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The Impact of Climate Change on Maritime Transport: A Review of the Situation in the Kymenlaakso Region

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ABSTRACT: In the context of international trade logistics, Finland is an island. Due to the significant reduction in trade with Russia following the war in Ukraine, maritime transport has become the predominant mode of transportation for exports and imports, accounting for approximately 95%. The Port of Hamina-Kotka, located in south-eastern Finland, is the primary freight port in the region and plays a crucial role in the maritime logistics of the heavy industry in eastern Finland. The consequences of climate change are being felt acutely in the area, especially during the winter months. Rising temperatures are leading to a decline in winter sea ice cover annually, exerting a substantial influence on winter weather conditions in the region. However, the variability of weather conditions, which is expected to continue in the future, poses an additional challenge. The ILMERI project (Impacts of Climate Change on Maritime Transport, implemented between March 1, 2025, and February 28, 2026), conducted by the South-Eastern Finland University of Applied Sciences and funded by the European Regional Development Fund, studies the effects of changes in conditions caused by climate change on maritime transport in the Kymenlaakso region. This article presents a summary of the baseline situation, including a review of the region's fairway system, marine transportation infrastructure, typical cargo types transported, and available climate data. This is significant because fairway and port solutions represent long-term investments, and any recommendations must be based on reliable data to prevent both over and under-preparedness for future challenges.

1 INTRODUCTION

1.1 *The background of the ILMERI research project*

Climate change is significantly impacting weather conditions in southern Finland [1], particularly during the winter months [2]. Rising temperatures have led to a decrease in the annual ice cover in the Baltic Sea [3]. Whereas in the past, the Gulf of Finland was completely covered in ice during a typical winter, nowadays, during many winters, the sea is almost ice-free, with only archipelago areas on the Finnish coast or locations at the end of the Gulf of Finland remaining ice-covered [4]. The complete freezing of Lake Ladoga is no longer guaranteed, which also contributes to the local climate in south-eastern Finland [5]. Generally, the ice-free sea facilitates winter navigation, but in practice, the change in conditions is not straightforward [6]. On the polar front, weather conditions can vary significantly, leading to the periodical continuation of cold winters and/or cold periods during winters [7]. For winter navigation, this creates conditions that can be difficult to predict. The sea ice field, which is formed during freezing temperatures, may not remain stable when temperatures rise again [8]. Dynamic moving and packing ice can pose significant challenges for ships operating in ice fields or for maritime safety equipment, such as buoys or other navigation marks [9]. Conversely, during the winter months, the presence of non-frozen sea can heighten the risk of heavy snowfall in coastal regions, thereby presenting challenges to both port operations and safe navigation [10-12]. Similarly, the rapid melting of snow increases the likelihood of winter floods. The summer season has also been impacted by climate change. Prolonged heat waves in Central European countries have led to significant health concerns, particularly among high-risk populations. These problems may also become more common in Finland if summer heat waves become more frequent and last longer.

The ILMERI research project (Impacts of Climate Change on Maritime Transport), conducted by the South-Eastern Finland University of Applied Sciences and funded by the European Regional Development Fund, aims to map the potential impacts of climate change on maritime transport in the Kymenlaakso region. The project will be implemented between March 1, 2025, and February 28, 2026, in close cooperation with stakeholders. The project supports the implementation of the Climate Resilient Kymenlaakso Adaptation Plan [13]. Preparing for climate change at the infrastructure level is a long-term effort, and defining the appropriate level of preparedness is challenging. Over-preparedness generates unnecessary costs, while under-preparedness can be critically damaging. The project aims to support the definition of a proper level of preparedness.

1.2 *Fairway channels*

The maritime area of the Kymenlaakso region contains numerous fairways, some of which are suitable for boating, as well as significant deep-water channels that connect the lanes of the Gulf of Finland to the various harbours of the Port of Hamina-Kotka [14]. The port has several berths; Mussalo and Hamina harbours are the main loading areas. However, there is also significant activity in Hietanen and Sunila, and the port includes parts of Kantasatama and Halla. The various harbours of the port are responsible for distinct types of port operations, as well as cargo handling facilities and infrastructure. Consequently, the size and type of vessels berthing in these harbours also vary significantly.

