and *de Volkskran*t, 10 February 2006, 'Tientallen zeecontainers overboord bij Terschelling'.

containers were not investigated, as the occurrence was not classified as a serious accident.

Figure 7: Photograph of a beach on Terschelling following the incident involving the container ship the Mondriaan. (Source: Arie Ouwerkerk - ANP)

In addition to pollution and potential environmental damage, the loss of containers can also represent a serious hazard to shipping. Floating containers generate a risk of collisions, and sunk containers can form a hazard if they become entangled with the nets of fishing boats.

3.2 Shipping routes

3.2.1 Setting shipping routes

Ships' routeing is essential in order to successfully manage shipping traffic. Sea shipping is an international matter and so is the setting of shipping routes. The international standards for the routeing of ships are laid down in various international conventions drawn up by the IMO. Freedom of shipping and 'innocent passage' are essential basic principles in both international standards and national legislation and regulations. The UN Convention on the Law of the Sea (UNCLOS) says on these issues: "Passage is innocent so long as it is not prejudicial to the peace, good order or security of the coastal state. Such passage shall take place in conformity with this Convention and with other rules of international law."[38]

38 Article 19 of the United Nations Convention on the Law of the Sea (UNCLOS).

The purpose of ships' routeing is to improve safety for shipping, for example in areas with high traffic intensity, where water depth is restricted or where there are obstacles. The imposition of measures or restrictions for the regulation of shipping traffic flows was originally aimed primarily at reducing the risk of collision, following a series of serious collisions in the Dover Straits in the nineteen sixties. Over time, it has increasingly become part of the spatial planning at sea. The growth in the size of ships and the focus on pollution from shipping has led to a broadening of the number of possible measures. Examples of routeing measures are:

- Traffic Separation Scheme (TSS), where opposing traffic flows are separated in order to reduce the risk of collision.
- Inshore traffic zone, an area between the coast and a traffic separation scheme reserved for vessels with a length of less than 20 metres, sailing boats and fishing vessels. Larger vessels are only permitted to make use of this zone under certain conditions.
- Precautionary area, a routeing measure that encompasses an area in which the vessel must navigate with particular caution and in which the direction of traffic flows can be recommended.

At international level, the IMO can determine measures for ships' routeing. The international standards refer to the possibility of Member States to monitor the shipping traffic.[39]

The initiative for taking measures for determining a route for shipping is the responsibility of the Member State or Member States in question. A Member State or multiple Member States with a common interest can submit proposals for routeing to the IMO, for adoption. As well as for new routeing, this also applies to adjustments to already adopted routes.

IMO Resolution A.572(14) General Provisions on Ships' Routeing
(5.5) When establishing areas to be avoided by all ships or by certain classes of ship, the necessity for creating such areas should be well demonstrated and the reasons stated. In general, these areas should be established only in places where inadequate survey or insufficient provision of aids to navigation may lead to danger of stranding, or where local knowledge is considered essential for safe passage, or where there is the possibility that unacceptable damage to the environment could result from a casualty, or where there might be hazard to a vital aid to navigation. These areas shall not be regarded as prohibited areas unless specifically so stated; the classes of ship which should avoid the areas should be considered in each particular case.

39 SOLAS Chapter V Regulation 10.6.

The ships' routeing as specified by the IMO appears in the IMO publication *Ships' Routeing*. A specific routeing can be made compulsory for all ships, for certain categories of ships or for ships carrying a specific cargo. A condition for this obligation is that the routeing must be adopted and implemented in accordance with the guidelines and criteria drawn up by the IMO. Given the international character of the routeing, implementation via the IMO of a new routeing measure is a lengthy procedure that can often take a number of years.

3.2.2 The shipping routes north of the Wadden Islands

Along the North Sea coast, there is a detailed system of routeing measures for route-bound sea shipping, such as large container ships, see Figure 8.

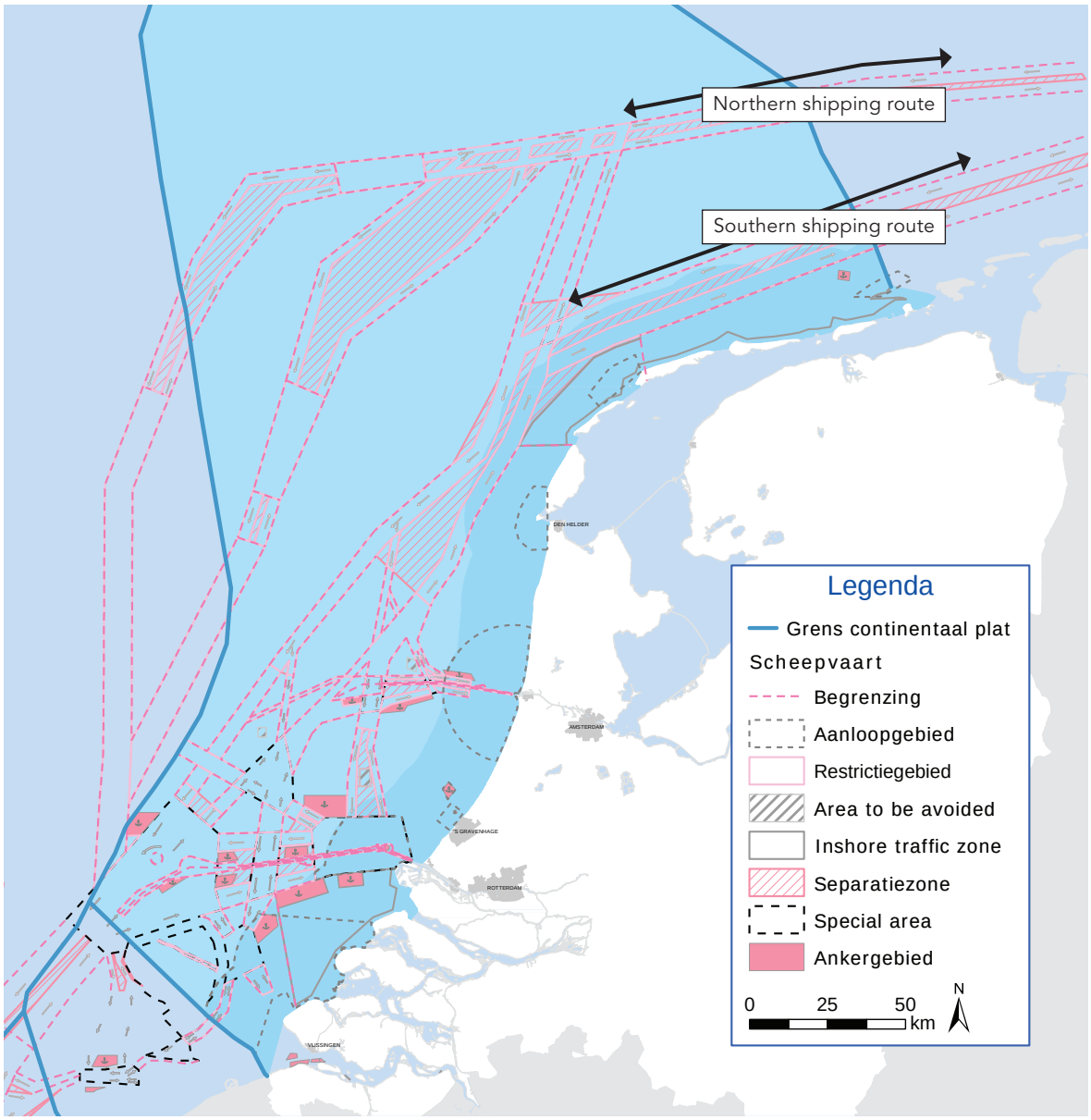


Figure 8: Shipping routes on the Dutch sector of the North Sea. (Source: Rijkswaterstaat)

At national level, routeing on the North Sea is laid down in the *Besluit routerings- en meldingssystemen voor schepen in volle zee voor de Nederlandse kust*[40] (Decree on routeing and reporting systems for ships at sea off the Dutch coast) and the Regeling routerings- en meldingssystemen voor schepen in volle zee voor de Nederlandse kust[41] (Regulations for routeing and reporting systems for ships at sea off the Dutch coast).

For ships sailing north of the Wadden Islands, the routeing measures are based on two traffic separation schemes:

- TSS Terschelling - German Bight, referred to in the remainder of this report as 'the southern route'[42];
- TSS East-Friesland - German Bight Western approach, referred to in the remainder of this report as the 'northern route'.

The southern route lies approximately 20 to 30 kilometres from the coast and has separated shipping lanes of 3 nautical miles width. The shipping route has limited water depth and has shallow areas of around 20 metres depth.

The northern route is listed in the IMO ships' routeing as a deep water route. A deep water route is a route within defined limits which has been precisely surveyed for clearance of sea bottom, free from submerged obstacles up to a minimum specified water depth. The northern route, in absolute terms is deeper than the southern route (on average around 10-15 metres deeper), but as compared to other deep water routes it is not especially deep. It is therefore effectively a shallow deep water route. The northern route is also recorded as the mandatory route for a number of categories of tankers containing oil, liquefied gases or harmful liquid substances.[43] This obligation was imposed with a view to the vulnerability of the Wadden Sea for possible damage caused by these categories of sea shipping. The location of the route further out from the coast offers improved possibilities for tackling spilled oil or other harmful liquids before they are washed ashore.

In addition to the through routes, there are routes to the various ports. The complexity of traffic flows is influenced by crossings involving non-route-bound traffic (such as ferry services, fishing vessels, workboats and recreational shipping), anchor areas, wind farms and other offshore infrastructure. Closer to the ports, the traffic intensity is higher, with more traffic crossings by both route-bound and non-route-bound shipping traffic.

3.2.3 Traffic intensity on shipping routes above the Wadden Islands

The North Sea is one of the most heavily used seas in the world. The southern and northern shipping routes above the Wadden Islands represent no exception from this situation, given their location close to major ports in Germany, Belgium and the Netherlands and the access to the Baltic Sea via the Kiel Canal and Kattegat. Since 2006,

40 https://wetten.overheid.nl/BWBR0008956/2005-05-18.
41 https://wetten.overheid.nl/BWBR0033648/2016-01-01.
42 In fact TSS Off Vlieland also is part of the southern route.
43 IMO, Colreg.2/Circ.38/Add.1, 14 May 1997.

the maritime research institute MARIN has regularly undertaken a North Sea network evaluation commissioned by Rijkswaterstaat. One of the purposes of this evaluation is to map out the traffic flows on the North Sea based on analysis of Automatic Identification System (AIS) data from ships.[44]

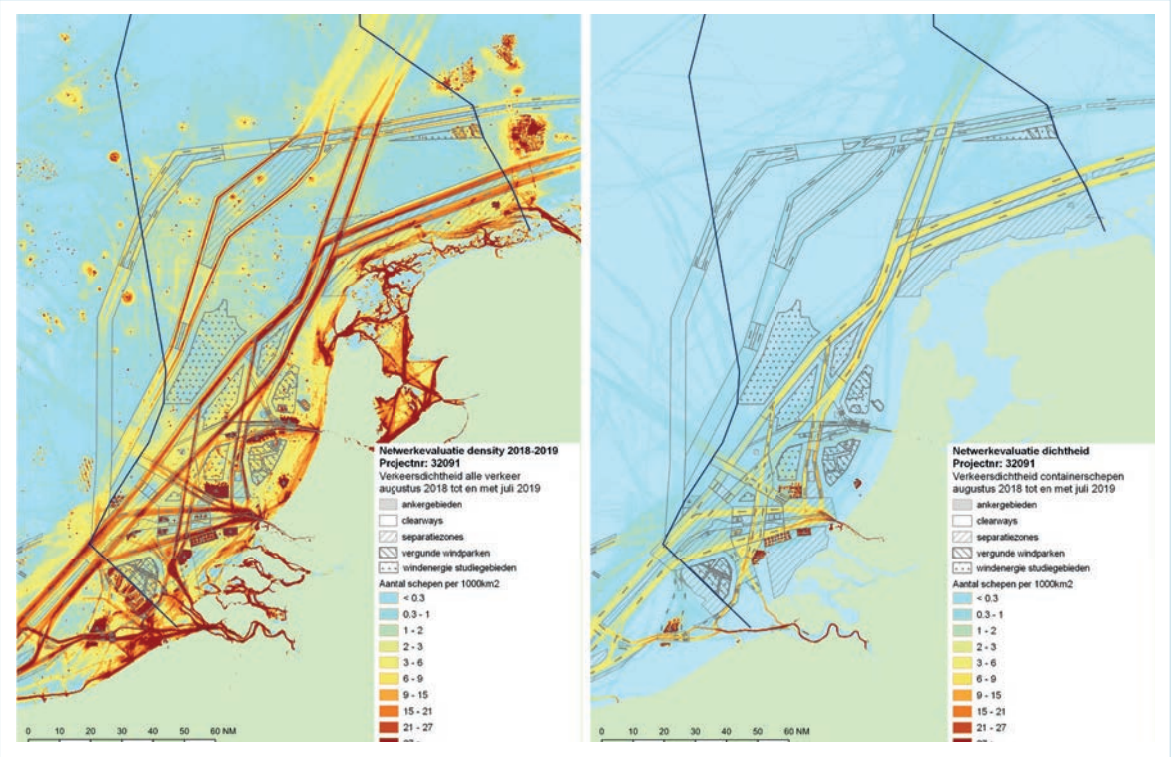


Figure 9: Overview of the density of shipping traffic in total (left) and for container ships (right). (Source: Netherlands Coastguard[45])

Figure 10 and Figure 11 show the data from the network evaluations for the periods August 2013 through to July 2014, June 2015 through to May 2016 and August 2018 through to July 2019.[46] For the periods under observation, the total number of passages in both directions on the southern route was far greater than on the northern route. The data also reveal that the vast majority of container ships opt for the southern route. The total number of passages by containers ships on the southern shipping route is falling but at the same time we see that the proportion of large container ships with a length of 275 metres or more has risen. The rise in the number of large container ships is also reflected on the northern route.

44 AIS devices automatically transmit radio waves at regular intervals. This takes place via a VHF transmitter built into the device. The radio waves contain such information as position, speed and vessel data relating to the journey (Source: Rijkswaterstaat https://www.rijkswaterstaat.nl/zakelijk/verkeersmanagement/scheepvaart/scheepvaart-verkeersbegeleiding/river-information-services/automatic-identification-system/index.aspx). The radio signals can be received by AIS transponders fitted on other vessels or on stations on shore.

45 Graphs were taken from a memorandum prepared by MARIN (*Network evaluation 2019, parts 1, 2 and 3*, 6 December 2019) for the Netherlands Coastguard.

46 Based on network evaluations prepared by MARIN and commissioned by the Netherlands Coastguard (MARIN, *Network evaluation 2019 – parts 1, 2 and 3*: *Density maps, traffic intensities and ships movements*, 6 December 2019; MARIN, *Network evaluation North Sea - Traffic flows on the North Sea based on AIS data between June 2015 and May 2016*, 1 December 2017; MARIN, *Network evaluation North Sea following introduction of new system - Determining the intensities of traffic flows after 1 August 2013*, 7 November 2014).

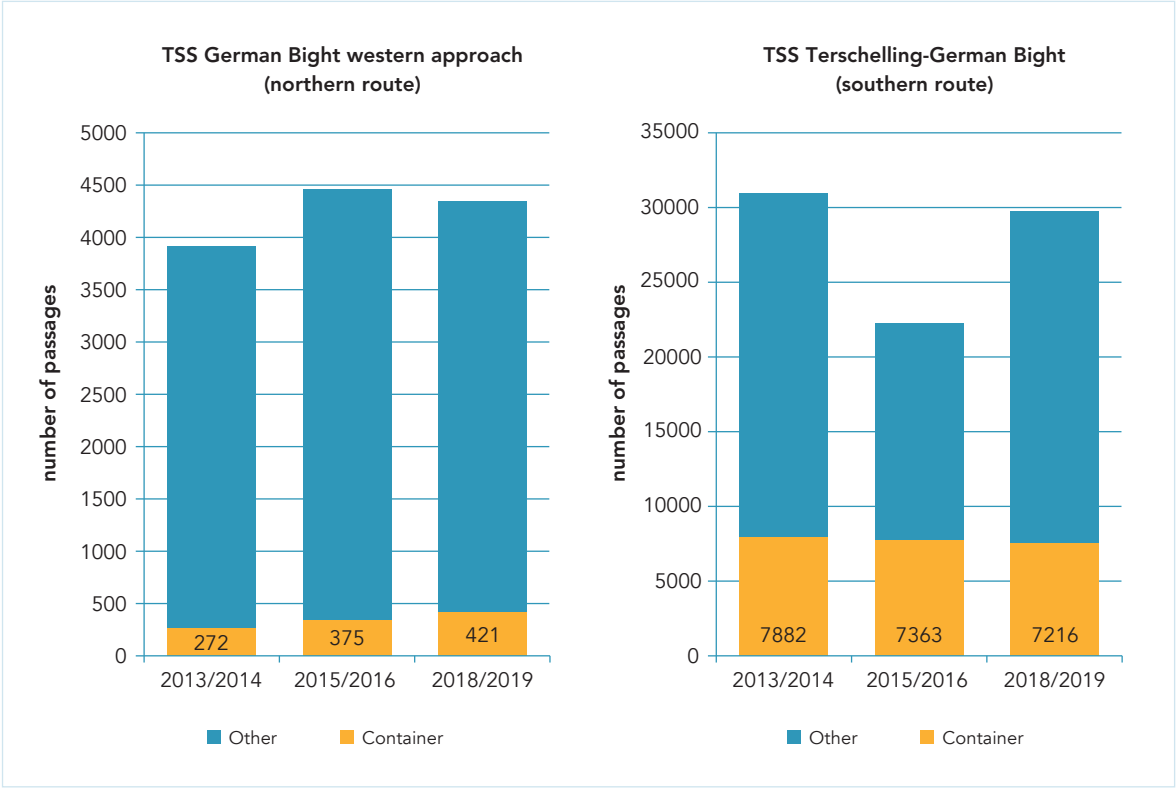


Figure 10: Number of passages by vessels on the northern and southern route.

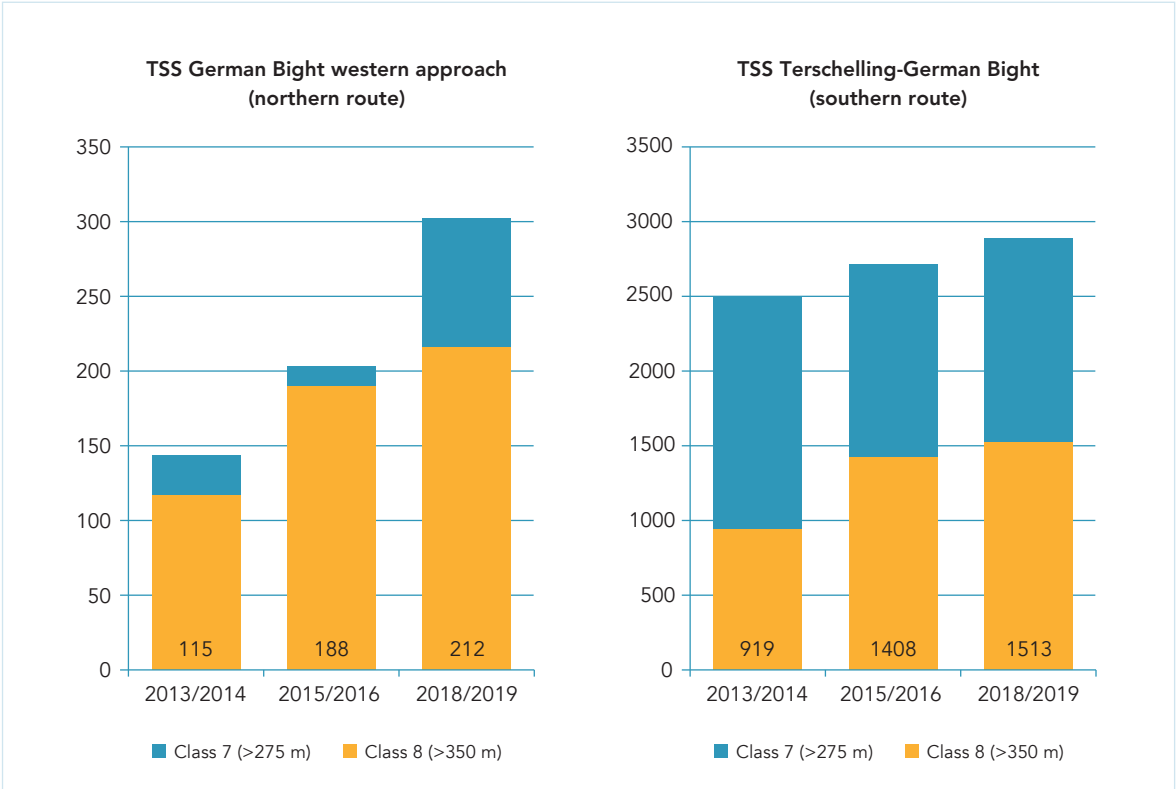


Figure 11: Number of passages by container ships class 7 and class 8 on the northern and southern route.

Explanatory note to shipping class, expressed in Gross Tonnage (GT):

- *Size class 7: 60,000 – 99,999 GT, typical length per ship type 275 metres*
- *Size class 8: from 100,000 GT, typical length 350 metres*

3.3 Use of space on the North Sea

3.3.1 Legal classification

The North Sea is a peripheral sea of the Atlantic Ocean with boundaries in Belgium, France, the United Kingdom, Norway, Denmark, Germany and the Netherlands. The Dutch sector of the North Sea consists of the area from the Dutch coast to the outer limit of the Dutch Continental Shelf (NCP) and the Exclusive Economic Zone (EEZ), and covers approx. 58,000 km2. The outer limit of this area is determined by means of border conventions with Belgium, Germany and the United Kingdom. The EEZ and the continental shelf are overlapping zones in terms of space and content. The continental shelf encompasses the seabed and subsurface, while the EEZ also encompasses the water column situated above the shelf.[47]

The North Sea is legally divided into different zones, each with their own legal regime. These zones are based on the United Nations Convention on the Law of the Sea (UNCLOS Convention)[48]. Two zones are further elaborated below: territorial sea and the Exclusive Economic Zone. The boundaries of these areas are shown on the map in Figure 12 in Section 3.3.2.

Territorial sea

The Dutch territorial sea is part of Dutch territory and extends to 12 nautical miles off the coastline, measured from the low water line.[49] The territorial sea is subject to the sovereignty of the Netherlands. According to the United Nations Convention on the Law of the Sea, all ships have the right of innocent passage (see also Section 3.2.1). The UNCLOS Convention also states that the coastal state is permitted to lay down legislation and regulations relating to this innocent passage, for example in relation to the safety of shipping and the regulation of traffic at sea, or the protection of the environment of the coastal state and the prevention, reduction and tackling of pollution of that environment.[50] In addition, where necessary with a view to safety, the coastal state may also demand the use of special shipping routes and traffic separation schemes.[51]

In the zone adjacent to the 12 nautical miles zone - with a maximum width of 24 nautical miles - the coastal state may carry out supervision to prevent violation of the customs, tax, immigration or public health regulations within its territory and territorial sea, or to penalize any such violation.

Exclusive Economic Zone (EEZ)

Dutch jurisdiction of the EEZ is more restricted than of the territory sea. The Netherlands has no sovereignty over this area. In accordance with the UNCLOS Convention, the Netherlands does exercise sovereign rights in the EEZ for exploration, operation,

47 Source: https://www.helpdeskwater.nl/onderwerpen/wetgeving-beleid/internationaal/verdragen/virtuele-map/zeerechtverdrag/.
48 https://www.un.org/depts/los/convention_agreements/texts/unclos/unclos_e.pdf
49 Adopted in the *Dutch Territorial Sea Act*, (https://wetten.overheid.nl/BWBR0003748)
50 UNCLOS, Article 21.
51 UNCLOS, Srticle 22.

maintenance and management of the living and non-living natural riches of the water above and on the seabed and in the subsurface below the seabed. This also applies for other activities related to the economic operation and exploration of the zone, such as the generation of power from the water, currents and wind. In addition - in accordance with the UNCLOS Convention - the Netherlands does have jurisdiction in this zone with regard to the construction and use of artificial islands, installations and facilities, marine scientific research, and the protection and conservation of the marine environment.

Within the EEZ, all states have freedom of shipping and innocent passage.[52] Where necessary, however, the coastal state can impose safety zones around artificial islands, installations and facilities, within which it can take appropriate measures to ensure the safety of both shipping and of the artificial islands, installations and facilities.[53]

The southern and northern shipping routes above the Wadden Islands
The southern and northern shipping routes above the Wadden Islands are located in the EEZ. The southern shipping route runs partially inside and partially outside the Dutch territorial sea. The northern shipping route is entirely outside this 12-mile zone. Because the routes are part of the international and continuous shipping routes determined by the IMO, the Netherlands has no independent authority to impose binding regulations in respect of use of the southern or northern shipping route or to adjust the location of the routes.

3.3.2 Policy and management in the Netherlands

Affected parties
All aspects (with the exception of international ships routeing) of the policy and management of the North Sea - from approx. one kilometre off the coast to the borders of the Dutch EEZ - are the responsibility of national government. The Minister of Infrastructure and Water Management is the coordinating minister for the whole of the North Sea policy and management. In addition, a number of other ministries are involved: the Ministries of Economic Affairs and Climate Policy, Defence, Finance, Education, Culture and Science, the Interior and Kingdom Relations, and Foreign Affairs. These ministries cooperate within Interdepartmental Directors' Consultation on the North Sea (IDON). The IDON also includes the implementing organizations Rijkswaterstaat and the Netherlands Coastguard. As the implementing body for the Ministry of Infrastructure and Water Management, Rijkswaterstaat is the manager of the North Sea, with core tasks relating to water safety, adequate water supply, clean and healthy water, and rapid and safe shipping.

Operational nautical management of the North Sea has been mandated to the Netherlands Coastguard. The Coastguard Centre coordinates and undertakes fifteen operational government tasks on behalf of six ministries in the Dutch sector of the North Sea. These tasks include the provision of services such as maritime assistance, search and rescue, disaster and incident management, and traffic control (in the open sea).

52 UNCLOS, Article 58.
53 UNCLOS, Article 60.

The Netherlands Coastguard also has enforcement tasks, including supervision of compliance with legislation and regulations in respect of the environment, fishing and shipping traffic.[54] A large proportion of these tasks are carried out from the Coastguard Centre in Den Helder.[55]

Use of the North Sea

The Dutch sector of the North Sea is very intensively used, as reflected in the map in Figure 12. The North Sea is not only used for sea shipping, fishing and recreational shipping, but also for oil, gas, sand and shell production, the generation of wind energy and military exercise activities. Various parts of the North Sea are also designated as Natura 2000 areas (see also Section 3.3.3). Each of these use functions require space on the North Sea. The Dutch government has laid down frameworks for the spatial use of the North Sea in the *North Sea Policy Document 2016-2021*[56] and the accompanying *North Sea 2050 Area Agenda*[57].

In the *North Sea Policy Document 2016-2021*, it is suggested that the expected further intensification of use of the North Sea necessitates a cautious approach to the limited space available. Due to increased use, the marine ecosystem is under pressure. The aim of Dutch government policy is to allow use of the space on the North Sea to develop efficiently and sustainably, within the limits of the marine ecosystem.

In the *North Sea 2050 Area Agenda*, a long-term vision has been drawn up for the changing and developing activities on the North Sea. This agenda indicates that for shipping, the ambitions are 'safe and environmentally friendly shipping, access to the Dutch ports and clear passage'. As concerns the separation between shipping routes and wind farms, design criteria have been drawn up in the form of a consideration framework. The document also indicates that economies of scale with larger vessels and the introduction of faster ships[58] are contributing factors to changes in the traffic picture. Moreover, energy generation offshore, such as the construction of wind farms, will represent a far greater use of space. On the one hand this will result in a reduction in the sailing area available to shipping and on the other to a shift in traffic patterns due to a rise in shipping traffic from and to these offshore activities.

54 Source: https://kustwacht.nl/nl/kustwachtwat.html.
55 The package of tasks of the Netherlands Coastguard was the subject of investigation in the report Zorg tussen wal en schip (Dutch Safety Board, 2016).
56 Ministry of Infrastructure and Environment, Ministry of Economic Affairs, North Sea Policy Document 2016-2021, December 2015.
57 Ministry of Infrastructure and Environment, *North Sea 2050 Area Agenda*, July 2014.
58 For container shipping, greater speed does not apply: the speed of container ships has in fact fallen over the past few years to achieve savings on the huge fuel costs.

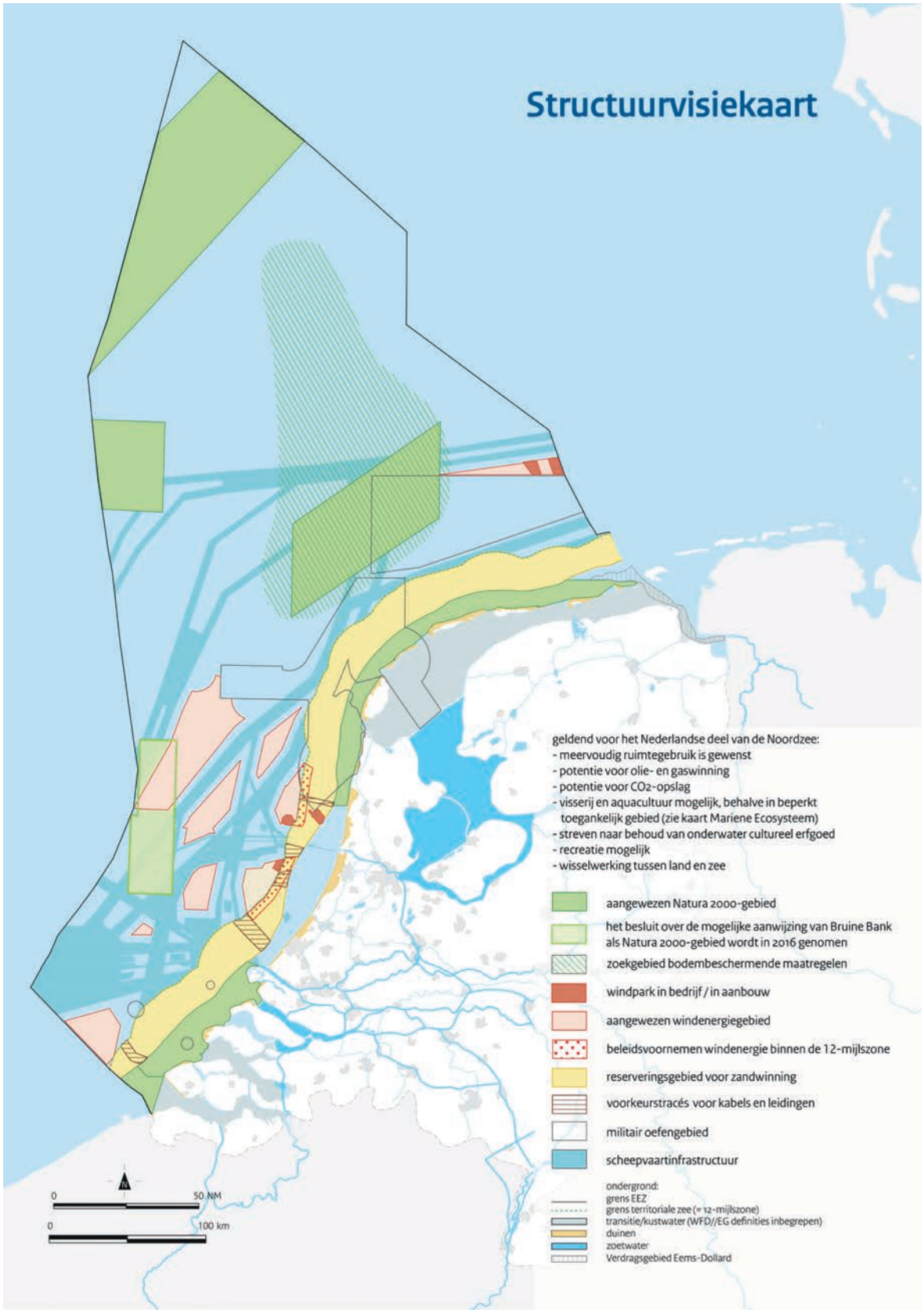


Figure 12: Structural vision map for the North Sea. (Source: North Sea Policy Document 2016-2021)

3.3.3 Nature areas

A number of areas close to the northern and southern shipping routes above the Wadden Islands have been designated by the European Commission as *Natura 2000 areas*[59]. The southern shipping route runs to the north of the Natura 2000 area 'Noordzeekustzone'[60] and crosses the Natura 2000 area in German waters, the 'Borkum Riffgrund'.[61] The northern shipping route crosses the Natura 2000 area 'Friese Front'[62] in the North Sea. The Wadden Sea is also a Natura 2000 area. The Natura 2000 areas are subject to the Nature Conservation Act. Certain activities are not permitted in these areas in order to protect natural values, or are subject to compulsory application for an exemption. Access restrictions apply and certain forms of fishing are forbidden.

The Wadden Sea is the world's largest uninterrupted tidal zone. The special ecological conditions make the Wadden Sea an environment with an extremely varied flora and fauna. The residents include marine mammals such as the harbour or common seal, the grey seal and the porpoise. Between ten and twelve million birds travel each year to the Wadden area for feeding, for breeding and to spend the winter months.[63]

Environmental and nature protection organizations are making every possible effort to preserve the natural habitat of the Wadden area and to protect the plant and animal species that live there. Governments are also implementing policy to protect nature in the Wadden area from disruptive human activities. In connection with the status of the area as a Natura 2000 area, the Dutch government has drawn up a *Wadden Sea Management Plan*[64] that lists provisions and rules of conduct for all persons and organizations that move through or undertake activities in the protected area.

The vulnerability of the Wadden Sea was officially recognized in 2002 by the IMO by the designation of the Wadden Sea in Denmark, Germany and the Netherlands as a *Particularly Sensitive Sea Area* (PSSA).[65] International recognition of this kind of area as a PSSA offers member states the possibility to take the initiative to, through IMO, come to additional protective measures, such as routeing measures. An example of a routeing measure is the current obligation for a number of categories of tankers to use the northern shipping route (designated deep water route) on the North Sea.[66] This routeing measure was in fact already imposed before the Wadden Sea was designated a PSSA.[67]

59 Natura 2000 is a European network of protected nature areas. In Natura 2000 areas, specific species and their natural living environment are protected in order to preserve biodiversity.
60 The North Sea coastal zone consists of 'sand banks permanently flooded by shallow seawater'. This area is designated based on the Bird and Habitat Directive.
61 The southern shipping route crosses the area 'Borkumse Stenen' (to the north of Schiermonnikoog), which shares a boundary on the southern side with the Dutch Natura 2000 area 'North Sea coastal zone' and on the eastern side the German Natura 2000 area 'Borkum Riffgrund'. This area is potentially also ecologically valuable and current investigations are underway to determine whether this area should also be designated a Natura 2000 area.
62 The Friese Front is located approximately 75 km north of Den Helder and encompasses a sea area of approx. 2,880 km² and is a Bird Directive area.
63 UNESCO World Heritage Centre (https://whc.unesco.org/en/list/1314/).
64 Ministry of Infrastructure and the Environment, *Natura 2000 Wadden Sea Management Plan Period 2016-2022*, July 2016.
65 IMO, Resolution MEPC.101 (48), Identification of the Wadden Sea as a particularly sensitive sea area, 11 oktober 2002.
66 IMO, Colreg.2/Circ.38/Add.1, 14 May 1997
67 As of 2005, the proposal of an associated protective measure is a more explicit condition for the designation of an areas as PSSA (IMO Resolution A.982(24)).

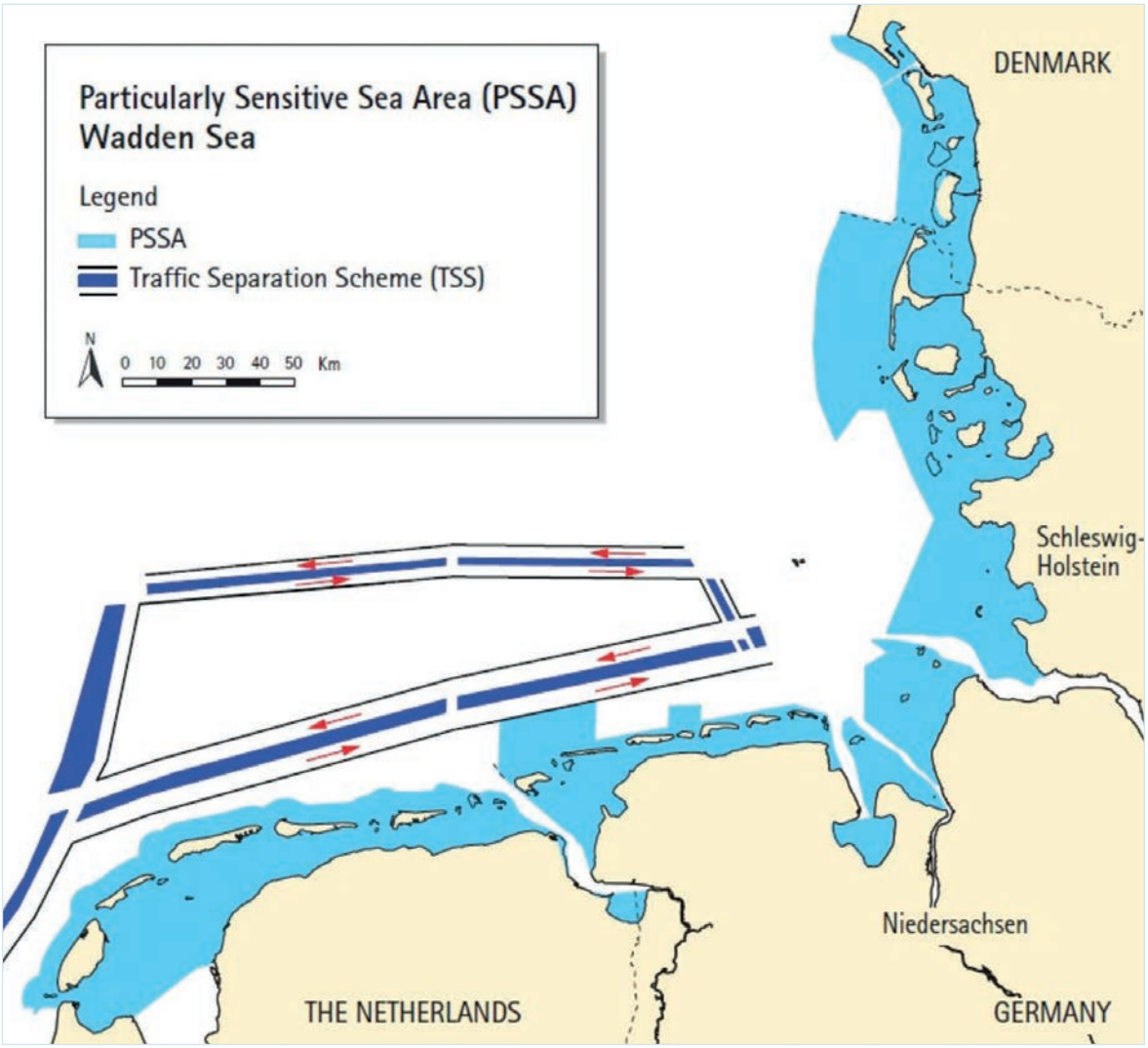


Figure 13: Area around the Wadden Sea designated as PSSA. (Source: https://www.waddensea-worldheritage.org/fisheries-and-shipping)

In 2009, the nature area received further international recognition when UNESCO[68] placed the Wadden Sea on the list of world heritage sites in the category biosphere reservations. This status imposed the obligation on the Netherlands[69] to take due care of the world heritage, to preserve its value and to show accountability to UNESCO. In response, in its national legislation, the Netherlands laid down provisions aimed at preventing damage or destruction of the world heritage.[70] Activities in the area may not harm the core qualities of the world heritage.[71]

68 UNESCO stands for United Nations Educational, Scientific and Cultural Organization.
69 Convention concerning the protection of the world cultural and natural heritage (1972), Article 4 and beyond.
70 Specific duty of care, Article 14.9 Decree on Activities in the Living Environment. https://zoek.officielebekendmakingen.nl/stb-2018-293.html (This Decree will enter into force at the same time as the Environment and Planning Act, planned for 2021)
71 Decree on the Quality of the Living Environment, Article 9.2. https://zoek.officielebekendmakingen.nl/stb-2018-292.html (This Decree will enter into force at the same time as the Environment and Planning Act, planned for 2021).

4 ROUTE-SPECIFIC RISKS

4.1 Introduction

In the night of 1 to 2 January 2019, the MSC ZOE was sailing on the southern shipping route north of the Wadden Islands and lost 342 containers. The entire series of circumstances in which the accident occurred must be viewed as a high-risk scenario. This scenario ('*a large container ship such as the MSC ZOE in the weather and wave conditions as present on the day of the occurrence*') has been investigated to gain a greater insight into the extent to which environmental conditions on the shipping routes above the Wadden Islands contribute to the risk of loss of containers. This chapter considers the question how large container ships with dimensions and cargo comparable to that of the MSC ZOE behave in the scenario referred to above and what this means for the risk of the loss of containers.

For this investigation, the Dutch Safety Board requested the knowledge and research institutes Deltares and MARIN to submit a contribution based on their fields of expertise. Based on models, Deltares calculated the current, water level, wind and wave conditions for reference positions along the southern and northern shipping routes at the moment of the accident involving the MSC ZOE.[72] Based on the results, MARIN made calculations and undertook extensive basin tests with a ship model to gain a greater insight into the conditions and ship motions that occur in the area to the north of the Wadden Islands. This combined research provides new insights in the conditions, ship motions and phenomena that occur in the area north of the Wadden Islands and how these lead to the risk of container loss.[73] The reports of the studies from Deltares and MARIN are enclosed as Appendix F and G respectively.

4.2 Scenario for the MSC ZOE accident

The scenario MSC ZOE has been elaborated based on studies from Deltares and MARIN. In order to understand and interpret the results, first the set-up of the studies is explained.

72 Deltares, *North Sea conditions on 1 and 2 January 2019 – Metocean conditions during the incident with the MSC Zoe*, June 2020.
73 MARIN, *Behaviour of an Ultra Large Container Ship in shallow water - Discussion report*, June 2020.

4.2.1 Structure of studies by Deltares and MARIN

Based on an analysis of the Voyage Data Recorder (VDR) data, the Dutch Safety Board specified three locations along the sailing route of the MSC ZOE (the southern shipping route) for further analysis. The locations are shallow water locations, locations where containers were discovered during the recovery and/or locations where, based on analysis of the VDR data, more violent roll motions occurred.[74] In addition, a reference position was determined on the northern route (the deep water route). For these four locations, Deltares determined the meteorological and maritime conditions at the moment of the accident involving the MSC ZOE in order to further elaborate the scenario. This scenario served as a basis for the calculations and the test conditions in the basin tests by MARIN. In addition to these four locations with a determined water depth, MARIN also considered deep water, where the waves are no longer influenced by the seabed. Wave conditions with higher waves were also considered.

The figure and tables below provide an overview of the locations and wave conditions studied. In the remainder of this chapter, in discussing the results from the studies, reference is made to the water depths and wave conditions shown in the tables below.

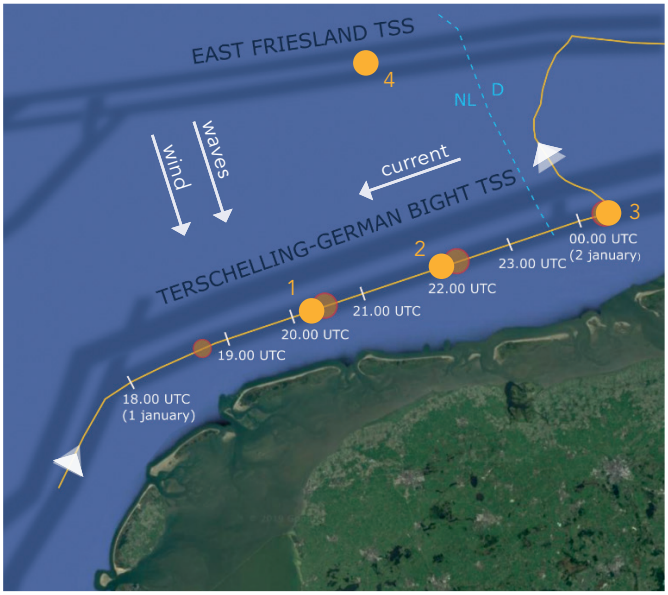


Figure 14: The four reference locations (yellow dots) on the shipping routes above the Wadden Islands for the research by Deltares and MARIN. The red dots indicate a number of suspected locations[75] where containers were lost from the MSC ZOE. The indicated time is the Coordinated Universal Time (UTC; local time = UTC + 1 hour). (Source: MARIN)

74 See international report into the course of events for a further description of the locations where containers from the MSC ZOE were recovered.

75 In the figure four locations where containers were lost are indicated as originally identified in the investigation, but not two additional locations that were identified at a later stage in the investigation.

Reference location (from Figure 14)	Shipping route	Water depth [m] relative to mean sea level[76]
Location 1	Southern shipping route	21.3
Location 2	Southern shipping route	26.6
Location 3	Southern shipping route	21.3
Location 4	Northern shipping route	37.5
Location 'deep water'	Not applicable	632.0

Table 3: Overview of water depth at reference locations as employed in the research by Deltares and MARIN.

Significant wave height Hs [m]	Peak period Tp [sec]	Explanatory notes
5.2	11.8	Refers to wave conditions when the MSC ZOE passed location 1.
6.5	12.4	Refers to wave conditions when the MSC ZOE passed location 3.
6.5	14.5	Refers to wave conditions when the MSC ZOE passed location 3 with adjusted peak period.[77]
7.5	14.5	Increased wave height for sensitivity analysis.