The Orrengrund-Kotka channel [15] is comprised of several fairways that provide access to both Mussalo Harbor and the inner harbour areas of Kotka, including Kantasatama, Hietanen, Sunila, and Halla. Many sections of the channel are lit, including the route from Orrengrund to Kotka. However, the channel also contains unlit sections mainly concentrated in the Mussalo and inner harbour areas. The channel is unsheltered against southerly winds as far as the entrance of Mussalo harbour, and strong winds and rough seas can hamper navigation. However, no official traffic recommendations have been established regarding wind, ice conditions, or visibility. The fairway channel is illustrated in Figure 1.

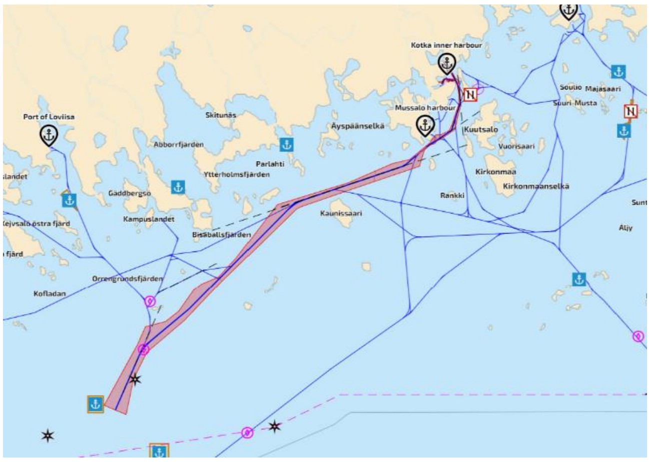

Figure 1. Orrengrund-Kotka channel (IDs: 5605, 5535, 5690, 5570, 5615, 5590, 5532, 5533, 5385). Data source: Fairway card, Finnish Transport Infrastructure Agency [15]

The Mussalo channel is an illuminated route that [16], in contrast to the Orrengrund-Kotka channel [15], provides direct navigation to the harbour of Mussalo from the lanes of the Gulf of Finland. The channel is fully lighted, except for certain sections within the harbour basin. The outer part of the channel is in the open sea and is unsheltered against east, south, and south-west winds, and strong winds and rough seas may hamper navigation. As in the Orrengrund-Kotka case, no official traffic recommendations regarding wind, ice conditions, or visibility have been established in this channel. The Mussalo channel is illustrated in Figure 2.

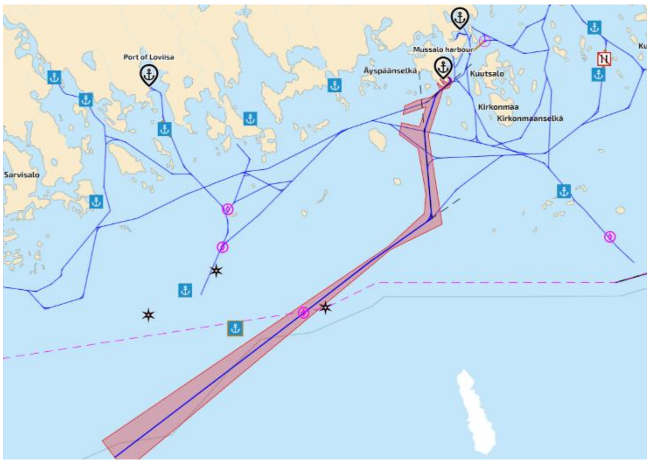

Figure 2. Mussalo channel (IDs: 5510, 5532) Data source: Fairway card, Finnish Transport Infrastructure Agency [16]

The Hamina Channel [17] connects the open sea lanes to the harbour of Hamina. The fairway is equipped with leading lights and beacons, and it includes one meeting and overtaking prohibition area. The outer parts of the channel are open sea areas that are unsheltered against south-west, south, and east winds. Navigation may be hampered by the rough seas or strong winds. The inner parts of the channel are sheltered by islands. A visibility recommendation has been established for the fairway. Visibility should be at least 0.5 nautical miles. The fairway alignment is illustrated in Figure 3.