Table 4: Observed wave conditions in the MARIN research (based on the Deltares research)

The ship model used for the basin tests is a container ship of a comparable shape and size to the MSC ZOE. The ship model with measuring equipment is made according to international standards[78], whereby the containers are modelled as one block with a container photo print. The wooden ship model is stiffer than a steel ship as the MSC ZOE. In addition, the basin has a concrete bed and the shipping route a sandy bed. Figure 15 shows pictures of the basin tests.

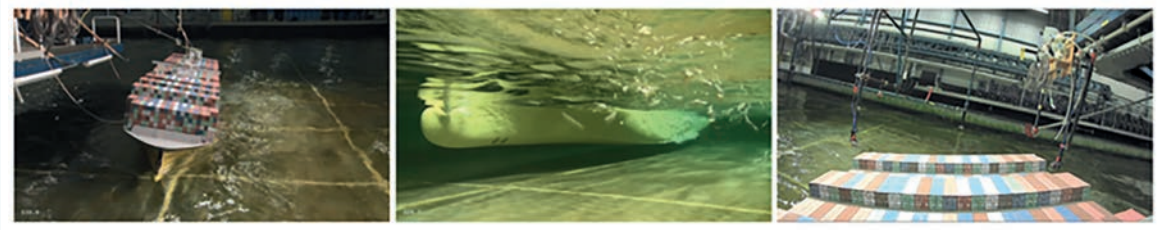


Figure 15: Images of the ship model in the MARIN test basin, respectively with images of the ship, under water and from the bridge of the ship.

76 Mean Sea Level (MSL) is the average height of the sea surface for all phases of the tide.
77 Peak period is based on the measured peak period at a nearby buoy.
78 International Towing Tank Conference (ITTC).

4.2.2 Meteorological and maritime conditions

Explanatory notes to waves

Waves are formed by the local wind (known as the seaway) and the swell, the waves that are created elsewhere and which ran out at that location. A wave in deep water can be simplified reproduced as a sine shape wave. The wave has the following characteristics: the wave height (from wave crest to wave trough), the wave length (distance between two wave crests) and the wave period (the time between the passing of two wave crests).

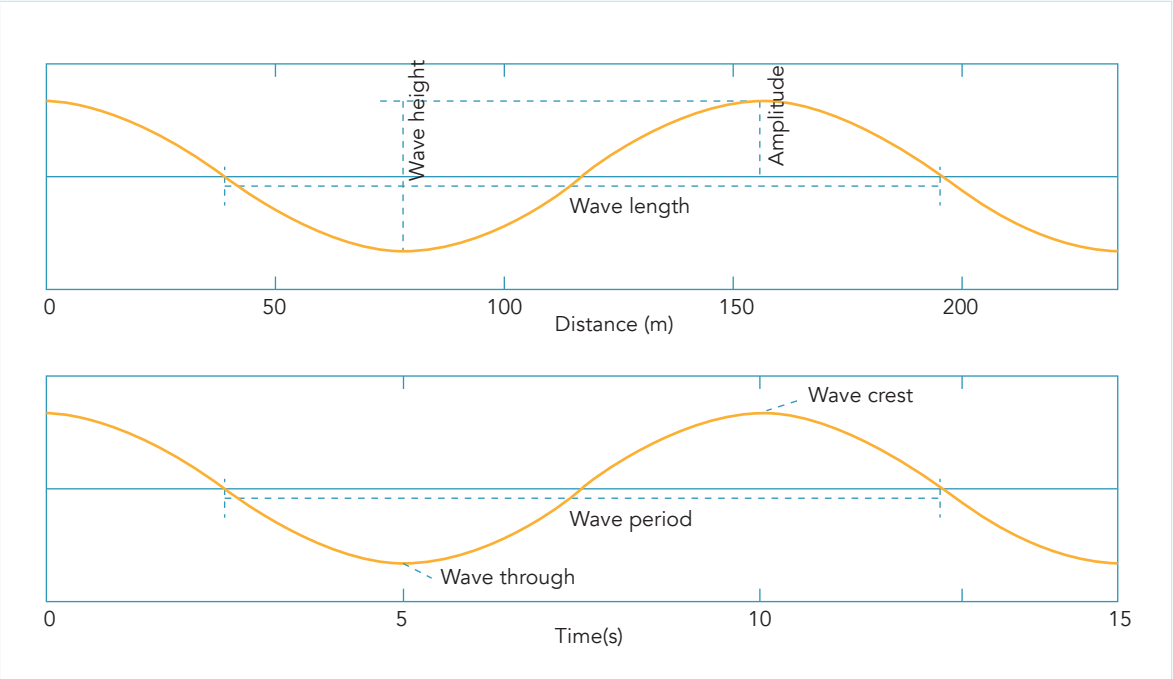


Figure 16: Diagrammatic representation of waves as a sine wave with the parameters wave height, wave length and wave period. (Source: Deltares)

For a good understanding of the research results it is necessary to understand how waves can be characterised. For this it is important to realise that the sea is a surface with irregular waves. For a realistic characterisation of a wave field at sea mainly three indicators are used: significant wave height, maximum wave height and peak period. Given the irregular pattern of waves on the water surface, the wave height is designated by the term 'significant wave height' (Hs) of the waves present. This is the mean value of the highest third of all occurring waves in a wave field at a given wave condition. The maximum wave height (H_{max}) designates the height of the highest occurring wave in that wave condition. As the highest occurring wave in a wave condition partly depends on the duration of the occurring wave condition, in general a statistical measure of H_{max} is used, for example the highest individual wave height that is exceeded once in every 1000 waves. The peak period is determined according to the energy present in a wave field. A water surface with irregular waves can be described as the sum of a great number of sine waves of different wave periods and wave heights (and possibly also wave directions). By reproducing the wave energy as a function of the period, the wave spectrum is determined. The peak period (T_p) is defined as the period at which the most wave energy is present. This peak period is used as a characteristic value for the typical wave period of a wave field.

As a wave approaches the coastline, the shape of the wave changes into a wave pattern with higher, shorter and therefore steeper waves. In the case of high waves in shallow water, the wave crests and wave troughs become (more) asymmetric: the height of the wave crest is greater than the depth of the wave trough, and flatter, broader wave troughs occur (see Figure 17). These short, steep waves in shallow water can break more easily. In that process, the higher crest of the wave tumbles forward at greater speed.

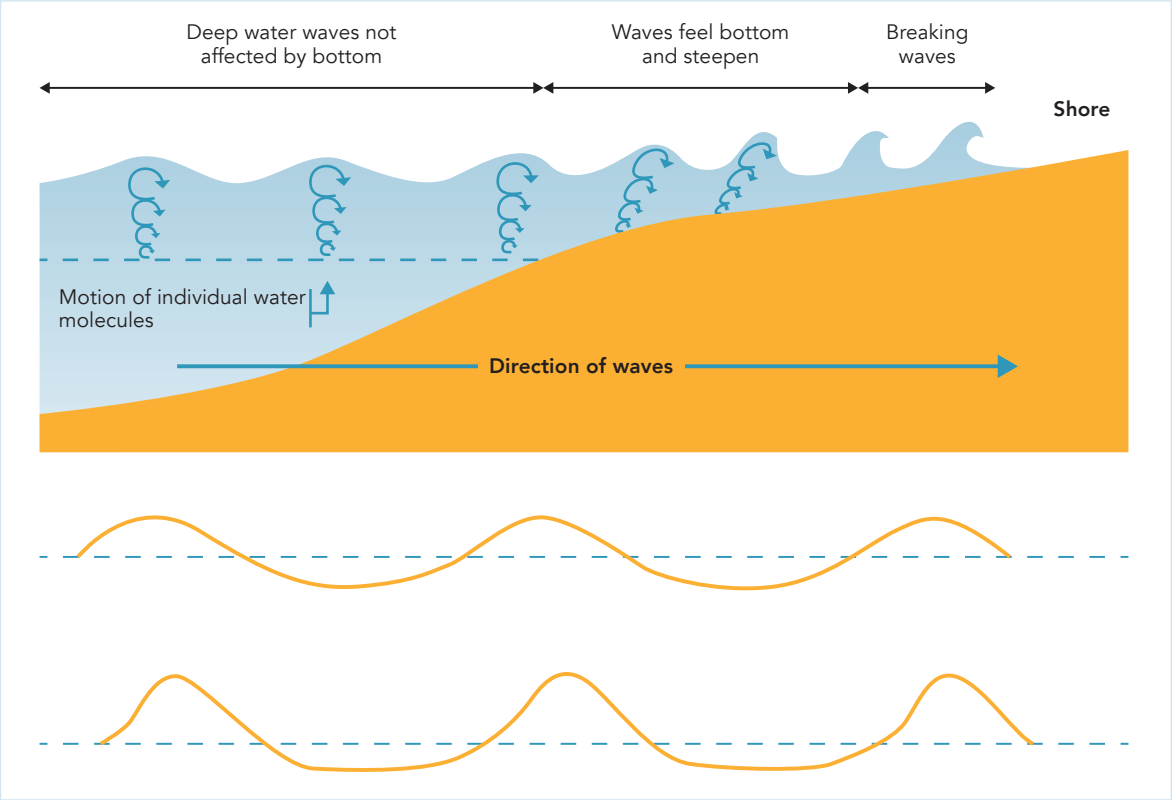


Figure 17: Reproduction of waves approaching the coastline (top) and the shallow water effect (below): the sine shape wave in open sea (above) changes in shallow water to a wave pattern with high, steep wave crests and flat, wide wave troughs (below). (Source: Deltares)

To describe a wave situation, a distinction is made between a situation with 'long-crested waves' whereby all waves are moving in the same direction, and a situation with 'short-crested waves' in which the directions taken by the waves are more spread.[79] The situation with short-crested waves is characteristic for a situation at sea in which waves are created under the direct influence of the wind.

Findings

While following the easterly course on the southern shipping route, the MSC ZOE was confronted with severe weather conditions: a stormy wind (gale) and high waves, both from a north-northwesterly direction, that approached the vessel from the port side almost perpendicular to the sailing direction of the ship. In these northwesterly storm conditions,

79 The phenomenon of short-crested and long-crested waves is not only a question of direction but also of frequency. In practice, long-crested wave conditions only occur in combination with higher peak periods.

waves on the North Sea have sufficient time and space to build in both height and period until they reach the Dutch and German Wadden coast.

Table 5 shows a summary of the highest values of a number of parameters occurring in the night of 1 to 2 January 2019.

Parameter	Critical conditions	Frequency of occurrence
flow speed	up to 0.5 m/s (1 knot)	Daily
water level[80]	average +0 to +1 m	
wind speed	16 – 18 m/s (7-8 Bft)	Average one to two times per year
significant wave height (H_s)	5 – 6.5 m	
peak-wave period (T_p)	11 – 13 s	

Table 5: Critical maritime conditions on the southern shipping route in the scenario 'accident MSC ZOE'. (Source: Deltares)

The southern shipping route along which the MSC ZOE was sailing is a shallow water shipping route with a minimum seabed level of 20 metres (relative to mean sea level). The current speed of the seawater - a direct consequence of tidal action occurring twice a day - was normal. The seawater level had been somewhat raised by the northerly wind but was still within the margin of the daily fluctuations of sea level. The wind reached maximum speeds of 18 m/s.[81] This is a gale force wind which is not exceptional for the North Sea area. The significant wave height reached 5 to 6.5 metres with a chance of individual waves up to a height of around 11 metres. In the scenario 'accident MSC ZOE', waves occurred on the southern shipping route that are typical for shallow water: steep, high waves occasionally breaking.

Based on statistical analysis, it was determined how often these values occur in this part of the North Sea. According to this analysis, the circumstances in the observed scenario can be considered severe, but neither extreme nor exceptional. The combination of wind speed and wave conditions confronting the MSC ZOE that night occur on one or several occasions each year on both the northern and the southern shipping route. There is a visible pattern whereby the highest wave conditions most frequently occur in the winter, followed by the autumn.[82]

80 Water level is the level of the water as compared with mean sea level (Mean Sea Level, MSL, the average height of the sea surface for all phases of the tide).
81 This refers to an hourly average at a height of 10 metres.
82 For the distribution across the seasons, the meteorological definition has been maintained.

Sub-conclusions
The conditions in the scenario of the accident with the MSC ZOE are characterized by waves with a significant wave height of between 5 and 6.5 metres, a peak period of 11-13 seconds and the possibility of individual waves up to a height of 11 metres. The waves came from a north-northwesterly direction, perpendicular to the southern shipping route. This situation occurs statistically on one or several occasions each year on the North Sea north of the Wadden Islands.

4.2.3 Ship behaviour

Explanation of ship motions
Ship motions are the movements made by a ship in response to external forces, such as waves. Precisely what effect a wave has on ship motions will depend on the shape of the ship, weight distribution, stability, speed and the direction (of sailing) in respect of the waves. A ship moves in six degrees of freedom:

- Heave in a vertical direction
- Sway in a lateral direction
- Surge in a horizontal direction forwards or backwards
- Roll, rotating around the longitudinal axis
- Pitch, rotating around the horizontal axis
- Yaw, rotating around the vertical, upright axis

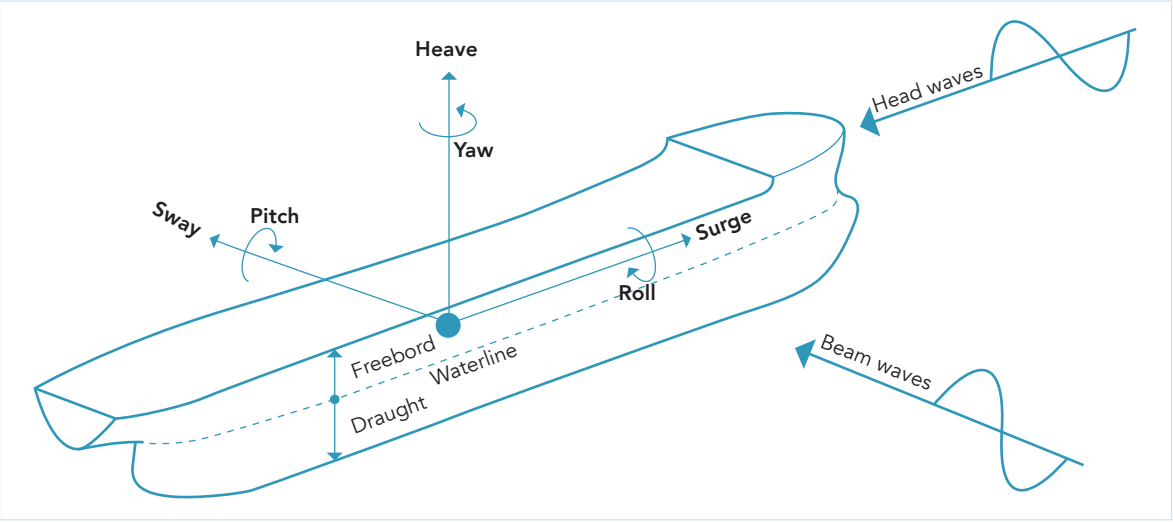


Figure 18: Overview of ship motions. (Source: report MARIN)

In the basin tests by MARIN, where the waves approached the ship from the side, three motions were dominant: roll along the longitudinal axis, heave in a vertical direction and sway in a lateral direction. The roll motion means that, in a series of successive waves, the ship rolls back and forth along its longitudinal axis, as shown in the illustration below. The ship adopts a heel angle.

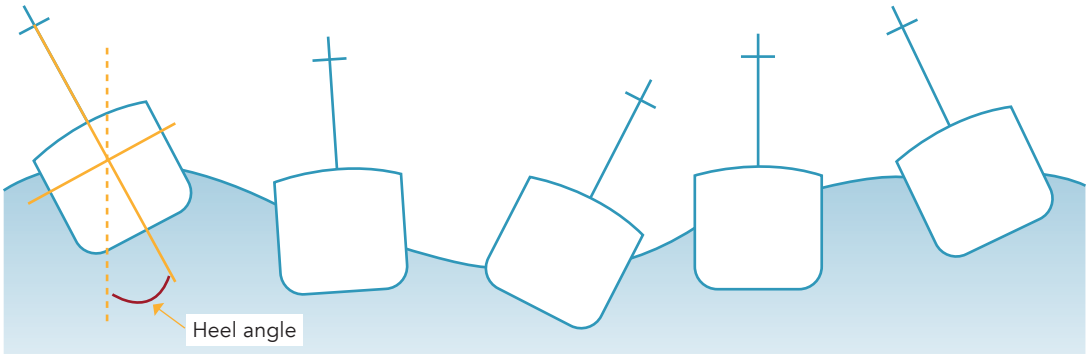


Figure 19: Diagrammatic representation of the roll motion of a ship in a beam sea.

Explanation on ship stability and resonance

Ship stability is the degree to which a ship can right itself after having been put out of balance by external forces such as wind and waves. A ship with a high level of stability will in principle be more difficult to put out of its steady state and once out of steady state will be quicker to return to its steady state.

The stability of a ship depends on the shape of the ship and the loading condition. The interplay of forces as a consequence of the gravitational force of the weight of the ship (including cargo) and the upward force of the water on the ship plays a crucial role. See Figure 20 for a diagrammatic representation. The more stable a ship is, the stronger it will return to its steady state. The measure for the stability of a ship is known as the GM value: the metacentric height expressed in metres.[83] A ship with a high GM value will be more stable than a ship with a low value.

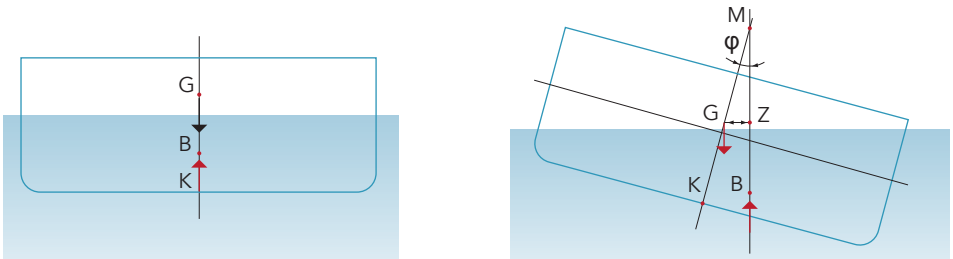


Figure 20: Diagrammatic representation of forces on a stable ship in steady state (left) and a stable ship out of balance (with a heel angle φ athwartships).

83 When in this report is referred to the GM value as measure for the stability of a ship, the initial stability at small heel angles is meant. The height of the Metacenter (M) is determined by the shape of the ship and especially by the beam of the ship. The height of the center of gravity (G) is determined by the distribution of the weight of the ship and the cargo on the ship.

The second aspect that plays an essential role in ship motions, is the phenomenom of resonance[84] at the natural roll period of the ship. The natural roll period is the period at which the ship will roll by itself when it is pushed. The natural roll period depends on the stability and weight distribution of the ship[85]. A very stable ship (high GM-value) has a short natural roll period: the ship wants to return fast to its steady state. A less stable ship (low GM-value) has a longer natural roll period. When the ship sails in beam wave conditions with a period close to the natural roll period of the ship, resonance originates: strong roll motions, that are larger than the slope of the waves (for an illustration see Figure 19).

For waves with a wave period close to the natural roll period of the ship, the ship reacts strongly to the wave; less with other wave periods. This can be expressed by a transfer function, as depicted in Figure 21 (a). This transfer function indicates how strong the wave motion is being transferred to the motion of the ship. There is a high resonance peak at the natural roll period. The shaded overlap between the wave spectrum and the transfer function determines the reaction of the ship to the present wave spectrum.

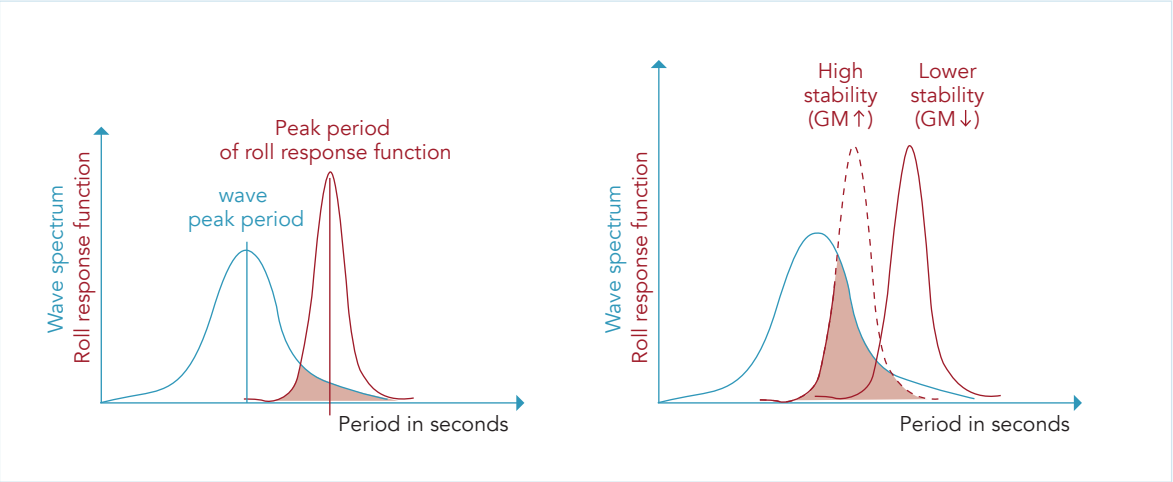


Figure 21: Figure with peak period of wave spectrum and natural roll period of a ship (a) with transfer function, the shaded area (b) with two different ships with a low and a high GM-value. (source: MARIN)

When a ship is more stable (higher GM-value), the natural roll period becomes shorter (see Figure 21 (b)). The transfer function of the ship now moves to a shorter natural roll period whereby the ship becomes more sensitive for roll at wave spectra with short peak periods.

Accelerations on containers

In addition to containers in their hold, containers are also stacked on the deck of large container ships.[86] As a consequence of roll motions, accelerations occur on the containers that are stacked on the ship's deck. Because containers are lashed using lashing rods and are interconnected through twistlocks, the lateral accelerations on a ship rolling back and forth result in tensile and compressive forces in the frame of the containers and the

84 Other known examples of resonance are the pendulum of a clock, or a child on a swing. It takes only little energy to initiate a movement when they are being pushed at the natural period of the pendulum or swing.
85 The distribution of the mass over the ship is expressed by the radius of inertia.
86 In the accident with the MSC ZOE, containers were placed on deck in stacks of up to eight containers high.

lashing systems with which the containers are connected to each other and/or to the deck. These forces can cause the lashing systems and the construction of the container to be overloaded. If these forces are larger than those for which the lashing system was designed, the lashing system will fail, as a result of which containers can fall overboard. If the construction of the container fails, a container can for example collapse. As a result, an entire stack of containers could fall over, which could then fall overboard or fall against another stack of containers.

The hull of a ship itself will undergo forces as a consequence of the ship motions described above. Depending on the rigidity of the ship in the waves, a ship will for example bend and twist to a certain extent. This will also lead to vibrations and forces on the containers and the lashing systems on the deck.

In summary - as a consequence of ship motions - a complex interplay of accelerations and forces will affect the ship and cargo. The stacks of individual containers will experience lateral and vertical forces. In addition, in the event of large motions, these stacks can affect each other.