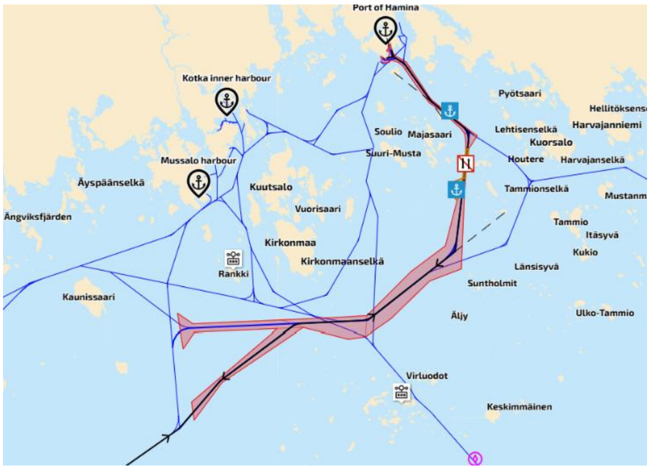

Figure 3. Hamina channel (IDs: 5507) Data source: Fairway card, Finnish Transport Infrastructure Agency [17]

1.3 *Port of HaminaKotka*

The Port of HaminaKotka is a versatile general port comprised of several harbours, of which the main harbours are the ports of Hamina and Mussalo [14]. Container traffic is concentrated in Mussalo, while bulk cargo and RoRo traffic is distributed among all harbours of the port except Sunila. The old Kantasatama harbour, located in the centre of Kotka, is being converted into a passenger-only terminal. Detailed information regarding all harbours and their respective cargo handling capacity is included in Table 1.

Table 1. Port traffic statistics

Harbour	Berths	Cargo type
Halla	2	Dry and breakbulk, LoLo, RoRo
Hamina*	29+2**	Dry and liquid bulk, gas, RoRo, StoRo, LoLo, project shipments
Hietanen	10	RoRo and dry bulk
Kantasatama	3	RoRo, cruise passenger traffic
Mussalo*	20	Containers, dry and liquid bulk, RoRo, StoRo, project shipments
Sunila	2+2***	Mainly exported pulp

* Most important harbors
** Finngas
*** Sunila Ltd
Data: Port of HaminaKotka statistics [14]

Table 2. Port traffic statistics 2020-2024, import and export

Year	Export (t)	Import (t)	Vessel traffic
2024	8,607,239	4,537,454	2,181
2023	9,411,216	4,706,592	2,265
2022	11,279,507	4,985,805	2,575
2021	11,055,407	3,518,840	2,345
2020	11,426,842	3,419,894	2,420

Data: Port of HaminaKotka statistics [14]

Table 3. Port traffic statistics 2024, cargo types

Variable	Export (t)	Import (t)
Dry bulk	2,137,411	429,959
Liquid bulk	188,441	1,035,857
Sawn goods	1,577,904	-
Wood pulp	1,474,007	-
Raw wood	-	2,211,068
Paper	2,114,671	-
Other goods	811,992	407,317
General cargo	302,813	453,2

Data: Port of HaminaKotka statistics [14]

As shown in Table 2, the port's export and import volumes, as well as vessel traffic, are listed for the period from 2020 to 2024. Cargo volumes have traditionally been weighted towards exports, although between 2022 and 2024, this difference has narrowed considerably (see statistics in [14]). The distribution of exports and imports for different types of cargo is shown in Table 3 for 2024. The most significant export product categories include dry pulp, sawmill products, wood pulp, and paper. Among the imported products, liquid bulk and raw wood stand out as the most notable.