Findings

The MARIN research considered the ship behaviour of a ship model of a container ship in the conditions described in Section 4.2.1. This study revealed that above all the waves determine the ship behaviour of a large and wide container ship in conditions such as those present in the scenario for the accident. The tests carried out in the basin revealed that large, wide container ships demonstrate considerable roll motions and vertical heave movements in beam waves, at different water depths. A downward heave movement sometimes coincides with a large roll motion. As a result, the side of the ship moves further downwards towards the seabed. Another observed effect in the tests is that the bilge keels[87] on the underside of the ship emerged above water as a consequence of extreme ship motions.

By way of illustration, the figure below shows the maximum roll motion measured for the various test conditions in the basin tests with the scale model of a large container ship (modelled according to the dimensions of the MSC ZOE). In shallow water (26.6 metres) as present along the southern shipping route above the Wadden Islands, a maximum roll motion (at Hs=6.5m and Tp=14.5s) of approximately 16 degrees was measured. At a depth such as that present along the northern shipping route (37.5 metres), in these conditions, a maximum roll motion of approximately 14 degrees was measured. The conclusion is that large, wide container ships like the MSC ZOE can make large roll motions on both the southern shipping route and northern shipping route.[88]

87 Bilge keels are long, protruding fins placed along the length of the ship at the level of the bilges (the major bend in the ship's hull on the underside of the ship) with the aim to, amongst others, dampen resonant roll at the natural roll period.

88 There is no uniform classification to designate the size of the roll angle. Broadly speaking, based on expert judgement for large container ships, it can be stated that a roll angle of between 0 and 5 degrees is seen as acceptable and no further measures need to be taken; a roll of between 5 and 10 degrees must be viewed as serious and as a point at which a master will probably take measures. Larger roll angles would then be viewed as extreme.

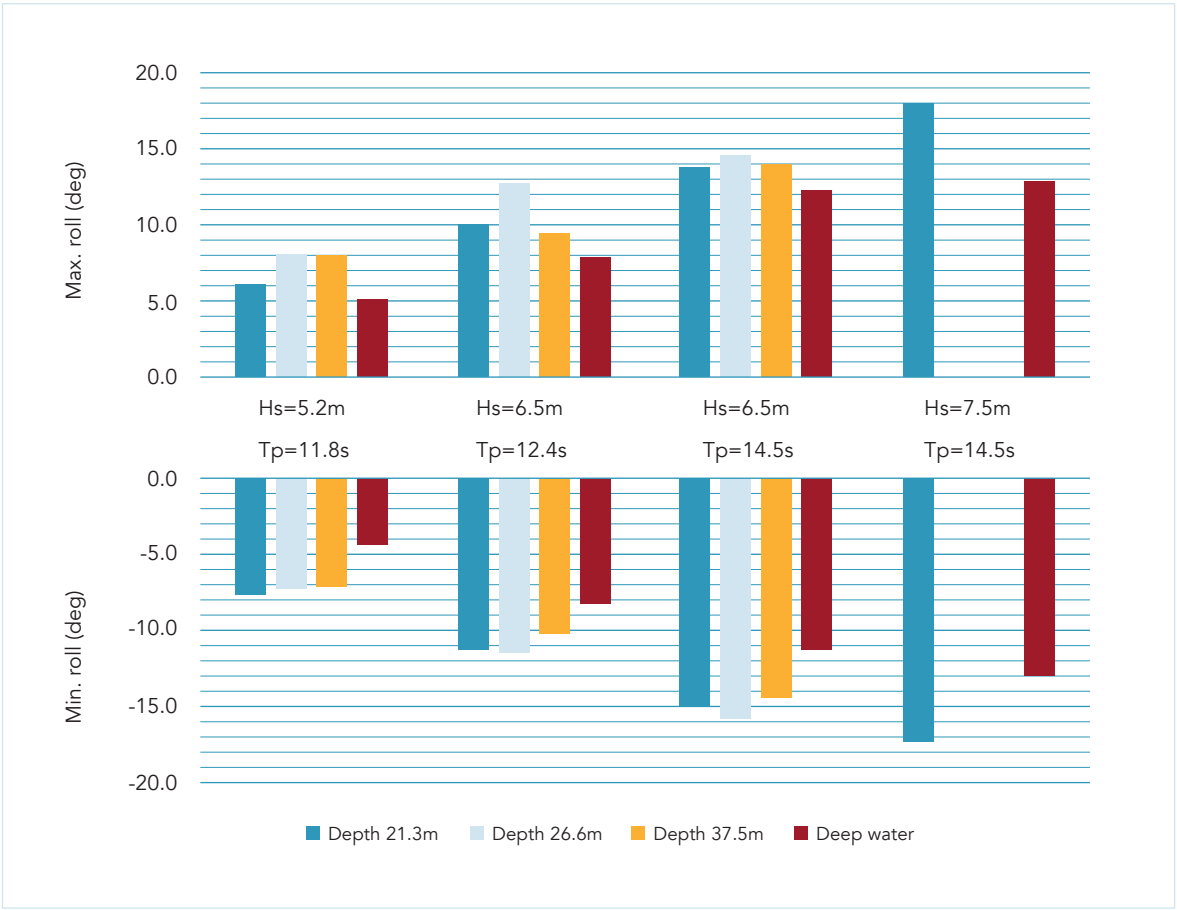


Figure 22: Maximum roll motion at the tested water depths and environmental conditions. A positive roll angle is to starboard and a negative roll angle to port. (Source: MARIN)

It is most notable that a large and wide container ship with a high stability like the MSC ZOE is sensitive to the wave periods present in the North Sea and shows strong roll motions. Large, wide and stable container ships like the MSC ZOE can have in certain loading conditions a natural roll period between the 15 and 20 seconds, while ships with a lower stability often have natural roll periods between 25 and 30 seconds. The effect of the higher stability is that the roll period more closely matches the periods of the wave spectrum, and as a consequence the level of response of the ship to the wave periods present in the North Sea increases. Although this may appear counterintuitive, on large, wide container ships with a high stability this means larger roll motions in beam waves than on less stable ships. In addition, the higher stability also leads to larger accelerations on the ship because the natural roll period is shorter and the ship wants to return faster to its steady state.

It subsequently emerged from the MARIN tests that the relatively restricted depth of the southern shipping route causes effects that influence the ship behaviour. The high beam waves are barely able to pass beneath the ship, as would be the case in deep water. Complex water movements occur below and alongside the ship. Large water masses occur which on the wave side flow both upwards and downwards against the side of the ship. During the tests in the basin, it was shown that at certain moments, the water locally rose above the deck.

Sub-conclusion

- A large and wide container ship like the MSC ZOE with a relatively high stability has a shorter natural roll period, whereby the ship by itself rolls stronger. As a result, these ships react more notably to the wave periods present in the North Sea than less stable ships. Consequently, large, wide, stable container ships roll more in beam waves on the North Sea than less stable ships.
- In the MSC ZOE scenario - a container ship in stormy weather conditions with beam waves with a significant wave height of 5 to 6.5 metres and peak period of 11 to 13 seconds and with possibly individual waves of 11 metres height the ship motions of large, wide, stable container ships on both the southern and the northern shipping routes are large.
- The shallow nature of the southern shipping route causes complex water movements below and along the ship. As a result, effects originate in the water that influence the ship behaviour.

4.3 Phenomena with risks of loss of containers

The MARIN research has gained new insights in the behaviour of large, wide container ships north of the Wadden Islands that represent a risk of loss of containers. The four phenomena in question are as follows:

1. Extreme ship motions resulting in large accelerations.
2. Contact with the seabed in the event of large heave and roll motions;
3. Greenwater load on the containers;
4. Impulsive wave impacts against the ship hull (slamming).

These phenomena can occur individually, in combination or in quick succession, thereby amplifying each other and with that increasing the forces on containers and lashing systems. These phenomena apply to large, wide container ships with high beam waves on the southern and partly also on the northern shipping route above the Wadden Islands.

The four phenomena are explained below.

4.3.1 Extreme ship motions resulting in large accelerations

Large container ships in stormy weather conditions with beam waves are sensitive to roll motions, vertical heave movements and lateral sway. These movements cause an acceleration (measurement for the force applied to an object)[89] on parts of the ship and on the ship itself.

89 According to Newton's second law, a force is equal to acceleration multiplied by the mass of an object. The acceleration of objects has the same direction as the resulting force that caused the accelerated movement of the object.

Container ships are particularly sensitive to athwartships accelerations that can apply considerable forces to the containers. Based on basin tests, the accelerations were determined at a number of points on the ship model. The figures below show the maximum measured lateral accelerations on the ship model for the various tested conditions. The consequence of these measurements is that at a significant wave height of 6.5 metres and a peak period of 14.5 seconds, lateral accelerations of 4.8 m/s^2 occur measured for containers high on the stack and greater than 5 m/s^2 measured at the centre of the wheelhouse at a water depth of 26.6 meters (reference location 2 on the southern shipping route). The maximum of the measured accelerations athwartships are slightly larger at a water depth of 26.6 metres than at 21.3 metres.[90]

At a water depth representative of the deeper northern shipping route, also high accelerations were measured on the ship model during the basin tests. These are however somewhat lower than the largest accelerations on the southern shipping route.[91]

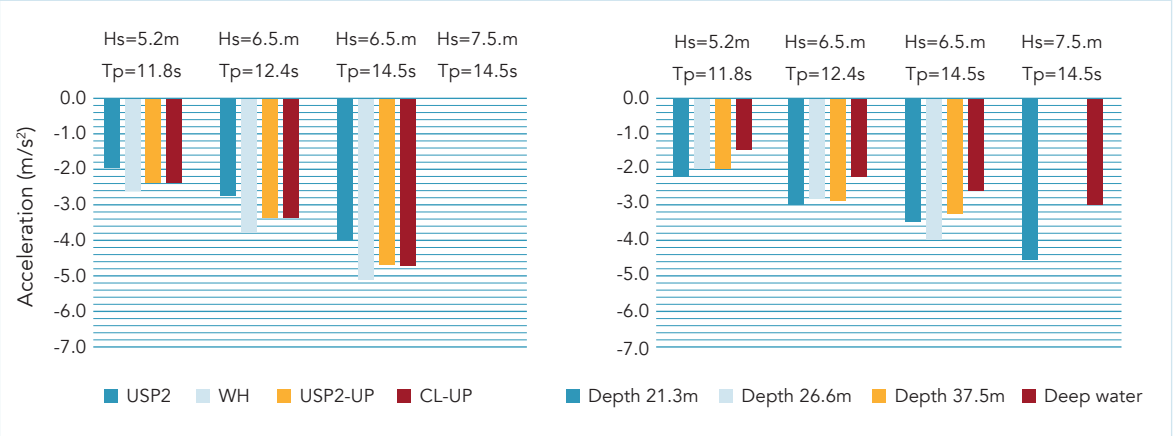


Figure 23: Maximum measured transverse acceleration measured in the tested wave conditions (left) at a water depth of 26.6 metres and different locations on the ship; (right) at different water depths on one location 'UPS2'. (Source: MARIN)

Key with locations:

- **UPS2:** *Lowest container on deck, against the windward side and approximately amidships;*
- ***WH:*** *Amid the wheelhouse (on centreline);*
- ***UPS2-UP:*** *High on the container stack above deck, against the windward side and amidships;*
- ***CL-UP:*** *High on the container stack above deck, on centreline and approximately amidships.*

90 It should be noted here that the accelerations are heavily dependent on the combination of stability (expressed as a GM value) and wave period. This is shown in the differences between results at GM values of 6 metres and 9 metres, but also in the differences in the 12.5s and 14.5s peak periods at the same significant wave height of 6.5 metres.

91 The maximum acceleration on a container low on deck (windward side, amidships), measured at Hs=6.5m, Tp=14.5s and water depth 37.5m, is however lower than de largest acceleration as measured on the same container at a water depth representative for the southern shipping route (measured at Hs=6.5m, Tp=14.5s and water depth 26.6m), respectively 3.3 and 4.0 m/s^2.

Based on the transverse acceleration values measured at a significant wave height of 6.5 (and at 7.5) metres, the accelerations acting on the lashing systems on a large and wide container ship in beam waves in environmental conditions for the Dutch coast - that on average occur every year - are close to the design limits for the lashing systems and containers.[92] If the occurring accelerations are higher than the design limits, lashing systems and/or containers may fail, as a result of which containers can fall overboard.[93]

The extreme ship movements described above with the accompanying accelerations can occur in conditions on the shipping routes above the Wadden Islands, in which other phenomena can also occur that cause (additional) accelerations and/or forces on the containers and the lashing material. These three phenomena are described in the following section.

4.3.2 Contact with the seabed in the event of large heave and roll motions

The southern shipping route to the north of the Wadden Islands features a number of specific shallow areas, so that in certain conditions, such as low tides with high waves and resultant vertical and roll motions of the ship, the water depth below the ship can be reduced.

MSC ZOE case[94]

When it set its course to Bremerhaven, the MSC ZOE was able to choose between the southern and northern shipping route. The ship took the southern route. Here, the MSC ZOE was faced with waves with steep, foamy wave crests and wide wave troughs. The relatively limited water depth on the southern shipping route not only influences the wave conditions but also means there is less space between the bottom of the ship and the seabed, known as under keel clearance. The MSC ZOE - which was in fact not loaded to the maximum and was therefore not sailing with the maximum possible draught - had an average draught of 12.4 metres. The figure below presents for the sailed route of the MSC ZOE above the Wadden Islands the seabed level in relation to the mean sea level.

92 This is also one of the findings of the international investigation into the course of events surrounding the accident involving the MSC ZOE. In addition to the basin tests at MARIN, this finding is also supported by model calculations carried out by the Technical University of Hamburg, commissioned by the Bundesstelle für Seeunfalluntersuchung.

93 From the international investigation into the cause of the accident with the MSC ZOE it follows that on the basis of the Cargo Securing Manual (CSM) it is not clear for which transversal accelerations the lashing system (containers and lashing equipment) is designed. It is concluded that the requirements of the lashing systems of large containerships are not transparent.

94 Source: International investigation into the course of events (PMA, BSU, DSB).

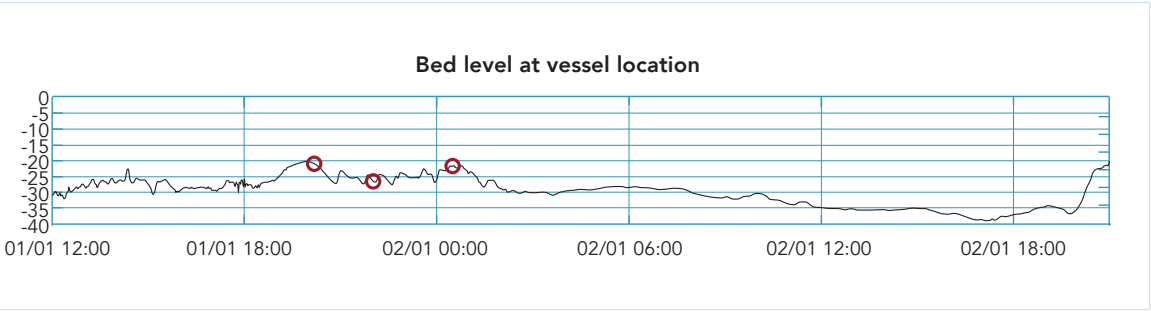


Figure 24: Seabed level along the sailing route of the MSC ZOE, indicated time in UTC (local time = UTC +1), the red dots are the reference locations 1, 2 and 3. (Source: Deltares)

In the least deep section of the shipping route (to the north of Terschelling), the mean water depth is 20 metres. The calculations show that on 1 January 2019 at around 20:00 UTC, the MSC ZOE encountered the lowest water depth. At that location, in flat sea conditions, for the MSC ZOE approximately 7.6 metres static keel clearance remained (local water depth minus the draft, without dynamic effects such as waves, ship motions and squat, the term that describes the lower position of the ship in the water as a result of forward speed). However, the sea was anything but flat in the night when the MSC ZOE lost its containers. There are no direct indications that the MSC ZOE contacted the sea bottom, but it can also not be ruled out.[95]

It should also be noted that this was not the minimum possible keel clearance on this route, since the MSC ZOE did not pass the least deep location at low tide. The lowest water level at the location with the highest seabed level occurred approximately 4 hours later than the passage of the MSC ZOE.

During tests in the basin, contacts between the ship model and the bed of the basin were observed (see Figure 25). The frequency of these contacts varied according to wave and ship conditions. The tests with both short-crested and long-crested waves[96] revealed contact with the seabed starting from a wave height of 6.5 metres and a peak period of 14.5 seconds. Analysis of the ship motions in the basin tests revealed that the ship model can come into contact with the bed if a large downward heave movement coincides with a large roll motion at that same moment.[97] These motions and the resulting seabed contact in the basin tests were the consequence of the passing of a group of relatively high waves.

95 Source: International investigation into the causes (PMA, BSU, DSB).
96 See Section 4.2.2 for an explanation of these terms.
97 Seabed contact was observed in tests in the test basin whereby the ship in the tests was held in the same position and therefore had no forward speed.

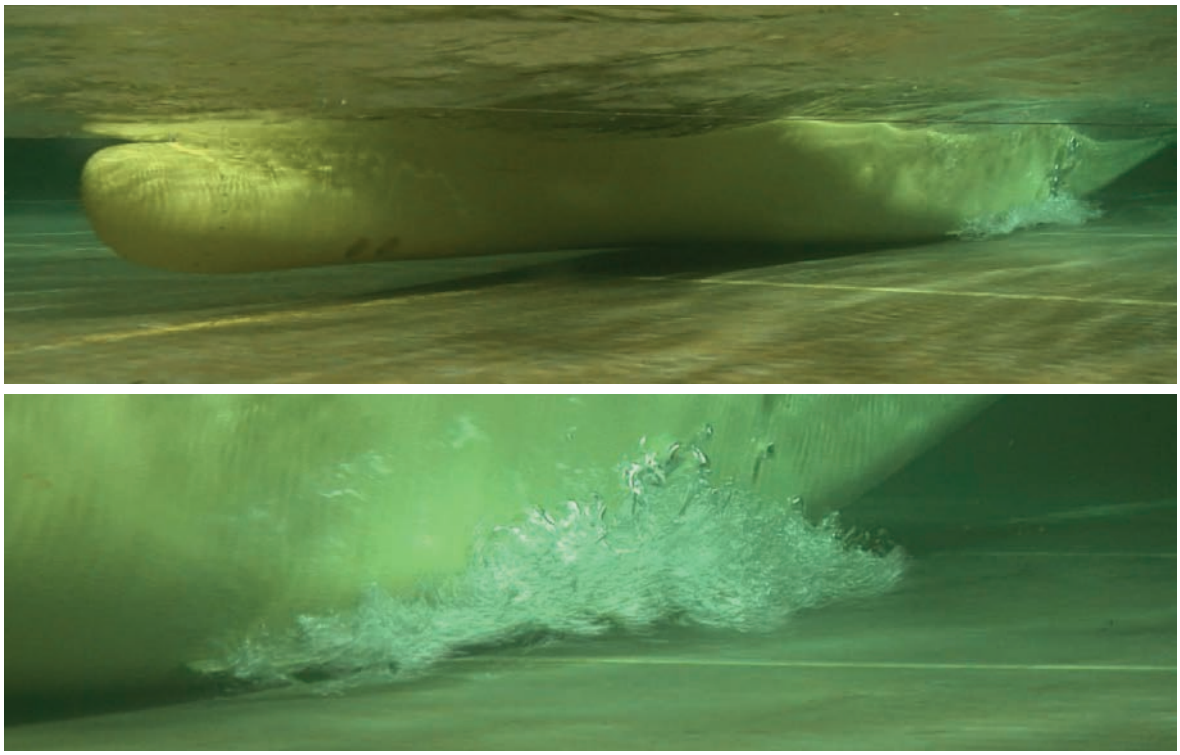


Figure 25: Underwater images of the ship model at the moment of seabed contact (water depth: 21.3 metres). (Source: MARIN)

Effects of contact with the seabed

If a ship comes into contact with the seabed, direct structural damage may be caused to the hull of the ship, but this need not necessarily be the case. It depends among other things on the hardness of the bed and the level of impact. The sandy seabed on the southern shipping route is expected to less rapidly result in significant damage than a rocky seabed. When a ship touches the seabed, also at a sandy seabed there will occur accelerations, vibrations and deformations in the hull of the ship, that will be transferred to the containers on deck. The high container stacks will be subjected to loads in different directions and will start to vibrate, possibly causing damages to containers and lashings.

The tests with the ship model reveal that vibrations pass through the ship at the moment that contact occurs with the seabed. However, the measured accelerations on the ship model can not be directly translated into full scale accelerations. The rigidity and flexibility of the model differ from the actual ship's hull (bending, torsion, vibrations). In addition, the test model came into contact with a level concrete bed, whereby the impulse load will differ from that of a sandy bed such as that on the North Sea. To gain a greater insight into the quantitative effects of seabed contact by a container ship on the southern shipping route north of the Wadden Islands, further research is needed.

Probability of seabed contact

The probability that a large container ship in the scenario of the accident with the MSC ZOE will contact the seabed on the southern shipping route depends on numerous factors. Firstly, it depends on the environmental conditions such as local water depth and wave conditions (wave height and wave period). Subsequently, the size, draught and shape of the ship play an important role. Finally, stability is of crucial importance.

The difference lies primarily in the roll motion. Basin tests revealed that a ship model with a lower stability (and therefore with less violent roll motions) had a smaller probability of contact with the seabed in the tested beam waves than a container ship with a higher stability (namely the ship model based on the MSC ZOE).[98]

Furthermore, the environmental conditions were not constant during the passage of the MSC ZOE through the shallow water of the southern shipping route. The water depth beneath the ship varied due to the bottom profile and the tide. The wave conditions also varied due to the development of the storm. The tests lead to the conclusion that a large and wide container ship on the southern shipping route in the observed conditions (beam waves with a significant wave height of 6.5 metres and a peak period of 14.5 seconds) at least could come into contact with the seabed. This finding prompted the Board to issue an interim warning in October 2019, see Appendix C.

4.3.3 Impulsive green water loads on the containers

The (solid) water from waves striking over the deck or against the cargo on the deck is known as 'green water'. Green water of this kind occurs on container ships in high, athwartships incoming waves. The horizontally moving water of an athwartships incoming (almost) breaking wave cannot pass through the ship and is forced upwards at high speed on the side where the wave comes into contact with the ship. This jet of water directed upwards can reach above the deck of the ship and can reach the bottom of the lowest container above the gangway. The water can also come into contact with the sides of the containers positioned higher up the stack. The green water effect is additionally amplified with high, steep wave crests, particularly if the waves are breaking forwards at high speed. This is characteristic for shallow water such as that on the southern shipping route and to a lesser extent the northern shipping route.

The effect of green water on a container ship is that an impulsive force is exercised on the containers. This can lead to a series of problems: the lower containers themselves can be damaged or containers can be lifted causing damage to the lashings. If one container is damaged or suffers broken lashings, an entire stack of containers can topple. The green water can also cause lateral forces on the containers positioned higher, thereby pushing the container against adjacent containers. This in turn can cause (part of) a row of containers to topple, like dominoes.

During the tests in the basin, the phenomenon of green water in wave conditions was most strongly visually observed with water depths representative for the southern shipping route (see Figure 26), and less for wave conditions at a water depth representative for the deeper northern shipping route. This can be explained by the fact that in the deeper water less breaking waves occur and there is more space below the ship, leading to a smaller wave reflection. This does not mean that green water effects cannot occur on a container ship on the northern route. During the basin tests, only the extreme cases were 'counted' visually. It can, however, be stated that the probability of green water is greater on the shallower southern route but that it can still occur on the northern route.

98 GM value of six metres (lower stability) rather than nine metres (higher stability, comparable with the MSC ZOE).

Figure 26: Images of the ship model at the moment of occurrence of the green water phenomenon. (Source: MARIN)

4.3.4 Impulsive slamming against the ship hull

In the wave conditions in the shallow southern shipping route, steep waves occur that occasionally break. The interaction of these waves with their high horizontal water speeds with the sailing and moving ship cause wave impacts (slamming) against the side of the ship. Visual observation during the basin tests suggests that major wave impacts against the hull of the ship occur over the entire length of the ship, also at the flared bow and stern part. The seriousness of the wave impacts on the bow and stern of the ship are influenced by the shape of the ship's hull.

Wave impacts (slamming) were observed both at a depth representative for the shallower southern shipping route and a depth representative for the slightly deeper northern shipping route. However, the frequency of the occurrence of wave impacts decreases as water depth rises. MARIN estimates based on the basin tests are that the phenomenon of wave impacts (slamming) on the southern shipping route occurs in the order of magnitude of twice as commonly as the phenomenon of green water.

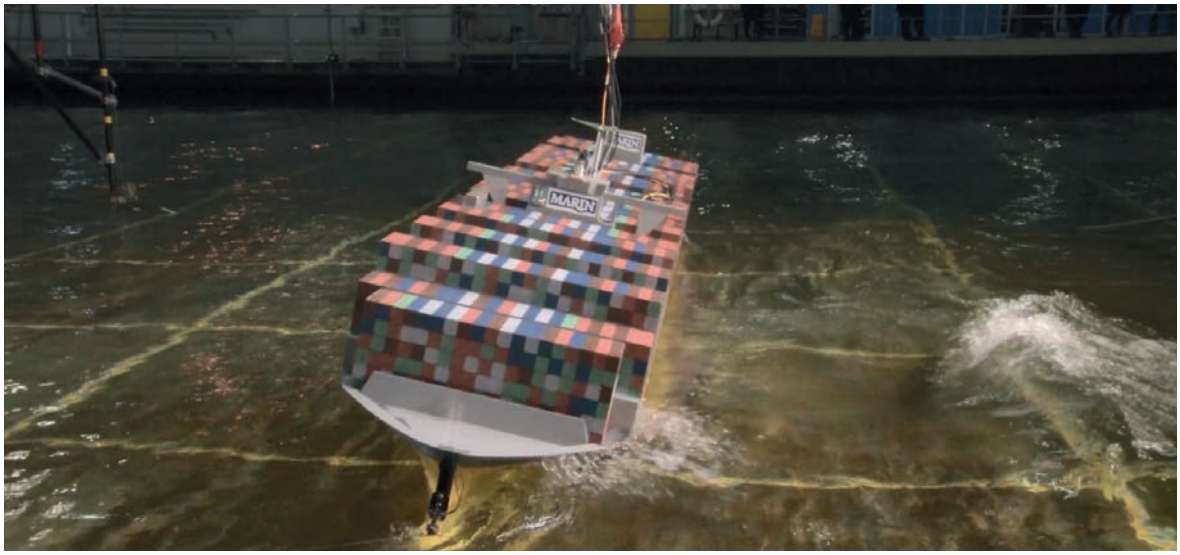


Figure 27: Image of the ship model at the moment of occurrence of a wave impact against the bow and a breaking wave close to the ship. (Source: MARIN)

The wave impacts led to vibrations in the ship model. Although these vibrations are less pronounced than the vibrations following contact with the seabed, they will certainly lead to vibrations in the hull and stacks of containers. These vibrations in turn generate forces on the frame of the containers and the lashing systems, thereby resulting in the risk that the lashing systems could fail and containers could fall overboard.

Sub-conclusion (Section 4.3)
Large, wide container ships in severe but not extreme weather on the southern shipping route, in beam waves, can be exposed to considerable forces acting on the containers and lashing systems. These forces are the consequence of extreme ship motions and the resultant accelerations, contact with the seabed, green water and wave impacts (slamming). Individually and in conjunction with one another, these four phenomena represent risks for the loss of containers from large, wide container ships on the southern route. With the exception of contact with the sea bottom, these phenomena can also occur on the northern route.

4.4 Comparison of the northern and southern shipping routes

Conditions on the route
In the event of a stormy wind (gale) and high waves from a north-northwesterly direction, as in the MSC ZOE scenario, the waves are almost perpendicular to the sailing direction of the ship. This applies to both the southern and the northern shipping route to the north of the Wadden Islands. One important difference between the northern and southern shipping route is the water depth. The figure below shows the two shipping routes above the Wadden Islands, including the seabed level in respect of the mean height of the sea level (mean sea level, MSL). One obvious difference is the 10 to 15-metre greater water depth on the northern route. The northern shipping route is therefore deeper than the southern, but in absolute terms is still a relatively shallow shipping route.

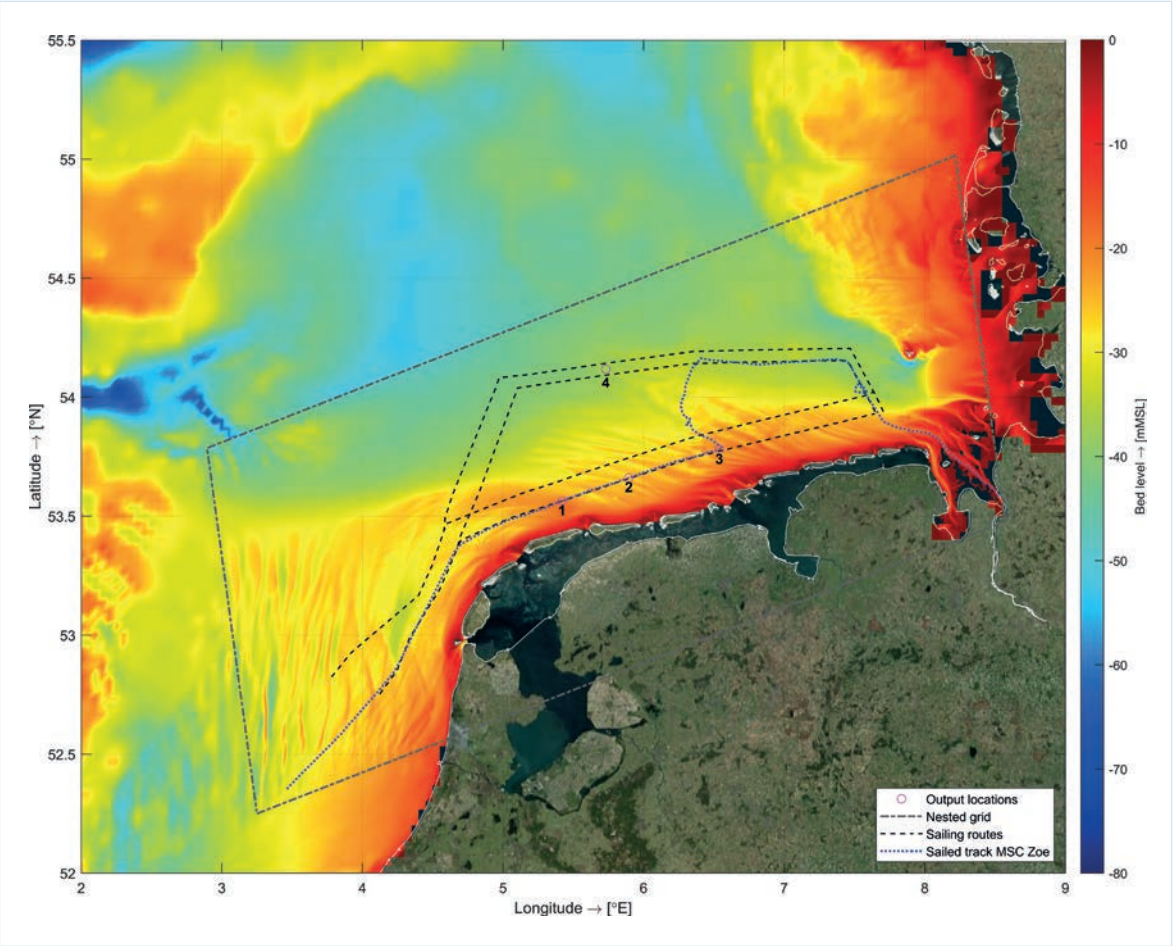


Figure 28: Shipping routes and seabed level. (Source: Deltares)

Additional points to the key: numbers 1 to 4 refer to the reference positions in the studies from Deltares and MARIN: locations 1 to 3 on the southern shipping route and location 4 on the northern route.

The relatively restricted water depth of both the southern and the northern shipping route affects the shape of the waves rolling in from the northerly direction. The wave crest becomes higher and steeper in shallower water, while the wave trough becomes shallower and wider (see also Section 4.2.2 for the influence of shallow water on waves). As the wave approaches the coastline, due to the proximity of the seabed, it will become increasingly asymmetric; foam crests will be created and finally the wave will collapse or break. In shipping terms, steep, foam-crested waves of this kind in shallow water are referred to as 'ground swell'. This term refers to the material scoured from the seabed that is sometimes visible at the surface. The shallow coastal water of the Wadden area are known for these ground swells; they can form a hindrance to rapid and safe passage.

Deltares compared the estimates produced for the meteorological and maritime conditions on the southern shipping route at the time of the accident involving the MSC ZOE with those on the northern shipping route during the same time period. The result, when looking at significant wave heights and peak periods, is a reasonably uniform picture of the meteorological and maritime conditions in this section of the North Sea. The local waves can be different: in the deeper northern route there will be less breaking waves.

Phenomena with risk of loss of containers

The basin tests performed by MARIN revealed phenomena with risks of loss of containers occurring both on the northern and the southern shipping route (see Section 4.3). On both shipping routes, large, wide container ships experience considerable accelerations as a consequence of extreme ship motions. There are also differences as a consequence of the depth of the shipping route. The table below provides an overview of the phenomena observed in the basin tests.

Risks	Southern shipping route	Northern shipping route
Accelerations as a consequence of extreme ship movements	X	X
Seabed contact	X	
Green water	X	x*
Wave impacts	X	x*

Table 6: Phenomena with risks of loss of containers on the northern and southern shipping routes for large, wide container ships (comparable to the MSC ZOE) in stormy wind and high waves from a north-northwesterly direction (comparable with the night of the accident involving the MSC ZOE)

** green water and wave impacts (slamming) occur on the northern shipping route, but are less common and less extreme than on the southern route.*

The additional metres' depth on the northern route as compared with the southern route mean that for large container ships like the MSC ZOE on the northern shipping route, the risk of contact with the seabed is negligible. Wave impacts were observed in situations on both shipping routes but less often on the northern route. The number of extreme green water effects also decreased as water depths rose.

Location of the shipping routes

Inherent to their location is the fact that the northern and southern shipping routes differ in terms of their course orientation: the track of the routes differs by approximately 10 degrees. The track of a ship in a shipping route determines how the waves affect the ship and therefore heavily influences the ship motions. It is possible for a ship on one route to be confronted by waves incoming athwartships that cause large ship motions, while on the other shipping route the effects are less pronounced because the ship experiences fewer beam waves. However, the difference between the ground course on the southern and northern shipping routes is limited, so that the effect of the difference on the incoming wave direction is also limited. This certainly applies for a ship in a storm, as a result of which it is not easy to sail a straight course.

Another difference between the shipping routes is that the northern route offers greater room for manoeuvre than the southern route, because it is located a greater distance from the coastline.[99] The water depth on the southern route is restricted and outside the route, towards the coast, the seabed rises rapidly. In severe weather with high waves, it is therefore easier to select a favourable course for the ship on the northern route.[100] The opportunities for manoeuvring are also determined by the direction of the waves present, and the possible presence of obstacles in the vicinity of where is being sailed, such as other ships, an offshore platform or a windmill park. The southern route has a higher traffic intensity. On the other hand, the shipping lanes of the northern route are less wide than those of the southern route[101] and south of the northern route is a wind farm, that will be expanded in the coming years (see Figure 12). The effect of other developing activities on the North Sea have not been further investigated for this investigation.

Effects of loss of containers

Although the number of container ships passing each year on the southern shipping route is far higher than on the northern shipping route, both shipping routes above the Wadden Islands are used, and there is a risk of loss of containers on both routes. For both routes, the loss of containers can result in damage on nature values, in particular the marine environment. The containers and their content, which can potentially escape, pollute the Wadden Sea and can – depending on de direction of wind and current - wash ashore on the coasts of the Wadden Islands and the coastline of Friesland and Groningen. Also at other locations to the north of the Wadden Islands, the loss of cargo represents damage to the natural values. Both routes run through or are located close to Natura 2000 areas (see Section 5.1 for a further analysis of the shipping routes through and past nature areas).

For both the northern and the southern shipping routes, given the presence of a vulnerable nature area, loss of containers will result in pollution of the North Sea and depending on the direction of wind and current of the vulnerable Wadden area. Whereas with regard to oil the northern route offers the advantage that there is more time to recover the oil that remains afloat, it is questionable whether and to what extent the same applies to the loss of containers. It is uncertain whether containers lost on the northern route are easier to recover and whether it is positive that it takes longer before the cargo from the containers reaches the coastline, because the resultant area of distribution is also larger, as is the period during which the waste washes ashore. Moreover, items from the containers that have spent more time in the sea may have been destroyed (to a greater extent) and may have disintegrated into smaller parts, which can make the clean-up operation more difficult.

99 De southern shipping route lies 20 to 30 km from the coast and the northern route globally 80 km.

100 A ship shall in principle follow the traffic lane in conformity with the COLREG Convention (rule 10), unless in cases of emergency deviating from this is necessary.

101 The southern shipping route has separated traffic lanes with a width of 3 nautical miles. The northern route also has separated traffic lanes with a width varying between 1.5 and 2 nautical miles. The shipping route north of Vlieland that connects the southern and northern shipping routes, does not have separated traffic lanes.

Sub-conclusions

- The wave conditions (wave height and period) on the southern shipping route north of the Wadden Islands were at the time of the accident with the MSC ZOE comparable to the wave conditions on the northern route. On both the northern and the southern shipping route waves occurred that are typical for shallow water: steep, high waves occasionally breaking. The local waves can be different: in the deeper northern route there will be less breaking waves.
- On both the southern and the northern shipping route, phenomena occur that generate risk of the loss of containers. The forces on the ship, the cargo and/or lashing systems as a result of extreme ship motions in stormy wind and waves from a north-northwesterly direction occur both on the southern and the northern shipping route above the Wadden Islands.
- On the southern shipping route there is a risk of contact with the seabed as a result of violent ship motions in stormy wind and waves from a north-northwesterly direction. For the northern route, a 'safe' depth is guaranteed, and contact with the seabed can be excluded.
- Although wave impacts (slamming) and green water can occur on both shipping routes, the basin tests undertaken suggest that these phenomena occur more often on the shallower southern shipping route.
- In terms of location, the orientation of the sailing direction on the southern and northern shipping route is not entirely identical. This influences the angle at which the waves impact on a ship, but only to a limited extent.
- The northern route offers more room for manoeuvre than the southern route since this route is located at a further distance from the coast and ships have less nuisance from other ships as a result of the lower traffic intensity. As a consequence, there are more options for reducing the risks by manoeuvring and course changes if the ship finds itself in a high-risk situation on the northern route compared to the southern route.
- Whereas following the northern route offers a clear environmentally favourable effect for tankers, in terms of oil clean-up operations, the same does not apply to loss of containers. For both the northern and the southern shipping route, loss of containers will result in pollution of the North Sea and depending on the direction of wind and current of the vulnerable Wadden area.

4.5 Knowledge of the risks

No prior investigations have been carried out into the specific risks of the shipping routes above the Wadden Islands. Generally speaking, only limited scientific research has been carried out into ship motions in shallow water.[102] The phenomena are not unknown, but the phenomena 'accelerations as a consequence of extreme roll motions', 'contact with the seabed', 'green water' and 'wave impacts (slamming)' were never previously researched in relation to the shipping routes above the Wadden Islands. The shipping routes were not previously identified as representing a risk with a view to the loss of containers close to a vulnerable nature area.

The present investigation and the international investigation into the course of events surrounding the accident with the MSC ZOE demonstrate that there are route-specific risks that must be taken into account given the vulnerability of the Wadden Sea and Wadden Islands to pollution as a consequence of loss of containers. At the same time, the risks identified in this investigation relate to a single scenario, namely the circumstances in which the accident involving the ultra large container ship MSC ZOE occurred and the ship lost containers: severe but not extreme weather on the southern shipping route with high beam waves. These insights represent an important first step in mapping out the route-specific risks in relation to the loss of containers.

In addition to the scenario that forms the central focus of this investigation, other high-risk scenarios and/or circumstances are conceivable that could result in comparable or other risks of loss of containers. Moreover, other ship sizes and types will demonstrate other ship behaviour in the waves. On the basis of the results from this investigation, the Ministry of Infrastructure and Water Management has commissioned MARIN to carry out additional research into other ship sizes and environmental conditions. Three types of container ships will be examined: an ultra large container ship of 380 metres, a shorter and narrower Panamax ship of 279 metres and a small Feeder of 163 metres.[103]

Sub-conclusion
This investigation has revealed previously unrecognized risks on the two shipping routes above the Wadden Islands. The risk of loss of containers as described in the report relate to a single scenario, namely the conditions in which the accident involving the MSC ZOE occurred and the ship lost containers. In addition to this scenario, there are other conceivable high-risk scenarios and/or conditions.

102 Numerical methods have their limitations in reproducing shallow water effects, given the complexity and non-linear nature of the effects.
103 MARIN, *Position paper tbv hoorzitting/rondetafelgesprek Tweede Kamer 'Status MARIN onderzoek Scheepvaart zuidelijke vaarroute boven Wadden'*, 5 March 2020.

5 MANAGING THE RISK OF LOSS OF CONTAINERS

5.1 Introduction

Loss of containers on the shipping routes above the Wadden Islands results in pollution that negatively impacts on the natural value (quantity and quality of the nature) in the nearby nature areas. This is specifically confirmed by the loss of the cargo from the MSC ZOE. The pollution became visible when it washed up on the coastline of the Wadden Islands. Although the effects of the 'rubbish' in the sea or washed up on the beaches cannot be unequivocally specified,[104] it is still essential to tackle such pollution. The unrest that arose in the Netherlands and Germany also demonstrates that the loss of containers in (the vicinity of) a nature area is perceived as extremely undesirable.

Case of the MSC ZOE: Scale of the loss of containers and cargo
In the night of 1 to 2 January 2019, to the north of the Wadden Islands and the German island of Borkum, the MSC ZOE lost 342 containers overboard, 232 in the Dutch sector of the continental shelf and 110 in the German sector. In total, estimates suggest that 3257 tonnes of cargo (containers plus content) were lost into the sea. The vast majority of the lost cargo consisted of consumer articles and the accompanying packaging materials. Over the next few days, mainly plastic objects were washed ashore on the coasts of the Wadden area. The beach acquired the appearance of a rubbish tip[105] with garden furniture, video equipment, car components, tyres, textiles, shoes, flip-flops, disposable cutlery, drinking straws, glass, pots and pans, balloons, toy cars, My Little Pony's, refrigerators, stools, kids' seats, fleece blankets, jackets, adhesive tape, bags, razor blades, flat screen TVs, scooters, suitcases, pump-action soaps, lights, vacuum hoover hoses, floor mats, sheets of plastic, polystyrene foam, mattresses, etc.

Read more on the next page

104 See Appendix E for an explanation of the impact of the lost cargo, based on current knowledge.
105 Based on a compilation of images of different media reports.

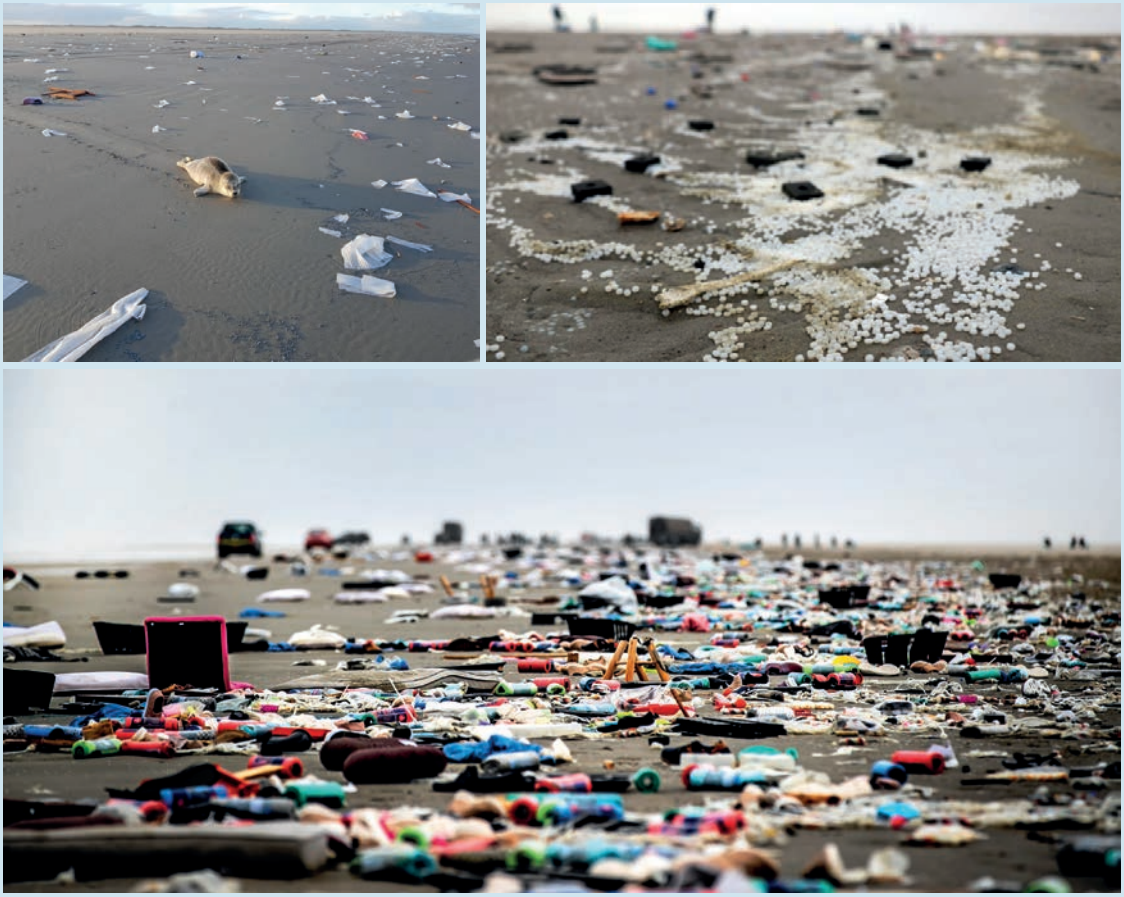


Figure 29: Photographs of objects from the MSC ZOE washed ashore. (Source from left to right: Arnold van der Wal – Natuurmonumenten, Jeroen Berkenbosch – RTV Noord, Remko de Waal - ANP)

Two of the containers lost overboard contained dangerous goods: one container held 160 boxes with sacks of a mixture of 50% dibenzoyl peroxide and 50% dicyclohexyl phthalate and 120 boxes with sacks of a mixture of 34% dibenzoyl peroxide and 66% dicyclohexyl phthalate.[106]The second container held 467 crates of lithium-ion batteries, in total weighing 1,400 kg. Although reports about hazardous substances initially attracted most attention from the authorities and emergency services, this component of the lost cargo represented just a limited part of the damage, both in terms of toxicity and scale. In addition, the containers included numerous plastics in the form of packaging material such as polystyrene foam, film and plastic granules. One of the fractured containers, also a dangerous goods container, held a huge quantity (22.5 tonnes) of polystyrene granules with a diameter of 0.5 mm.[107]

106 WUR, *Mogelijke ecologische gevolgen containerramp MSC Zoe voor Waddenzee en Noordzee – Een quickscan (possible ecological consequences containerdisaster MSC ZOE for Wadden Sea and North Sea – a quick scan)*, March 2019.