2 OBSERVATION METHODS

2.1 *Sea level*

The Baltic Sea does not have periodic tides, but significant variations in sea level are still observed [18]. The primary factor contributing to these variations is the prevailing weather conditions. The weather-affected currents through the Danish Straits influence the total volume of water in the Baltic Sea [19, 20]. Regionally, wind-driven currents move water from one sea area to another, a phenomenon particularly pronounced in geographical areas such as the Gulf of Finland. When winds cease, water masses settle, forming seiche waves [21]. Water level fluctuations caused by winds can be significant [18]. For instance, in the Kymenlaakso region, the recorded maximum and minimum water levels differ by over three meters [22]. Water levels are also influenced by regional air pressure, and extreme water levels frequently result from a combination of various factors.

This article utilizes data collected by the Finnish Meteorological Institute's mareograph station located on Pitäjänsaari Island in Hamina City (position 60.563° N, 27.179° E). The available data is recorded between January 1, 1980, and December 31, 2024. The recording interval is as follows: 1 hour from January 1, 1980, to April 16, 2013, 15 minutes from April 17, 2017, to December 31, 2017, and 1 minute from 2018 onward. The water level is reported in the N2000 system.

2.2 *Temperature and precipitation*

Temperature measurement is significantly affected by the micro-location of the meter. In urban areas, measurements often provide higher-than-average values, especially on sunny summer days [23]. On the other hand, measurements in the archipelago are highly impacted by the sea water temperature, particularly for small islands [24]. Additionally, precipitation measurements exhibit significant regional variations, and coastal areas are affected by distinct weather patterns [25]. For instance, while precipitation is recorded at the coast, the sky might be clear in the outer archipelago.

This paper utilizes data on average temperature and precipitation collected by the Finnish Meteorological Institute [22]. The data is presented as a grid data set, delineating a 10 x 10 km grid within the City of Kotka. The data are examined on an annual basis and separated according to the following seasonal categories: winter (December, January, February), spring (March, April, May), summer (June, July, August), and autumn (September, October, November). Climate change has a particularly significant impact on the region during the warmer winter months. It is, therefore, essential to closely observe the progression of these changes.

2.3 *Sea ice*

The extent of sea ice in the Baltic Sea has shown significant year-to-year variation [4]. In addition to the amount of ice, the challenges posed by sea ice to maritime transport are influenced by various factors, including the duration and thickness of the ice period, which are strongly influenced by winter weather conditions [8]. Even a reduction in the quantity of ice does not necessarily guarantee a more favourable winter for maritime transport. The presence of moving ice fields and packed ice can pose significant challenges for vessels with a lower ice-class [9, 26]. The formation of ice ridges typically occurs in areas where moving ice meets a fixed ice field that is positioned against the coast or an archipelago [27]. These regions are commonly encountered in the outer archipelago, though instances of ice jams are not uncommon in the central Gulf of Finland. In addition, the structure of the ice significantly impacts its strength and integrity [28]. Snow serves as an insulator, meaning that the amount of snowfall directly impacts the formation and strength of sea ice.

This paper examines sea ice data from the entire Baltic Sea as well as the coast of the Kymenlaakso region [22]. The size of the winter ice field in the Baltic Sea is a reliable indicator of the overall ice cover level. For the Kymenlaakso coast, the sea ice cover situation is analysed using data from the Haapasaari observation station. This monitoring station provides essential insights into the sea ice conditions in the outer archipelago. In contrast, the inner archipelago typically experiences longer periods of ice presence, though ice conditions tend to be more stable.

2.4 *Wind*

In terms of average wind speeds, the effects of climate change in the Kymenlaakso region are not entirely clear. While it is anticipated that global wind speeds will increase, with a corresponding intensification of extreme weather events, future changes in average wind speeds in the Kymenlaakso region are not fully elucidated at this time [29, 30]. This paper utilized data from the Haapasaari measuring station (operated by the Finnish Meteorological Institute) from January 1, 2004, to December 31, 2024, with an interval of one hour. Additionally, average wind speeds from October 1 to March 31 are considered separately. This is done because annual warming is influenced by the colder half of the year.

3 RESULTS

3.1 *Sea level observations*

Sea level observations are listed in Table 4. The results are obtained from the mareograph of Hamina Pitäjänsaari, operated by the Finnish Meteorological Institute [22]. For the periods 1980-1989, 1990-1999, and 2000-2010, minimum and maximum values, mean, median, and standard deviation have been considered on a decade-by-decade basis. For the period 2011-2024, the same variables are expressed annually as well. The range between the lowest and highest recorded values is approximately 3 meters. However, the mean and median values indicate that sea level conditions are, on average, more tranquil. The deviations also suggest that the outlier values are atypical, as anticipated. The reference level is N2000.

Table 4. Sea level (mm, N2000), Pitäjänsaari mareograph

Variable	Min.	Max.	Mean	Med.	Dev.
1980-1989	-748	1834	259	232	282
1990-1999	-826	1747	232	219	273
2000-2010	-946	2131	229	205	265
2011	-490	1699	277	230	269
2012	-703	1519	278	260	243
2013	-956	1472	220	161	265
2014	-633	913	110	84	223
2015	-355	1739	335	311	286
2016	-545	1040	188	163	251
2017	-712	1120	312	302	236
2018	-568	1440	142	123	251
2019	-523	1260	241	242	222
2020	-296	1520	376	337	267
2021	-504	1656	208	192	215
2022	-754	1343	263	248	245
2023	-477	1653	266	265	240
2024	-573	1460	249	244	243

Data: Finnish Meteorological Institute [22]

3.2 *Temperature and precipitation observations*

As shown in Table 5, the mean values of temperature and precipitation data from 1991 to 2020 are presented in a grid-based format for Kotka City [22]. The average annual temperature is 5.9°C. However, due to the proximity of the sea, the average winter temperature remains at -3.7°C. A tendency towards increased precipitation during the autumn months is observed. However, the discrepancy between winter and summer rainfall is not significant. Spring experiences the lowest precipitation, but the seasonal differences are relatively negligible.

Table 5. Temperature and precipitation 1991-2020 averages

Variable	Temp. (°C)	Precip. (mm)
Year	5.9	606
Winter	-3.7	142
Spring	3.7	99
Summer	16.5	171
Autumn	7.0	194

Data: Finnish Meteorological Institute [22]

Figures 4-8 illustrate temperature and precipitation anomalies in the years 1962-2024 compared to the 1991-2020 mean values [22]. As illustrated in Figure 4, there has been a notable increase in the average temperature trend of nearly 3°C over the past 60 years. The changes have been particularly evident in the average temperatures during winter (Figure 5) and spring (Figure 6). For precipitation, the trend has been increasing for winter precipitation, though there is greater variability for spring rainfall levels. The summer season is expected to see an increase in temperature levels (Figure 7), although not as significant as the trends observed, e.g., in the winter months. In addition, the past few years have experienced warmer-than-average conditions. No substantial changes have been observed in summer precipitation. For the autumn season (Figure 8), precipitation variability is greater, but there has also been an observed trend of increasing temperatures.

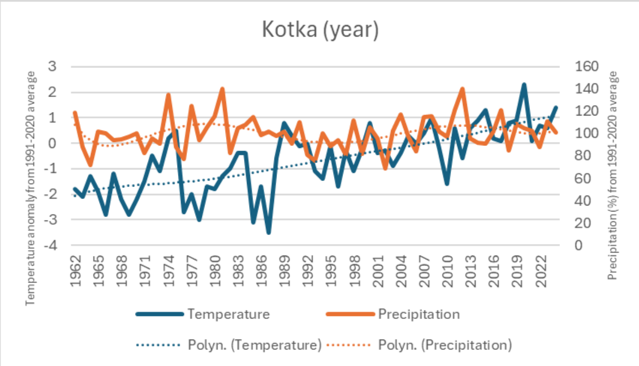

Figure 4. Annual temperature and precipitation levels in Kotka (1962-2024). Data: Finnish Meteorological Institute [22]