107 Source: WUR.nl website 'Five questions about the impact of the container disaster with the MSC Zoë' (consulted 3 March 2020)

In addition, a large number of industrial pellets of High-Density-Polyethyleen (HDPE), discs with a diameter of 4-5 mm, have been found in the sea and washed ashore on the beaches.[108] All these small plastic particles started washing ashore on the beaches immediately following the accident. The wind brought about further distribution of these plastic particles, which due to their small size are difficult to remove from the environment.

Large-scale clean-up operations along the coastlines and recovery actions at sea were successful to the extent that the majority of the lost cargo was retrieved and cleaned up. Mid-March 2020, 88% of the containers and 75% of the cargo had been salvaged and disposed of. At the same time, 41 containers and more than 800 tonnes of cargo were still in the sea.[109] The majority of this remaining cargo is not expected to be traceable or retrievable. Floating and gliding objects are spread by wind and sea currents; other objects end up on the seabed and are covered with sand.

The investigation into the course of events has revealed that a comparable accident such as that with the MSC ZOE could again take place in the future. The weather conditions at the time of the accident were not exceptional and in statistical terms recur several times a year, and this part of the North Sea is an intensively used area. This means that in order to protect nature and to ensure the safety of shipping, the risks of loss of containers on the southern and northern shipping routes close to the Wadden Sea and Wadden Islands must be managed.

Up until the interim warning, the route-specific risks on the shipping routes above the Wadden Islands as identified in this investigation were unknown or not recognized by shipping companies and vessels. However, containers have been lost at sea for years, also on the shipping routes above the Wadden Islands. The response must be a targeted approach to risk management for these shipping routes. This chapter considers and analyses how risks of loss of containers along these routes could be managed. Consideration has been given to the role of the Netherlands and the role of the shipping sector. Firstly, the international context of the problem is outlined.

5.2 International context

The northern and southern shipping routes above the Wadden Islands are internationally designated shipping routes partially located in the Dutch sector and partially in the German sector of the North Sea. There are no restrictions on container ships to use either route. In particular the southern route is a heavily used shipping route with shipping traffic not necessarily sailing to or from the Netherlands.

108 NIOZ & WUR, *Notitie over de status van het onderzoek naar ecologische effecten van het MSC ZOE incident met focus op microplastics,* 30 januari 2020.
109 Source: Ministry of Infrastructure and Water Management.

The routes are in the Dutch and German EEZ and broadly outside the territorial zone (12-mile zone).[110] In the EEZ, all States have freedom of shipping and innocent passage. This means that the Netherlands cannot unilaterally impose enforcement measures on shipping traffic in respect of the use of the northern and southern shipping routes. Only resolutions by the IMO can lead to obligations or regulations for shipping on the shipping routes above the Wadden Islands. At the end of the day, it is up to individual Member States to take initiatives to ensure that measures are taken within the IMO context, to better manage the risks of loss of containers on the northern and southern shipping routes. The Netherlands and Germany, the countries suffering negative consequences of loss of containers on the shipping routes above the Wadden Islands, are clearly the relevant parties to take action.

The IMO designation of the Wadden Sea in Denmark, Germany and the Netherlands as a Particularly Sensitive Sea Area (PSSA) does offer possibilities for adopting associated protective measures within the IMO. At present, no specific measures have been taken aimed at protecting the Wadden Sea against the risk of loss of containers from container ships.

Sub-conclusion
The northern and southern shipping routes are located both in the Dutch and German EEZ and are internationally designated shipping routes. Only resolutions by the IMO can lead to obligations or regulations for shipping on the shipping routes above the Wadden Islands. The Wadden Sea in Denmark, Germany and the Netherlands has been internationally recognized as a sensitive sea area. Within the IMO, this does offer international opportunities for taking additional (protective) measures for shipping. At present, no specific measures have been taken aimed at protecting the Wadden Sea against the risk of loss of containers from container ships.

5.3 Dutch approach

5.3.1 Policy

Risk-based approach
The Dutch policy with regard to the activities in or around the Wadden area is part of the policy for the North Sea. The underlying principle behind the policy as described in the North Sea 2050 Area Agenda is safe and sustainable economic development of the North Sea while preserving and recovering the integrity of the marine ecosystem. Risk management of loss of containers is an integral part of this policy.

110 The southern shipping route runs partially inside and partially outside the 12-mile zone. The northern shipping route is entirely outside the 12-mile zone.

In the framework of this policy, the Dutch government has opted for a risk-based approach.[111] This includes use of various instruments, including risk analyses and monitoring of traffic density and traffic flows. Since 2012, various national government bodies have been working together in implementing a risk analysis for the North Sea. To date, three risk analysis reports have been published by Rijkswaterstaat.[112] The purpose of the risk analyses is to assess the risks for shipping in the Dutch sector of the North Sea. In the Risk Analysis North Sea 2018[113], a 'top 10' of risks is identified based on analysis of shipping accidents on the North Sea and expert judgement. Loss of containers is not included in this top ten.

The risk analysis from 2018 contains a detailed area description of the Dutch sector of the North Sea. An analysis is made of the accident locations, accident causes and the experiences of shipping professionals on the North Sea. According to the report, it is 'difficult' to establish a direct link between the area description and the top ten identified risks. In the area description, no relationship is established with the nearby Wadden Sea, with the intention of protecting the nature area. Economies of scale in the shipping industry (not specifically container ships) are referred to as a development, and it is argued that this could result in greater consequences. No further explicit assessment is carried out.

It is specified in general terms in the Risk Analysis North Sea 2018 that the sailing conditions in difficult weather conditions can prove 'extremely problematic' and that this is also reflected in situation descriptions in the previously undertaken risk analyses for loss of containers due to weather. The risk analysis does not deal specifically with accident scenarios that could result in loss of containers. There is no specific attention for pollution from lost containers as an undesirable incident close to nature areas such as the Wadden Sea.

Existing concerns

Containers lost overboard on the shipping routes just above the Wadden Islands and the economies of scale in container shipping at sea have long been a cause of concern for local administrators. As early as 2007, mayors of the five Wadden Islands, in a joint letter, specifically drew the attention of the then Minister of Traffic and Water Management to the problem of containers lost overboard. The immediate background to this letter were two incidents in November 2007 (involving the loss of 8 and 45 containers respectively). The mayors also reported earlier incidents with containers lost overboard in 2001, 2002 and 2003, and expressed their real concerns about safety and harmful consequences for the environment.[114] In a reply letter to the mayors, the Secretary of State for Traffic and Water Management recognized that containers lost overboard can represent a hazard to shipping and that if containers with their cargo do wash up on the beaches, this can lead to danger to people and the environment. The Secretary of State noted that incidents

111 Ministry of Infrastructure and the Environment, Ministry of Economic Affairs, *North Sea Policy Document 2016-2021*, December 2015.
112 In 2012, 2015 and 2018.
113 Rijkswaterstaat, *Risk Analysis North Sea 2018*, July 2018.
114 https://www.waddenzee.nl/fileadmin/content/Dossiers/Overheid/containerincident/Waddeneilanden_brf_1_containers_2007.pdf

had regularly occurred in previous years, whereby on one occasion a large number of containers were lost overboard in a single incident (in 2006: 3 incidents, 67 containers in the sea, 2007: 2 incidents, 55 containers in the sea). She then noted that these numbers must be considered in relation to the overall scale of container transport on the North Sea. At the same time, she indicated that she did not wish to trivialize the problem, but pointed out that any effective approach depends in part on the international perception of the problem. The Secretary of State promised to take two actions: to have an investigation carried out by the Traffic and Water Management Inspectorate in the event of large-scale loss of cargo from ships, and to consult internationally with other countries about their estimation of the scale of loss of containers and whether this is perceived as a problem, so that additional measures can be taken.

This response led the mayors at the start of 2008 to once again call upon the Secretary of State to focus additional attention on the problem of loss of containers, and to call for a more robust approach.[115] According to the mayors, it was not so much the question of whether the loss of containers is perceived as a worldwide problem, but far more whether there was any recognition that every container with environmentally burdensome material that ends up in the sea results in an unacceptable risk. The Secretary of State issued no further response to this letter.

At the start of 2008, two parliamentary questions were asked about the transport of containers with hazardous substances transported by ship along the southern shipping route. The background to these questions was a television report[116] and the concerns expressed by the mayors of the Wadden Islands about the problem of loss of containers. In response to questioning, the Secretary of State indicated that she saw no grounds to increase the separation of the route followed by ships from the coast in the event of the placement of containers with hazardous substances on deck.[117] She referred to the international obligation adopted partly in response to a joint proposal from the Netherlands that requires tankers containing oil and hazardous substances to sail further away from the coast of the Netherlands and Germany. According to the Secretary of State, a similar obligation for container ships would result in practically no safety gains, also because it would result in a considerable increase in traffic in the northern shipping route. Also against that background, she did not expect any new assessment to bring about a different result. She also indicated that due to stricter international rules on the construction of containers, the risk of the escape of hazardous substances from containers washed overboard has been minimized. In her judgement, as a result, the transport of containers represented less of a threat to the environment than the transport of hazardous substances in tankers. In response to subsequent parliamentary questions (June 2008) on the same subject, the Secretary of States repeated her position.[118]

115 https://www.waddenzee.nl/fileadmin/content/Dossiers/Overheid/containerincident/Waddeneilanden_brf_2_containers_2008.pdf

116 EenVandaag broadcast, 12 January 2008.

117 Dutch House of Representatives, meeting year 2007-2008, Appendix to Proceedings no. 1263, Questions from member Poppe (SP) to the Minister of Transport and Water Management and the Minister of Public Housing, Spatial Planning and Environmental Management about the transport of containers with hazardous substances by ships. (Submitted 15 January 2008), https://zoek.officielebekendmakingen.nl/ah-tk-20072008-1263.html.

118 Letter from the Secretary of State of Transport and Water Management tot he Dutch House of Representatives with replies to questions from members Jacobi and Kuiken regarding the safeguarding of safety on the water around the Wadden Islands, 2 September 2008, reference RWS/SDG/NW2008/776/67100.

In 2018, an incident involving 24 lost containers above Ameland and Terschelling led the mayors of the Wadden Islands to express their concerns in a letter to the Ministry of Infrastructure and Water Management about the increased shipping intensity in the traffic separation schemes adjacent to the Wadden Sea area in relation to safety and the environment. The mayors also referred to the economies of scale in container shipping and a series of incidents involving loss of containers. They then issued a series of proposals to improve safety, including via more intensive traffic management for shipping to the north of the Wadden area, and a more proactive approach by the Netherlands Coastguard.

In response, the Ministry of Infrastructure and Water Management expressed an understanding of the concerns, but did not respond specifically to the worries about the loss of containers. In addition, the Ministry pointed out that traffic control, such as Vessel Traffic Services (VTS) and Vessel Traffic Management (VTM),[119] cannot be imposed on shipping routes outside the Dutch 12-mile zone, except in the form of information issued to ships. The imposition of traffic management measures outside this zone was not possible, according to the Ministry.

Following the accident with the MSC ZOE, 'KIMO Nederland en België"[120] (an association of coastal municipalities with common interests on and around the North Sea) observed that insufficient notice had been taken of signals issued by the mayors of the Wadden Islands, on previous occasions.

The Ministry of Infrastructure and Water Management did participate in the research project Lashing@Sea and also co-financed the project.[121, 122] This research focussed on the evaluation of the regulations and technology in sea transport, among which container transport.

The Ministry shared the results of the research within the IMO. This had led amongst other to amendments of international standards on the subject of container mass verification and a revision of container standards.

The above referenced research and the resulting actions have focused on IMO and international standards. Not all recommendations from the research have been taken up.[123] In addition, the incidents of lost containers and signals from local administrators and the Dutch House of Representatives about the risks of loss of containers have to date not been seen as sufficient grounds for the Dutch government to investigate the risks of loss of containers north of the Wadden Islands and the occurring increase in scale of container ships in any greater depth, and to consequently develop new policy and a new approach.

119 VTM is a less restrictive form of traffic management than VTS. In the case of VTM, the emphasis is on information provision to traffic participants; in the case of VTS, traffic controllers can issue instructions to the traffic participants.
120 The Norwegian abbreviation KIMO stands for 'Kommunernes Internationale Miljøorganisation'.
121 [Netherlands] parliamentary paper II (Attachment) 2007/08, nr. 1263.
122 This research project took place from June 2006 – June 2009 and was a Joint Industry Projects executed by a consortium of 23 organisations, including MARIN.
123 More information van be found in the international investigation report.

Following the accident with the MSC ZOE, the Ministry has initiated several studies, amongst others a study into the possibility of the tracking of containers, an investigation by ILT into container lashing and additional basin tests with other types of ships as mentioned in Section 4.5.

Sub-conclusion

- In the framework of the policy for the North Sea, the Dutch government has carried out no specific risk analyses for the southern and northern shipping routes above the Dutch Wadden Islands. Economies of scale in the shipping industry have been identified by risk analyses undertaken by the Netherlands as a development that must be taken into account, because the effects of occurrences can be more serious. In the risk analysis carried out for the North Sea, potential effects of loss of containers for the Wadden Sea are not specifically referred to.

- Historical concerns on the Dutch Wadden Islands about the loss of containers have not resulted in a focused approach to the risks of loss of containers above the Wadden Islands.

5.3.2 Information provision and advice by the Netherlands Coastguard

The Netherlands Coastguard is the nautical manager of the North Sea, and monitors the use of the North Sea. Specifically for the North Sea area for which the Netherlands is responsible,[124] weather forecasts and safety reports, including weather warnings, are announced to shipping by the Netherlands Coastguard by radio telephone, MF (medium wave) and NAVTEX reports. Neighbouring countries such as Germany and the United Kingdom also issue warnings for the North Sea area, which may result in a certain degree of overlap. In this way, international shipping is kept informed of imminent forecasts and warnings. This therefore also applies to shipping that makes use of the northern and southern shipping routes above the Wadden Islands.

NAVTEX messages

NAVTEX is an international telex service to transmit maritime safety information such as navigation and weather warnings, and urgent reports from coastal stations to shipping. The meteorological information provides forecasts concerning current wind warnings ((≥7 Bft), a general synopsis, wind direction and force, weather, visibility and significant wave height in each district. Wave period and wave direction are not part of the NAVTEX reports broadcast by the stations.

124 The Netherlands is responsible for the Dutch EEZ in the North Sea.

At the Coastguard Centre in Den Helder, the Coastguard maintains an overview of which vessels are sailing in the northern and southern routes. The Netherlands Coastguard does not have a task to actively monitor all traffic flows and does not issue direct instructions for the routeing of ships, but it can make contact with vessels and issue safety recommendations. These are indeed actions taken by the Coastguard in response to the interim warning in relation to the risk of seabed contact on the southern shipping route above the Wadden Islands. The masters of vessels at all times retain final responsibility for the choice of shipping route.

Interim warning from the Dutch Safety Board
The risk of contact with the seabed on the southern shipping route gave grounds on 31 October 2019 for the Dutch Safety Board to issue an interim warning to the Dutch Ministry of Infrastructure and Water Management to announce this risk on the southern shipping route (see Appendix C for this warning). Immediately following the issuing of the warning, the Dutch Minister of Infrastructure and Water Management called upon the Netherlands Coastguard to announce the warning in the form of a note on the electronic sea charts and to broadcast to shipping the specific wind and wave conditions and tide situation.

In consultation with the Directorate General for Aviation and Maritime Affairs (DGLM), the Netherlands Coastguard identified the vessels for which the warning would apply. Because the warning contained no precise instructions about the type of vessels, the Coastguard decided to impose a safety margin with regard to which ships should be warned. Since 1 November 2019, the Coastguard has been broadcasting a daily navigation report to shipping in which shipping is informed about the warnings.

Navigation report Coastguard[125]:
ZCZC PA60
Netherlands Coastguard
Navigational warning Nr. 60 061050 UTC NOV
TSS Terschelling - German Bight
ships with a length above 300 mtrs and a beam above 40 mtrs
navigating during seas with a wave height above 5 mtrs and
heavy weather conditions are at risk of grounding.
Alternative routeing via TSS East Friesland
strongly recommended
NNNN

Read more on the next page

125 Source: Coastguard website , https://kustwacht.nl/nl/node/575 (consulted on 2-3-2020)

If a (significant) wave height of 5 metres or more is actually measured[126], the Coastguard actively warns ships (by VHF maritime radio channel) with a length in excess of 300 metres and beam in excess of 40 metres, wishing to take the northern or southern shipping route sailing in an easterly direction) from the Dutch side.

In the period between 01-11-2019 and 13-02-2020, the Coastguard Centre has actively called 16 vessels.[127] All called vessels followed the 'urgent' recommendation, with the exception of a single vessel. This vessel followed the southern shipping route towards Germany (on 09-02-2020 10.57 UTC) because it considered this a better option given the southwesterly wind on the day in question.

The warnings to ships by the Coastguard are based on the limited information in the interim warning from the Dutch Safety Board. On this basis, large container ships are warned irrespective of wave and wind direction, while the identified risk of seabed contact on the southern shipping route is related to beam waves, in this case when the waves come from north-northwesterly direction.

The way in which the Netherlands Coastguard today actively sends warnings to large container ships sailing west to east in high wave conditions is not yet reciprocated for ships using the northern or southern shipping route to sail from east to west. These vessels make a choice for the northern or southern shipping route when they are in German waters and receive no advice.[128] It is common practice for ships at sea that are sailing along the coastline of several different countries to make contact with several different coastguard services. The coastguard in each country is organized in an individual way, based on the tasks allocated to the coastguard in that country.

Sub-conclusion
The Netherlands Coastguard has no formal role in the routeing and monitoring of container ships. The Coastguard can advise vessels sailing in an easterly direction on the choice of the southern or northern shipping route. Since the interim warning by the Dutch Safety Board, this advisory role is actively implemented. Vessels sailing along the northern and southern shipping routes in a westerly direction from German waters do not at present receive any warning. The warnings are intended to increase alertness among large container ships to the route-specific risk on contact with the seabed on the southern shipping route.

126 Measured at the L9 platform on the North Sea, located approximately 34 kilometres north of Vlieland.
127 Source: Coastguard (operational Vision system).
128 Also not from the German authorities; they are awaiting the final results of the current investigations.

5.4 Approach by the shipping sector

5.4.1 Options available to ships

The risk of loss of containers is influenced by the preparation for the journey and by choices made by the masters in poor weather conditions and difficult wave conditions on the shipping routes above the Wadden Islands.

Voyage preparation

The deployment and routeing of container ships are planned in detail by the shipping company. In many cases, fixed sailing timetables are used that are adjusted depending on delays that occur during a voyage. The relevant commercial and operational interests are constantly balanced. It can for example be necessary to adjust loading plans in ports, to raise or reduce sailing speed or to replan a vessel's voyage as a consequence of a delay. Arrival and departure times in port are often precisely determined, for example due to availability of a mooring at the dock or because of the tidal situation, which means that large vessels are not always able to enter or leave a particular port. The time spent by a ship in port also depends on the number of containers to be loaded and unloaded. This requires precise planning. A key cost factor is fuel consumption by the vessel, mainly influenced by the length of a route and the sailing speed.

A plan is drawn up by the ship's crew, prior to each voyage. This plan is based on the schedule prepared by the operator, which takes account of availability in the ports. Prior to departure from the port, the crew draws up a detailed timetable and sets the waypoints (intersections on the route), whereby account must be taken of recent and local weather forecasts, the draught of the ship, the water depth, the tidal situation, obstacles and other possible hazards. Since some vessels often sail the same routes, plans from previous voyages are consulted or reused. An assessment of the weather conditions must be an integral part of the plan. For voyage planning on the North Sea, in addition to availability of ports, in particular wind, visibility, tidal conditions, wave height, wave period, wave direction and navigation hazards play a role.

Choices during the voyage

During the voyage, the plan must be monitored and where necessary revised. The voyage preparation is therefore not a static document but must be adjusted as necessary according to the circumstances. A shipping company often has an operational department that is able to assist the master from shore in preparing routeing and navigation in relation to weather conditions. On board the ship, weather information is among other things available in the form of NAVTEX reports, short reports issued by the relevant coastal states (see also Section 5.3.2). Information on wave periods and wave directions are not included in the transmitted NAVTEX-messages.

It is the responsibility of the crew to be aware of any safety warnings that apply to the route to be taken by the vessel. In addition, operators make use of commercial meteorological service providers that offer more detailed weather information and that may also assist in route changes that avoid unfavourable weather.[129]

If a vessel finds itself in severe weather despite careful preparation, or if sailing conditions are different from what was expected based on the forecasts, the master and his crew can and must take measures, such as adjusting the course to be followed by the vessel so that the vessel approaches the waves at a favourable angle, adjusting speed, selecting a different route or finding a safe haven and waiting for better weather.

'Good seamanship' on the part of the master and crew must ensure that they anticipate circumstances in good time. The underlying principle is that the master and crew have sufficient knowledge and experience, but also information, to make the right choices when sailing in poor weather conditions so as to sufficiently reduce the risk of harm. This means in addition to familiarity with the characteristics of a ship and loading, also insight in how the ship will react to specific environmental conditions. If necessary, the master is permitted to deviate from the applicable shipping rules. The master must be able to take and implement any decisions he considers necessary for the safe navigation of the ship and the protection of the marine environment.

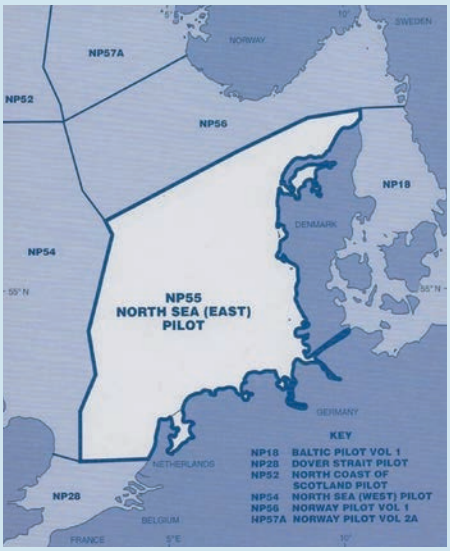
A side note is that accelerations on container ships are not being measured and the crew on board container ships have no accurate picture of the forces and accelerations acting on the containers on deck during these ship motions.[130] Previous research[131] has shown that for the master and crew it may be difficult to assess when the forces or accelerations on the cargo actually become risky and when the time has come to anticipate by for example changing speed or course.

Risks of the shipping routes above the Wadden Islands

The voyage preparation and available options outlined above during the voyage mean that the master and crew must be aware of the risks on the shipping routes. For vessels above the Wadden Islands, there are two standard shipping routes available: the northern route and the southern route (see also Section 3.2.2). In the IMO standards, no specific conditions are imposed on the routeing of container ships with regard to these two routes. Container ships often opt for the southern route because of the shorter distance and therefore shorter journey time, lower fuel consumption and strict port planning. At the same time, the section to the north of the Wadden Islands is relatively short in relation to the entire voyage of a container ship carrying containers on an international passage (for example from China to Europe).

129 Commercial meteorological services obtain their information from a variety of sources, including the HMC (Hydro Meteo Centre) that provides up-to-date hydrological information (current, sea level and waves).
130 There are systems to measure ship motions and accelerations, but these are not mandatory.
131 MARIN, *Lashing@sea (Executive summary)*, September 2009.

A standard element of the voyage preparation is consultation of the sailing directions for the locations where vessels are due to sail. The box below contains the warnings in force for the southern and northern shipping routes above the Wadden Islands. On this basis, masters should be aware that on the southern shipping route in poor weather with heavy wave conditions they can be confronted with shallow water.



Specific text with regard to the North Sea above the Wadden Islands from the Admiralty Sailing Directions: North Sea East Pilot (NP55)[132]

Chapter 1:

- Rough seas 2 to 5 metres normal between October and March. Storm force winds between SSW and NNW 2.5 to 9 metre waves. 10 Bft winds can result in confused rough sea with waves of between 9 and 14 metres.
- Persistent N to NW storms cause rough to very high seas along the coast between Den Helder and the Elbe, with large breakers.

Chapter 4:

- 4.5) average depth TSS is 30 m but above Terschelling and Borkum shallows of 20 m
- 4.7) Northerly storms can cause very rough, short and steep seas in the coastal route from Texel and the German Bight. In these conditions, the alternative Off Friesland TSS can offer more favourable conditions ('better seas') and more manoeuvring space.

From an operational point of view, the northern route offers more manoeuvring space than the southern route in severe weather and high waves, given the distance from the coastline. In southwesterly and even more in southeasterly winds, the southern shipping route can offer safer sailing conditions because of the protective effect of the land on this shipping route close to the coastline. Explicit knowledge is essential in making the correct choice. Even though the route north of the Wadden Islands is known for the potential risky sailing conditions during storms, the route-specific risks of loss of containers on the southern and northern shipping routes as identified in the basin tests (see Section 4.3) are at present unrecognized in the container shipping world.[133]

132 British Admiralty, *Admiralty Sailing Directions: North Sea East Pilot (NP55)*. These publications, also known as pilots, offer information for the safe navigation of ships on the sea and in seaports.

133 It should be noted that at present the Dutch Coastguard advises large container ships to take the northern rather than the southern route above the Wadden Islands in case of high waves, see Section 5.3.2.

In the current rules with regard to the use of shipping routes above the Wadden Islands and the choices made by ships for a particular shipping route, no explicit account is taken of the risks of pollution of the Wadden area as a consequence of loss of containers. Some masters of large container ships may opt for the northern route in the event of poor weather because the southern route is notorious for the possible presence of more extreme waves. Other masters can and will continue to opt for the southern route based on their own experiences and risk assessment. Managing the risks of loss of containers on the shipping routes above the Wadden Islands depends to a large extent on the situational decision-making on the ship if risks actually arise in the event of poor weather. The master and his crew will have to respond and make choices based on good seamanship, such as changing course or shipping route. This is a vulnerable situation, given that no context has been established (lack of knowledge, no specific policy by the Dutch government or IMO) whereby the master and his crew are alert to the risks of loss of containers on these shipping routes close to a unique and vulnerable nature area. The warnings from the Coastguard to large container ships at specific wave heights are intended to increase the level of alertness on the risk of contact with the seabed.

Sub-conclusion
For container ships, no specific guidelines or requirements are imposed on the choice of northern or southern shipping route above the Wadden Islands. Managing the risks of loss of containers on the shipping routes above the Wadden Islands currently depends on the situational decision-making on the ship if risks actually arise. This is a vulnerable situation, given that the crew has no insight in the forces and accelerations acting on containers. Also information on wave periods and wave direction is lacking in NAVTEX-messages, which is essential information for the purpose of assessing risks as a result of roll motion. The Dutch government or IMO routeing measures do not point explicitly to the risks of container loss on these shipping routes in the vicinity of a vulnerable nature area.

5.4.2 Vision on the loss of containers in relation to nature areas

Container ships at sea lose containers with some regularity. For the container industry this is a given that is inherent in the transport of containers by sea. However, the loss of containers from container ships does imply pollution of the sea and in nature areas this leads to damage to the natural values. This idea is not yet common knowledge within the shipping sector or the container industry. Loss of containers is not seen as an incident that must always be avoided in order to protect nature values, as is the case for the transport of environmentally harmful substances by sea (for example oil, toxic gases and radioactive material).[134] In addition, within the shipping sector, no link has so far been established on the shipping routes above the Wadden Islands between the undesirability of damaging nature values in the Wadden area and the polluting consequences of the loss of containers.

134 See for example the International Maritime Dangerous Goods Code from the International Maritime Organization.

In the shipping sector, the loss of containers, certainly if relating to a limited number, is dealt with as an 'insurance issue' and not as an avoidable case of environmental pollution. Moreover, the loss of containers, as long as the number of containers lost is limited, will not result in an accident investigation. When 58 containers fell overboard from the ship Mondriaan in 2006, for example, this was not considered a serious marine casualty according to IMO criteria, and no investigation was carried out within the framework of IMO regulations on marine casualty investigation.

Sub-conclusion
In managing the risks on the shipping routes above the Wadden Islands, the shipping sector has not yet established any link between the undesirability of damage to nature values (in particular the Wadden area) and the polluting consequences of the loss of containers.

5.4.3 Attention for the risks of loss of containers in the development of larger container ships

While container ships have become ever larger and continue to grow, the way in which containers are secured has not fundamentally altered. Ships have become wider and therefore more stable. This increased stability has an effect on the behaviour of the ship. This investigation has shown that wave conditions on the shipping routes above the Wadden Islands can lead to extreme ship motions on large, wide (stable) container ships resulting in large accelerations. As a consequence, the margins between design criteria for lashing systems and the forces or accelerations on large container ships during ship motions have been reduced. In addition, the increasing number of containers on deck of large container ships in itself is already an increase of the risk, as more and more containers could fall overboard.

The development of container transport at sea is focused on operational efficiency. Economies of scale, however, are certainly reasons for considering the risks.[135] This applies all the more since the potential consequences are also ever greater as more and more containers are transported in ever higher stacks, which can fall overboard. At the same time, the awareness of the loss of containers from large container ships has become less.

The MSC ZOE case revealed that the master and crew were not prepared for the extreme effects that occurred on the ship on the southern route during the severe weather in the night of 1 to 2 January 2019. They did not notice that at various moments they had lost containers.[136] Under certain conditions, it is therefore possible for a large container ship to lose containers without the master or crew being aware of the fact.

135 Source: Council for Spatial, Environmental and Nature Research (RMNO), *New risks in view*, 2004.
136 Source: International investigation report (PMA, BSU, DSB).

Sub-conclusion
The development of ever larger container ships is leading to a greater risk of loss of containers both in terms of probability and scale of the effects of such an incident. The economies of scale towards ever larger container ships have not resulted in a revised inventory or evaluation of the risks of loss of containers from these ships.

6 CONCLUSION

Following the accident with the MSC ZOE, the Dutch Safety Board investigated the route-specific risks of loss of containers for large container ships on the shipping routes to the north of the Wadden Islands.

Route-specific risks of loss of containers on the southern shipping route
In the event of a northwesterly stormy wind, large container ships on the southern shipping route are confronted with specific risks of the loss of containers. These risks are the consequence of high beam waves, the limited water depth on the shipping route and the high stability of large, wide container ships.

In northwesterly storm conditions, waves have time and space to build in height and peak period until they reach the Dutch and German Wadden coastline. A northwesterly stormy wind such as the one during the accident with the MSC ZOE on average occurs between one and several times a year in the area, and is therefore neither extreme nor extraordinary. Subsequently, the limited depth of the North Sea above the Wadden Islands impacts on the waves and hence the ship behaviour of ships on the southern shipping route. Under these circumstances, tests using a model of a large container ship in a test basin revealed that if such large waves approach the ship athwartships, large, wide container ships can make violent ship movements.

During the tests, four hydrodynamic phenomena were measured and observed, which can individually and in combination introduce a risk of loss of containers:

- extreme ship motions resulting in large accelerations and forces on lashing equipment and containers;
- contact with the seabed due to a combination of the roll motion of the vessel and large vertical movements in the waves causing accelerations, vibrations and deformations of the ship's hull, that work through to the containers on deck;
- green water, whereby solid water from waves runs upwards against the ship side causing impulsive loads on containers above the gangway and possibly forces on the side of container stacks;
- impulsive wave impacts (slamming) against the vessel, thereby generating vibrations that move throughout the entire vessel and cargo.

A large and wide container ship sailing along this route in the given circumstances will encounter these phenomena and combinations of these phenomena. As a consequence, large forces are exercised on the vessel, the containers and the lashing systems. The interplay of forces is complex, partly as a result of the reaction forces that occur and according to which - depending on its rigidity - the vessel bends and twists.

The potential occurrence of extreme ship motions relates to the fact that container ships have gradually become larger and wider, and sail at high stability. The natural roll period of a large and wide container ship with a high stability more closely approximates the wave period that can prevail in the North Sea than the oscillation period of a ship with lower stability. In beam wave conditions with a wave period close to the ships' natural roll period, the ship reacts strong to the waves as a result of resonance, resulting in violent roll motions. Even though this may sound counterintuitive, this means that large and wide container ships with a high stability have greater roll motions in a beam wave scenario than less stable ships. In addition, a high stability also leads to the effect that the ship wants to return fast to its steady state. This leads to high accelerations and hence large forces on containers and the lashing material on board. The occurrence of contact with the seabed, green water and slamming can further amplify these accelerations and/or forces.

Comparison of route-specific risks between the southern and northern shipping routes
Both on the southern and the northern shipping routes there are route-specific risks in respect of the loss of containers. Whereas there is an obvious environmentally protecting effect of sailing the northern route for tankers, in terms of oil recovery, the same does not apply to loss of containers. For both the northern and the southern shipping routes, given the presence of a vulnerable nature area, loss of containers can result in pollution of the Wadden Sea and the Wadden Islands.

An investigation into meteorological and maritime conditions at the time of the accident with the MSC ZOE revealed that the wave conditions on the northern shipping route were comparable with those on the southern route. The northern shipping route is deeper than the southern, but in these meteorological conditions, waves typical for shallow water, namely steep, high waves that occasionally break, occur on both shipping routes. The forces on the ship, the cargo and/or lashing systems as a result of extreme ship motions in stormy wind and waves from a north-northwesterly direction occur both on the southern and the northern shipping routes. Wave impacts (slamming) and green water can also occur on both shipping routes but the basin tests suggest that these phenomena occur more often on the southern shipping route. On the northern shipping route, due to the additional metres of depth as compared with the southern route, the risk of contact with the seabed is negligibly small. Moreover, vessels on the northern route are more easily able to select a favourable course for the vessel in northwesterly storm conditions since manoeuvring space on this route is greater than on the southern route.

In a northwesterly storm as encountered by the MSC ZOE, in both shipping routes phenomena occur that may lead to container loss, although the chance is higher on the southern shipping route. The northerly shipping route is from the perspective of container loss not a safe route, at most a less risky route during northwesterly storm conditions. In different conditions the southern route may be less risky.

New insights

This investigation has revealed risks of loss of containers for large, wide container ships on the shipping routes to the north of the Wadden Islands. At the same time, the risks described in the report relate only to a single scenario, namely the circumstances in which the accident with the MSC ZOE occurred and this vessel lost containers. Hydrodynamic phenomena and ship behaviour in shallow shipping routes such as those above the Wadden Islands have only been subjected to limited scientific study. Further research is necessary in order to map out the risks on both shipping routes in other conditions and/or for other ship sizes and types.

Risk management by ships on the shipping routes

To date, in managing the risks on the shipping routes above the Wadden Islands, the shipping industry has not established links between the characteristics of large container ships, the specific circumstances to the north of the Wadden Islands, the consequences of pollution from the loss of containers and the undesirability of damage to the natural value of the Wadden area.

For container ships, there are no specific guidelines, restrictions or requirements for making use of the northern or southern shipping route above the Wadden Islands. The southern route is shorter and as a result economic factors such as time and fuel consumption play a specific role in the choice of route. The management of the risk of loss of containers on the shipping routes above the Wadden Islands in poor weather conditions depends on the situational decision-making on the ship if risks actually occur. The master and his crew have to respond and make choices based on good seamanship, such as changing course or shipping route. This is a vulnerable situation, as the crew currently does not have any insight in the forces and accelerations acting on containers. NAXTEX messages are also lacking information on for these shipping routes important parameters such as wave period, wave direction, which is essential information for the purpose of assessment of the risks as a result of roll. The Dutch government or IMO routing measures do not explicitly make the master and crew aware of the risks of container loss on these shipping routes close to a vulnerable nature area. An exception to this is that since November 1, 2019, the Netherlands Coastguard warns ships on the southern shipping route for the risk on contact with the seabed.

Protection of vulnerable nature areas in an international context

The Wadden Sea is a unique, internationally recognized and vulnerable nature area. From this perspective, the loss of containers both on the southern and the northern shipping route is undesirable. The two routes are internationally designated shipping routes. The Netherlands has no independent authority to impose binding regulations in respect of use of the southern or northern shipping route or to adjust the location of the routes. Only resolutions by the IMO can result in any obligations or regulations for vessels on these shipping routes. The recognition of the Wadden sea by IMO as Particularly Sensitive Sea Area (PSSA) creates opportunities for the member states involved, the Netherlands, Germany and Denmark, to propose associated (protective) measures for shipping. At present, no specific measures have been taken aimed at protecting the Wadden Sea against pollution as a consequence of containers lost overboard.

However, given the internationally recognized status of this area (UNESCO World Heritage), the affected coastal states are obliged to prevent damage to the natural value. This means that the coastal states of the Wadden Sea should share the findings from (the international investigation and) this investigation with IMO and develop a proposal for appropriate measures.

Perspective for actions Dutch government
The Netherlands Coastguard has no formal role in setting routes that must be taken by container ships north of the Wadden Islands. On the other hand, the Coastguard can advise vessels sailing in an easterly direction on the choice of southern or northern shipping route. Since the interim warning by the Dutch Safety Board, this advisory role is actively implemented by pointing to the risk of seabed contact during high waves on the southern shipping route. The warnings from the Coastguard are intended to contribute to the alertness among large container ships to one of the route-specific risks on the southern shipping route. Vessels sailing along the northern and southern shipping routes in a westerly direction from German waters do not at present receive any warning; the German authorities are awaiting the final results of the ongoing investigations.

In the framework of North Sea policy, the Dutch government has carried out no specific risk analyses for the shipping routes north of the Dutch Wadden Islands. The possible effects of loss of containers for the Wadden Sea have also not been further investigated. Concerns previously expressed by the Wadden municipalities among others have not resulted in a focused approach to managing the risks of loss of containers on the shipping routes above the Wadden Islands. Following the accident of the MSC ZOE it is evident that a more active approach of the Dutch government is requested regarding the risk management of container loss on the shipping routes north of the Wadden Islands.

7 RECOMMENDATIONS

Minimizing the risks of container loss on the two shipping routes north of the Wadden Islands requires an integrated approach by the parties involved: the container shipping sector, the IMO and the Dutch government. In the international investigation into the course of events of the accident with the MSC ZOE and this investigation into the risks on the shipping routes north of the Wadden Islands, recommendations are made to prevent container loss near the Wadden area. The recommendations of both studies must be considered in conjunction.

Recommendations from the international investigation
The international report[137] makes recommendations to the Panamanian, German and Dutch governments to review the technical requirements imposed on container ships in an IMO context. More specifically, this concerns:

1. the design requirements for lashing systems and containers,
2. the requirements for loading and stability of container ships,
3. obligations with regard to instruments providing insight into roll motions and accelerations, and
4. the technical possibilities for detecting container loss.

Recommendations are also made to the German and Dutch governments to investigate, in cooperation with Denmark, the need for additional measures on these shipping routes or adjustments to the routes and to submit a proposal to the IMO on the basis thereof. In addition, the shipping company of the MSC ZOE is instructed to explicitly draw the attention of crews sailing in this area to the route-specific risks, and to equip and load their ships in such a way that the loss of containers is prevented. Finally, through the World Shipping Council and the International Chamber of Shipping, the international maritime sector is called upon to actively communicate the safety lessons from the investigation and to take the lead in drafting safety requirements and in the innovation of ship design and container transport in order to minimize the risk of container loss, also in conditions such as near the Wadden area.

The recommendations that emerge from the investigation into the shipping routes are aimed specifically at Dutch parties and are listed below.

137 The recommendations are presented in the international investigation report. The full report is available on the website of the DSB and BSU.

Initiative for an international approach to prevent container loss
In the area north of the Wadden area, there are at present no restrictions for international container shipping with regard to the two internationally specified shipping routes: the southern and the northern shipping route. Additional routing measures for (a specific category of) container ships can only be adopted by IMO, on the initiative of one or more member states.

To the Minister of Infrastructure and Water Management

1. In collaboration with the Wadden states Germany and Denmark, take the initiative for a specific proposal to the IMO with measures for international container shipping to prevent the loss of containers on both shipping routes north of the Wadden Islands. This can for example take the form of a review of technical standards, the introduction of restrictions, recommended routes, precautionary areas, traffic control and/or information provision. Make particular use of the status of the Wadden Sea as a Particularly Sensitive Sea Area (PSSA) and the possibilities within the IMO standards for taking measures to protect a PSSA. Make use of the outcomes of this investigation and other investigations into route-specific risks (also see recommendation 5).

Short-term approach
Decision-making by the IMO is a lengthy process. Therefore, out of precaution to protect the Wadden Sea, the Netherlands itself must take immediate measures parallel to that process within the existing legal framework to minimize the risks of loss of containers. Above all, the container shipping sector itself has a social responsibility to prevent the loss of containers, certainly in the vicinity of the Wadden Islands, but also elsewhere.

To the Minister of Infrastructure and Water Management

2. Inform shipping companies and masters of large container ships in a structural manner about the four hydrodynamic phenomena that emerged from this investigation, which can occur in the event of high beam seas on both shipping routes north of the Wadden Islands. In providing this information, also make it clear that these phenomena and combinations of these phenomena can generate forces on large, wide and stable container ships which can result in the loss of containers. If further route-specific risks emerge from other investigations, shipping companies and masters should also be immediately informed of those outcomes.

3. Grant the Netherlands Coastguard the tasks, authorities and resources it needs to monitor container ships so that ships can sail safely past the Wadden Islands in all wave and weather conditions. With this in mind, investigate the possibilities for traffic control of container ships, such as establishing a VTS area, actively disseminating warnings to shipping about prevailing weather and wave conditions in the Dutch part of the North Sea and innovating the way such information is provided. Involve the Netherlands Coastguard and Rijkswaterstaat in defining this role and responsibility. Also seek cooperation and/or harmonization with Germany on the intended tasks.

To Maritime by Holland and the Royal Association of Netherlands Ship Owners (KVNR)

4. Actively communicate the lessons learned from this investigation and the international investigation into the course of events and in your national and international networks, take up a pioneering role in reaching agreement on and disseminating the principles and industry standards that promote the safety of container transport close to the Wadden area.

Insight into route-specific risks north of the Wadden Islands

The risks revealed by this investigation relate to a scenario for large, wide and stable container ships. Further investigation is necessary to also chart out these risks in other conditions and for other types of (container) ships besides Ultra Large Container Ships like the MSC ZOE. The first steps for this follow-up investigation have already been taken by the Ministry of Infrastructure and Water Management. These must be followed up further.

To the Minister of Infrastructure and Water Management

5. Investigate the extent to which the route-specific risks of loss of containers on the shipping routes near the Wadden Islands as referred to in this report can occur on different types of container ships and in different meteorological and maritime conditions. In this investigation, include all incidents and other signals which could suggest other as yet unrecognized risks of loss of containers on the specific shipping routes.

6. Make a periodic risk analysis of the route-specific risks that can lead to container loss on the shipping routes close to the Wadden Islands, with a view to the safety of shipping and protection of the North Sea and the Wadden area, and include this analysis as a fixed element of North Sea policy. Under all circumstances, make use of a system of monitoring and analysis of shipping incidents and near misses on these shipping routes. Also include developments in shipping such as economies of scale, changes in the picture of shipping traffic and (future) changes to infrastructure and area activities on the North Sea.

APPENDIX A

JUSTIFICATION OF THE INVESTIGATION

This appendix describes the general investigation process, the most important quality assurance measures and the project organization.

A.1 The Dutch Safety Board

The Dutch Safety Board investigates both specific occurrences and broader safety issues and unsafe situations that occur gradually. The aim of these investigations is not only to identify direct causes but also to examine possible structural safety shortcomings and administrative processes that can influence safety. The aim of all investigations is to learn from occurrences and to issue recommendations in order to enhance safety. The investigations of the Board do not consider questions of blame or liability.

A.2 Background to the investigation

On the night of 1 to 2 January 2019, the Panamanian container ship MSC ZOE lost 342 containers north of the Wadden area. The beaches of the Wadden Islands and the coastline of Friesland and Groningen were strewn with the contents of the containers. The German Wadden area was also affected by the consequences of the accident. The course of events surrounding the accident with the MSC ZOE was investigated by an international investigation team consisting of investigation bodies from Panama, Germany and the Netherlands. Given the impact on the environment, the accident with the MSC ZOE was classified as a 'very serious' marine casualty. In accordance with IMO regulations for marine casualty investigation, the Panama Maritime Authority (PMA) was placed in charge. Because of the location and the impact of the accident, the Netherlands and Germany were involved in the investigation as substantially interested states. The PMA, the German Bundesstelle für Seeunfalluntersuchung (BSU) and the Dutch Safety Board jointly investigated the course of events leading up to this accident. The results of this investigation appear in the international report into the course of events.