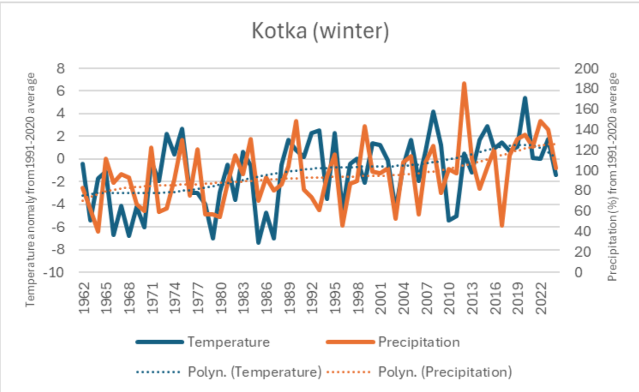

Figure 5. Winter temperature and precipitation levels in Kotka (1962-2024). Data: Finnish Meteorological Institute [22]

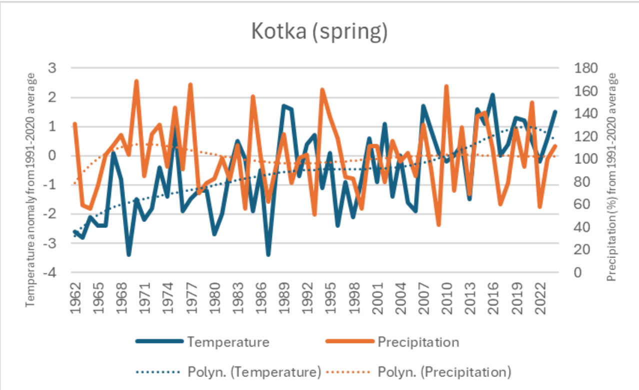

Figure 6. Spring temperature and precipitation levels in Kotka (1962-2024). Data: Finnish Meteorological Institute [22]

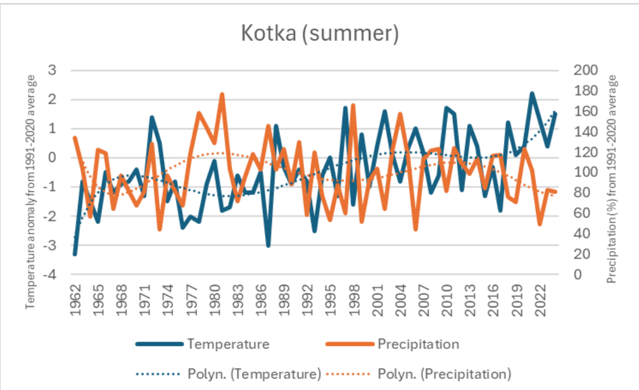

Figure 7. Summer temperature and precipitation levels in Kotka (1962-2024). Data: Finnish Meteorological Institute [22]

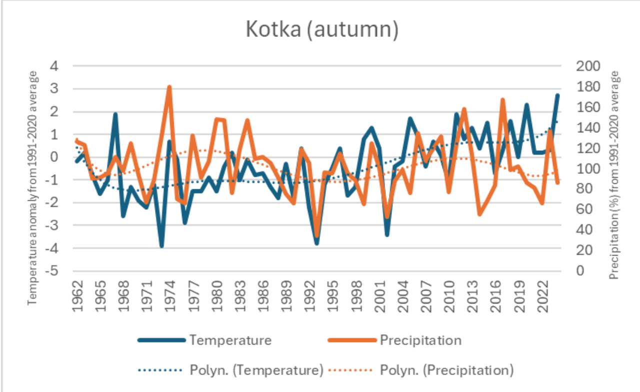

Figure 8. Autumn temperature and precipitation levels in Kotka (1962-2024). Data: Finnish Meteorological Institute [22]