There was no Dutch involvement in the occurrence with the MSC ZOE besides the fact that at the time when the containers fell overboard, the MSC ZOE was located in the Dutch sector of the North Sea. Together with Germany, the Netherlands had to deal with the consequences of this accident, namely the pollution of the Wadden area. The question is what the Netherlands can do to prevent accidents of this kind occurring, and if they do take place, to limit the harmful consequences as far as possible. With that in mind, the Dutch Safety Board carried out an additional investigation focusing on the

shipping routes above the Dutch Wadden Islands. The results of that investigation are included in this report.

A.3 Purpose, investigation questions and demarcation

The aim of the investigation by the Dutch Safety Board is to contribute to improved risk management for container transport on the shipping routes on the North Sea north of the Wadden area. This requires consideration of the route-specific risks of container loss from large container ships. The focus has been placed on the circumstances that could potentially lead to unsafe situations involving Ultra Large Container Ships on the shipping routes above the Wadden Islands and how the various stakeholders in international container transport can best take account of the route-specific risks on the southern shipping route. For the investigation, the circumstances at the time of the accident with the MSC ZOE were taken as the starting point.

The following key questions form the central focus of the investigation by the Dutch Safety Board:

What are the route-specific risks of loss of containers for large container ships such as the MSC ZOE in the southern shipping route north of the Wadden Islands?

To what extent are these route-specific risks also applicable to the northern shipping route?

How are the route-specific risks of the shipping routes above the Wadden Islands taken into account in respect of maritime container transport?

Demarcation
The direct background to this investigation was the accident with the MSC ZOE. The course of events of the accident with the MSC ZOE was the subject of the international investigation led by the PMA.

This investigation by the Dutch Safety Board focused on route-specific risks of the loss of containers on the shipping routes in the North Sea north of the Wadden Islands for an Ultra Large Container Ship like the MSC ZOE. Because of the focus on the shipping routes, the investigation did not consider the technical design criteria and certification of container ships, containers and lashing equipment. Because of the focus on Ultra Large Container Ships like the MSC ZOE, this investigation did provide valuable but not precise insight into the risks of loss of containers by other types of (container) ships. Ship motions also engender risks to the crew, but this subject was beyond the focus of this investigation, with its emphasis on the risk of loss of containers. Moreover, the investigation did not focus on the lashing of containers and the lashing equipment.

The following subjects relating to the effects of loss of containers were also beyond the focus of the investigation by the Dutch Safety Board:

- Implementation of incident management and crisis management immediately following the accident. The Institute for Safety carried out an investigation into these aspects. The Dutch Safety Board studied the outcomes of this investigation in order to establish a clear picture of the seriousness of the consequences of the accident.
- Long and short-term effects of plastic pollution in marine and coastal areas around the Wadden Islands as a consequence of the accident with the MSC ZOE. The Dutch Safety Board did make use of other investigations into this issue. The Board also consulted experts in the field of marine ecology and (micro)plastic pollution.

An overview of the other current investigations is given in Chapter 1.

A.4 Investigation approach

Together with the PMA and BSU, on 6 January 2019, the Dutch Safety Board went on board the MSC ZOE in Bremerhaven and collected initial data on the ship. This included photographic material of the situation on the ship, information from the Voyage Data Recorder (VDR) and initial statements from a number of crew members.

On 10 January, the Dutch Safety Board communicated its intention to launch an investigation into the shipping routes in addition to the investigation into the accident led by the PMA.

Technical investigation
In order to map out the route-specific risks, the first requirement was an analysis of the route and environment-specific variables for the area north of the Wadden Islands. It was also necessary to investigate the effect of environmental conditions on large container ships such as the MSC ZOE. The Dutch Safety Board launched a technical investigation into both aspects.

The technical investigation was based on the following questions:

1. What were the prevailing environmental conditions at the time of the accident (1 January 2019) in the North Sea north of the Wadden area, both on the shipping route selected by the MSC ZOE and (in the vicinity of) the more northern deep-water route? To what extent are these conditions unique for the situation on the North Sea north of the Wadden area?
2. To what extent do environmental conditions and specific ship characteristics of container ships contribute to the risk of containers loss?

To answer these questions, the Dutch Safety Board worked closely alongside the scientific research institutes Deltares and MARIN. This technical investigation was carried out in the period between July and November 2019, and in addition to model calculations also involved basin tests with a ship model. The reports of the technical investigation are

given in Appendix F and G. Part of the investigation was financed by both parties, from their own funds. A number of expert sessions were organized with the investigation team and MARIN and Deltares, whereby the investigation results and the interpretation and further processing and analysis of those results by the Dutch Safety Board were discussed. The technical reports were also submitted to the supervisory committee and the PMA, BSU and University of Technology in Hamburg, in the framework of the international investigation and report into the course of events..

Investigation into social sciences, administrative and ecological aspects
In addition to the technical investigation, the investigation team also investigated the routeing of shipping on the North Sea and prospects for further action, mapped out the statutory frameworks for routeing (both national legislation and international standards), undertook policy analyses, and studied developments and incidents in container transport at sea (both national and international) and investigations into the ecological harm caused by plastic pollution.

As part of these investigations, the team studied a large number of documents, making use of both public sources (including legislation and policy documents) and information requested from the various parties relevant for answering the investigation questions. During the course of the investigation, the Dutch Safety Board also held around 26 semi-structured interviews. These semi-structured interviews were held on the basis of pre-prepared questions, whereby the interviewers were also open to subjects raised by the interviewees. Interviews were held among others with:

- Ministry of Infrastructure and Water Management
  - IDON
  - Rijkswaterstaat
  - DGLM
  - Royal Dutch Meteorological Institute
- Netherlands Coastguard
- MSC and crew members of the MSC ZOE
- A number of masters of large container ships
- A ship owner
- Wadden Area Control Board
- Wadden Academy
- University of Wageningen
- Deltares (ecotoxicology, water quality)

The Dutch Safety Board also organized a number of meetings. During a round table meeting with various parties from the Dutch container industry, the possibilities and/or measures recognized by these parties for minimizing the loss of cargo overboard were discussed. Furthermore, the Dutch Safety Board made a working visit to the port of Rotterdam (including an ultra large container ship) and to Schiermonnikoog, whereby the beach and dune area were examined. Subsequently, a meeting took place with the Municipality of Schiermonnikoog, area managers for the Wadden area, the Wadden Association and representatives of island residents. Finally, an administrative round table was organized with the Wadden provinces, island and coastal municipalities, the security region, water boards and Rijkswaterstaat.

Analysis and judgement
The Dutch Safety Board assessed its findings according to a reference framework (see Chapter 2). On the one hand, the reference framework consists of a legal framework made up of national and international standards, legislation, regulations and guidelines, and on the other hand a framework drawn up by the Board itself, based among other things on knowledge generated by this investigation, and by previous investigations and scientific insights. Using this reference framework, the Dutch Safety Board has identified what can be expected from the various stakeholders in managing safety risks in a specific field. By identifying shortcomings and non-conformities in relation to the reference framework, a clear picture has emerged of those aspects in respect of which safety can be enhanced.

A.5 Quality assurance

To guarantee the quality of the investigation, the following steps were taken:

- The investigation team held a series of analysis sessions to discuss and examine the findings from various angles of approach.
- To manage the risk of bias (such as hindsight bias and tunnel vision), the investigation team also organized sessions with colleagues who were not involved in the investigation, and peer assessment was carried out by colleagues from the Research & Development and Administrative Affairs and Advice & Communication departments. These sessions were organized at various phases of the investigation and were aimed at critically challenging and disputing hypotheses, assumptions and underlying theoretical frameworks, and any blind spots.
- The Dutch Safety Board also discussed the investigation with a supervisory committee. For the specific character of this committee, see the supervisory committee heading.
- The results of the technical investigation were also submitted to the PMA, BSU and University of Technology in Hamburg, to reinforce the scientific basis.
- In accordance with the Dutch Safety Board Act, a draft version of this report was submitted to the involved organizations and persons for consultation, with the request to check the report for errors, omissions and inaccuracies and to provide comments where applicable. Appendix B identifies those parties who were granted access to the draft version, and how their responses were included.
- A stakeholder analysis was carried out to systematically determine the interests of the various parties, how these could influence the course of the investigation and how the investigating organization can best deal with these forces.

A.6 Interim warning

On 31 October 2019, the Dutch Safety Board issued an interim warning. It had emerged from the technical investigation that was still fully underway at that time that large, wide container ships in heavy sea conditions on the southern shipping route above the Wadden Islands ran the risk of bottom contact, and as a result forces on the vessel and the cargo. For this reason, the Board decided at that moment to issue an interim warning (see Appendix C). Immediately following the issuing of the warning, the Dutch Minister of Infrastructure and Water Management called upon the Dutch Coastguard to announce the warning in the form of a note on the (electronic) sea charts and, in the event of specific wind and wave conditions and tide situations, to broadcast a report to shipping. The Ministry also initiated additional investigation.

A.7 Supervisory committee

For the purposes of this investigation, the Dutch Safety Board appointed a supervisory committee, consisting of external experts able to offer expertise relevant to the investigation. These members were appointed to the supervisory committee in their personal capacity. The committee met on four occasions to exchange thoughts and ideas with the Board and the team members regarding the format and findings of the investigation, the conclusions and possible potential solutions. In addition, a number of written consultations took place. The committee fulfils an advisory role within the investigation. The Dutch Safety Board is responsible for the report and the recommendations.

Name	Position
M.B.A. van Asselt (chairman)	Board member, Dutch Safety Board
M. Vantorre	Emeritus professor University of Ghent
H. Ligteringen	Emeritus professor University of Technology Delft
E. Turnhout	Professor Wageningen University & Research
J.P.M. Verschelden	Managing Owner Threepoint
M.J.M. Borsboom, Vice Admiral (Rtd)	Chairman Board of Supervisory Directors Nederlands Loodswezen BV (NLBV)
H.L.J. Noy	Former extraordinary board member at the Dutch Safety Board and former CEO of Arcadis NV
P.J. Bindt	Extraordinary board member, Dutch Safety Board

A.8 Project organization

The project team consisted of the following persons:

Name	Position
A. Umar	Investigation manager
S.M. van Hijum	Project leader
L. van der Veen	Investigator
L.P. Sluijs	Investigator (from 20 January 2020)
E.V. de Vilder	Investigator (from 10 February 2020)
P.J.J.M. Verhallen	Investigator (until 20 January 2020)
M.C.B. van Helden	Investigator (external, until 1 November 2019)
R.D. de Wit	Secretary/Investigator
M.H. Verschoor	Research and development consultant (until 1 January 2020)
E.J. Willeboordse	Research and development consultant (from 1 January 2020)
N. Wierda	Project support
S. Lalmohamed	Project support

APPENDIX B

RESPONSES RECEIVED ON DRAFT REPORT

A draft version of this report, with the exception of the summary, consideration and recommendations, was submitted to the parties directly involved. These parties were requested to check the report for any factual inaccuracies and ambiguities. The draft report was submitted to the following parties:

- Ministry of Infrastructure and Water Management
- Netherlands Coastguard

The Board has taken note of the responses received. The responses and explanations are listed in a table which is available on our website www.safetyboard.nl.

INTERIM WARNING DUTCH SAFETY BOARD

ONDERZOEKSRAAD VOOR VEILIGHEID

Datum 31 oktober 2019
Contactpersoon
Doorkiesnummer
Uw kenmerk
Ons kenmerk 19.0009755
Project Overboord geslagen containers

Bladnummer 1 van 2
Bijlage(n)

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AANGETEKEND
Aan de minister van Infrastructuur en Waterstaat
Mevrouw drs. C. van Nieuwenhuizen
Rijnstraat 8
2515 XP DEN HAAG

Onderwerp **Tussentijdse waarschuwing n.a.v. onderzoek 'Overboord geslagen containers MSC Zoe'**

Geachte mevrouw Van Nieuwenhuizen,

Begin januari 2019 heeft het Panamese containerschip MSC Zoe containers verloren in de Noordzee in het verkeersscheidingsstelsel Terschelling-German Bight ten noorden van de Waddeneilanden. Panama doet als vlaggenstaat volgens de internationale standaarden onderzoek naar de oorzaak van het voorval en de situatie aan boord van het schip tijdens het voorval. Daarnaast is de Onderzoeksraad voor Veiligheid een eigen onderzoek gestart.

Als onderdeel van zijn onderzoek doet de Onderzoeksraad in samenwerking met de wetenschappelijke instituten MARIN en Deltares onderzoek naar scheepsbewegingen van zeer grote containerschepen in ondiep water bij wind- en golfcondities zoals deze zich voordeden ten tijde van het voorval met MSC Zoe. Dit technisch onderzoek, uitgevoerd in de periode van juli tot en met november, omvat naast modelberekeningen ook bassin-proeven met een scheepsmodel.

Gedurende het onderzoek zijn de contouren van een risico zichtbaar geworden dat de Raad ernstig genoeg acht om het onder de aandacht te brengen van de gebruikers van het verkeersscheidingsstelsel Terschelling-German Bight ten noorden van de Waddeneilanden.

Op deze route kunnen bepaalde wind- en golfcondities en getijde leiden tot grote domp- en slingerbewegingen van het schip die de veilige afstand tussen het schip en de zeebodem in gevaar brengen. Voor schepen met afmetingen vergelijkbaar met die van MSC Zoe ontstaat daarmee het risico van contact of bijna-contact met de zeebodem.

De Raad adviseert u daarom dit risico binnen uw organisatie bekend te stellen en te communiceren aan de gebruikers van het verkeersscheidingsstelsel Terschelling-German Bight.

Naar verwachting wordt het eindrapport naar aanleiding van de overboord geslagen containers in het voorjaar van 2020 gepubliceerd.

Hoogachtend,

ir. J.R.V.A. Dijsselbloem
voorzitter

CC: De heer J. van Zanten, directeur Kustwacht Nederland
De heer S. Hassing, voorzitter Koninklijke Vereniging van Nederlandse reders
Mr D. Aponte, president and CEO Mediterranean Shipping Company S.A.

Translation

Dear Ms Van Nieuwenhuizen,

At the start of 2019, the Panamanian flagged container vessel MSC ZOE lost containers overboard in the North Sea in the Terschelling-German Bight traffic separation scheme north of the Wadden Islands. Panama, the vessel's flag state, is investigating the cause of the event and the situation on board the vessel at the time of the event, in accordance with international standards. The Dutch Safety Board also launched its own investigation.

As part of its investigation, in collaboration with the scientific institutes MARIN and Deltares, the Dutch Safety Board investigates the ship motions of very large container vessels in shallow waters in wind and wave conditions similar to those occurring at the time of the event with the MSC ZOE. This technical investigation, undertaken during the period July through November, involved not only calculations but also basin tests with a ship model.

The investigation revealed the contours of a risk which the Safety Board considers sufficiently serious to bring to the attention of users of the Terschelling-German Bight traffic separation scheme north of the Wadden Islands.

Along this route, specific wind and wave conditions and tidal situations can lead to considerable heave and roll motions that threaten the vessel's under keel clearance. For vessels with dimensions comparable to those of the MSC ZOE, this may lead to a risk of contact or near-contact with the seabed.

The Dutch Safety Board therefore recommends you make this risk known within your organization, and you communicate this risk to users of the Terschelling-German Bight traffic separation scheme.

We expect to publish the final report on the loss of containers in the spring of 2020.

Yours sincerely,

J.R.V.A. Dijsselbloem
chairman

CC: Mr J. van Zanten, Director Netherlands Coastguard
Mr S. Hassing, Chairman of the Royal Association of Netherlands Shipowners
Mr D. Aponte, President and CEO Mediterranean Shipping Company S.A.

APPENDIX D

PRINCIPLES FOR SAFETY MANAGEMENT

Based on (inter)national legislation and regulations and a large number of widely accepted standards, the Dutch Safety Board has below defined six points for attention for safety management in an organization undertaking an activity that involves safety and/or environmental risks:

1. *Understanding risks as the starting point*
   All parties/organizations involved must identify those risks that need to be managed based on a risk inventory.

2. *Demonstrable safety strategy*
   This includes recording a realistic and practical safety policy and identifying the necessary management measures.

3. *Implementing and enforcing the safety strategy*
   It is up to the management to ensure that the identified risks are systematically managed, among other things by clearly and actively ensuring the central coordination[138] of activities aimed at increasing safety.

4. *Continuous improvement*
   The safety strategy must be continuously improved, based on 1. periodic risk analysis (at least to be undertaken in the event of any change to the underlying principles), inspections, audits, etc. (proactive approach) and 2. a system of monitoring and investigation of incidents and (near) accidents including expert analysis (reactive approach).

5. *Management control, involvement and communication*
   The management of the parties/organizations involved must provide the parameters within which employees can work safely and ensure that other (for example commercial) interests do not outweigh safety aspects. Internally, the management must ensure the presence of clear and realistic expectations in respect of safety ambitions, and externally it must communicate clearly on the general approach, the way in which that approach is tested, the procedures in the event of non-conformities, etc.

138 Central coordination in this case means coordination by the ship management ('from head office'). From the perspective of management, coordination on the ship is decentral.

6. *Safe learning environment*
   To ensure optimum management of safety risks within organizations and within the shipping industry as a whole, a safe learning environment is essential. Among other things this means that all stakeholders must effectively learn from incidents and unsafe situations. Of key relevance is that employees and others are willing to call one another to account in regard of unsafe behaviour and are encouraged to report incidents without fear of punishment for their actions, omissions, mistakes or decisions (except in the event of deliberate or gross negligence on the basis of unsafe intentions).

APPENDIX E

IMPACT OF LOST CARGO ON ORGANISMS

Effects of plastics in the sea
Depending on the nature and size of the material, large animals such as birds and sea mammals can become entangled in or suffocate on plastics. Such incidents make individual animals direct victims. Scientists have more serious suspicions about the role of microplastics,[139] which can be ingested by organisms and passed on down the food chain by predators. Accumulation of microplastics in the food chain may harm the vitality of species and groups of organisms, and as such represents a threat to the entire ecosystem. For this reason, the Wadden Academy has advised Rijkswaterstaat to initially focus the investigation into the consequences of pollution by the MSC ZOE on the effects of microplastics on the ecology of the Wadden area. In line with this recommendation, Rijkswaterstaat has launched a multiyear monitoring and research programme that is currently being implemented.

One of the fractured containers, also a dangerous goods container, held a huge quantity (22.5 tonnes) of polystyrene granules with a diameter of 0.5 mm. In addition, a large number of industrial pellets of High-Density-Polyethyleen (HDPE), discs with a diameter of 4-5 mm, have been found in the sea and washed ashore on the beaches. It is important to point out that larger plastic objects from the cargo, hundreds of tonnes of which are still present in the environment, will weather and eventually disintegrate into microplastics under the influence of sunlight, heat and oxygen.

Even before the MSC ZOE lost its cargo, there was evidence of plastic pollution in the Wadden area. The actual contribution to plastic pollution by the MSC ZOE and the net effect of this occurrence on the ecological vitality of the Wadden area will hopefully be revealed by the research programme by Rijkswaterstaat referred to above.

Existing research into the consequences of microplastics in the marine environment
There is growing attention for the problem of plastic pollution in the seas. The United Nations Environment Programme (UNEP) has identified plastic in the world seas since 2011 as one of the most urgent environment problems.[140] Scientists have already discovered plastic in numerous marine organisms such as worms, molluscs, zooplankton,

139 Microplastics are defined as particles measuring between 1 µm and 5 mm.
140 United Nations Environmental Programme (UNEP), Year Books 2011 - 2018.

crabs, prawns and fish. It seems unavoidable that plastic particles that pollute seawater and the sediment are ingested by organisms, with their food. Microplastics have been discovered in the stomachs and intestines of sperm whales and other whales that have become stranded on the North Sea coastline, together with large plastic items such as plastic bags and sections of rope.[141, 142]

The majority of scientific research into harm caused by microplastics to marine organisms takes the form of laboratory experiments, whereby animals in aquariums are fed rising concentrations of microplastics in their diet.[143] One of the effects these experiments have revealed is the mechanism of food dilution. If an organism eats food containing plastic, it ingests fewer nutrients. This results in reduced growth, reduced reproduction, reduced vitality and eventually mortality. Plastic particles can also cause constipation. Sharp or serrated edges of microplastics can cause internal tissue damage and inflammation. Particles smaller than 100 nm, known as nanoplastics, may be able to pass through cell membranes and cause damage to genetic material.[144] Finally, many types of plastic contain additives such as plasticizers, UV protectors and flame retardants, toxic substances that can harm the health of living organisms.

Because all animals eat and are eaten, contaminants such as microplastics are passed on and can accumulate in the food chain. Humans who eat fish, crustaceans and shellfish are also part of the marine food chain and are therefore potentially vulnerable to health effects due to plastic pollution.

SAPEA,[145] a group of representatives of European academic institutions that provide the European Commission with independent scientific advice in support of policy making, published a literature study in January 2019[146] that brings together the most important results from scientific research into the risks of microplastics. The SAPEA working group report confirms the presence of microplastics in all segments of the environment: air, soil, freshwater, seas, oceans and in all organisms living in those environments, including humans. At the same time, the working group suggested that at present there is no reliable evidence available that microplastics bring about large-scale physical harm to the environment and living organisms. In controlled experiments it has been demonstrated that high concentrations of microplastics and nanoplastics negatively influence the vitality of flora and fauna, but outside the laboratory, these high concentrations rarely occur, with the exception of a number of highly polluted areas. The authors of the SAPEA report do, however, note that as yet there are no standardized methods for measuring plastic concentrations and their effects in nature. Risk estimates are therefore difficult to make, above all in respect of nanoplastics. Moreover, laboratory conditions cannot be translated one to one into reality. This means that it is possible that worn plastic particles originating from old, disintegrated macroplastics can be more

141 E. Besseling et al. (2015) Microplastic in a macro filterfeeder: Humpback whale Megaptera novaeangliae. Marine Pollution Bulletin 95 (1).
142 B. Unger et al. (2016) Large amounts of marine debris found in sperm whales stranded along the North Sea coast in early 2016. Marine Pollution Bulletin 112.
143 See: Y. Cae, & Y.J. An (2017) Effects of micro- and nanoplastics on aquatic ecosystems: current research trends and perspectives. Marine Pollution Bulletin 124 (2).
144 I. Zeegers (2014) Nanoplastics gevaarlijker voor milieu en gezondheid dan microplastics. Magazine over de zee (2).
145 SAPEA: Science Advice for Policy by European Academies.
146 SAPEA (2019) A scientific perspective on microplastics in nature and society.

harmful to organisms than plastics used in the standardized laboratory tests. According to the SAPEA working group, in many respects there is a lack of scientific knowledge. The knowledge that is available is surrounded by uncertainties.

The scientific reticence of the SAPEA working group gives way to greater certainty in the final conclusions of the report. These conclusions state that if plastic pollution of the environment continues at the current pace, within one century widespread ecological risks will occur. The persistent character of plastics makes plastic pollution both cumulative and irreversible. Without behavioural change and measures to prevent plastic emissions, it appears unavoidable that the natural environment will suffer as a consequence in the long term. In the marine range, shallow coastal waters such as the Wadden Sea will be the first areas to find themselves in the danger zone.

APPENDIX F

TECHNICAL INVESTIGATION DELTARES

The report from Deltares is available on www.safetyboard.nl.

APPENDIX G

TECHNICAL INVESTIGATION MARIN

The report from MARIN is available on www.safetyboard.nl.

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