3.3 *Sea ice observations*

Quantifying sea ice in absolute terms is challenging due to the dynamic nature of the ice field, which is subject to variation in the number of warm and cold periods and windiness during winters. Table 6 shows the sea ice cover of the Haapasaari area for the period 1961-1990 [22]. The table lists dates of first freezing, formation of permanent ice cover, end of permanent ice cover, and final disappearance of sea ice, including earliest, median, and latest dates. A similar data set is shown in Table 7 for the period 1991-2020 [22]. A comparison of median dates reveals the impact of global warming on prevailing ice conditions, as evidenced by a shortening of the average ice season. However, significant variations in ice formation are observed between years, as evidenced by the wide range of earliest and latest dates (Tables 6 and 7).

Table 6. Sea ice cover in Haapasaari region, 1961-1990.

Variable	Earliest	Median	Latest
First freezing	7 Dec	5 Jan	15 Feb
Formation of permanent ice cover	18 Dec	13 Jan	15 Feb
End of permanent ice cover	10 Jan	22 Apr	12 May
Final disappearance of ice	12 Jan	29 Apr	16 May

Data source: Finnish Meteorological Institute [22]

Table 7. Sea ice cover in Haapasaari region, 1991-2020.

Variable	Earliest	Median	Latest
First freezing	6 Dec	18 Jan	9 Feb
Formation of permanent ice cover	7 Dec	27 Jan	21 Feb
End of permanent ice cover	4 Feb	14 Apr	12 May
Final disappearance of ice	17 Feb	20 Apr	15 May

Data source: Finnish Meteorological Institute [22]

As shown in Table 8, which presents statistics on the coverage of sea ice in the Baltic Sea for the winters of 2003-2024, there has been significant variation in ice coverage [22]. During the observed period, the ice coverage was more than 8 times higher at its maximum (winter 2010-2011) compared to the mildest winter (winter 2019-2020). This provides insight into the variation, but as Tables 6 and 7 illustrate, regional differences can also be substantial.

Table 8. Sea ice cover in the Baltic Sea

Variable	Max (km²)
2023-2024	135,000
2022-2023	81,000
2021-2022	93,000
2020-2021	127,000
2019-2020	37,000
2018-2019	88,000
2017-2018	170,000
2016-2017	88,000
2015-2016	110,000
2014-2015	51,000
2013-2014	100,000
2012-2013	177,000
2011-2012	179,000
2010-2011	309,000
2009-2010	244,000
2008-2009	110,000
2007-2008	49,000
2006-2007	140,000
2005-2006	211,000
2004-2005	178,000
2003-2004	153,000

Data source: Finnish Meteorological Institute [22]

3.4 *Wind observations*

Table 9 presents the average wind data from the Haapasaari weather station [22]. The table includes the mean, median, and standard deviation values of the average wind speed for the period 2004-2024, along with annual categorized values. The analysis reveals no significant deviations in wind speeds during the considered timeframe. For the period 2019-2024, the mean values are slightly above the 20-year average, though there have been several years in the 2010s when the mean was slightly below the average. In terms of median values, the results are stable, with no major changes in standard deviation.

Table 9. Average annual wind observations in the Haapasaari region

Variable	Mean	Med.	Dev.
2004-2024	6.6	6.2	3.2
2004	6.2	6.0	2.9
2005	6.6	6.2	3.3
2006	6.3	6.0	3.2
2007	6.6	6.2	3.3
2008	6.9	6.6	3.4
2009	6.2	5.9	3.2
2010	5.9	5.6	3.1
2011	6.4	6.1	3.4
2012	6.5	6.3	3.2
2013	6.2	5.8	3.0
2014	5.9	5.5	3.0
2015	6.5	6.2	3.1
2016	6.2	5.8	3.1
2017	6.6	6.3	3.1
2018	6.5	6.0	3.3
2019	7.0	6.8	3.2
2020	7.5	7.3	3.4
2021	7.1	6.7	3.3
2022	6.9	6.7	3.1
2023	7.0	6.6	3.3
2024	6.9	6.4	3.4

Data source: Finnish Meteorological Institute [22]

As shown in Table 10, the corresponding variables are listed for the annual periods of 1 October to 31 March [22]. Periods under consideration extend longer than the standard winter season (December, January, February) to assess potential variations in windiness during the cold season. In comparison to the results presented in Table 9, the average wind speeds are slightly elevated. The trends observed in windy years remain consistent with those presented in Table 9. Otherwise, the results are in line with expectations.

Table 10. Average winter wind observations in the Haapasaari region

Variable	Mean	Med.	Dev.
1.10.2004-31.3.2005	7.2	7.0	3.4
1.10.2005-31.3.2006	6.9	6.8	3.3
1.10.2006-31.3.2007	7.5	7.3	3.5
1.10.2007-31.3.2008	7.8	7.8	3.6
1.10.2008-31.3.2009	7.4	7.0	3.5
1.10.2009-31.3.2010	6.1	5.9	3.4
1.10.2010-31.3.2011	6.9	6.6	3.3
1.10.2011-31.3.2012	7.6	7.3	3.6
1.10.2012-31.3.2013	6.7	6.3	3.2
1.10.2013-31.3.2014	7.2	7.0	3.2
1.10.2014-31.3.2015	7.3	7.3	3.1
1.10.2015-31.3.2016	7.0	6.6	3.3
1.10.2016-31.3.2017	7.1	7.0	3.3
1.10.2017-31.3.2018	7.5	7.1	3.4
1.10.2018-31.3.2019	8.1	8.1	3.3
1.10.2019-31.3.2020	8.5	8.5	3.5
1.10.2020-31.3.2021	7.9	7.8	3.3
1.10.2021-31.3.2022	8.3	8.2	3.4
1.10.2022-31.3.2023	7.7	7.7	3.3
1.10.2023-31.3.2024	7.4	6.9	3.5

Data source: Finnish Meteorological Institute [22]

4 DISCUSSION

Sea water level fluctuations pose challenges for shipping [18,20,21]. While commercial ports and fairways are designed to withstand significant fluctuations in sea level when determining berth heights, fairway depths, and the installation of navigational safety equipment [15-17], the potential for increased extreme situations can present challenges [18]. In the Baltic Sea, where prevailing wind conditions are the primary driver of water level fluctuations, extreme weather events may lead to increased occurrences of floods or exceptionally low water levels, even in the absence of a significant change in average annual wind speed. In terms of safety equipment, floating buoys have proven to be more resilient to sea water level fluctuations. However, there may be challenges associated with sea marks installed in archipelago fairways. The most significant challenges often arise from combinations of exceptional water levels coinciding with heavy rain, storms, waves, or moving ice fields [1,3,8]. Regarding prevailing sea water levels, it is important to note that fluctuations can be categorized as either momentary or gradual. Due to global warming, sea levels are rising worldwide, increasing the likelihood that new extremes will be reached. However, in the Baltic Sea, post-glacial land uplift is constraining this basement rise in sea level. It is important to note that small boat ports may be more susceptible to fluctuations in sea water levels compared to larger commercial ports. In smaller ports, the available amount of reserve water is often limited, and high water levels can easily lead to flooding in fixed piers or submerged boat mooring buoys. Conversely, the economic repercussions of restricting operations at larger commercial ports would be substantial.

The milder winters in Finnish latitudes will generally facilitate winter navigation in terms of ice conditions (except for dynamically moving ice) [8] but will also result in darker winters in terms of daylight, as the amount of light-reflecting snow and ice will decrease, but the amount of sunlight in the winter season will not increase [29,30]. Visibility is also impacted by prevailing weather conditions. Cloudy skies, foggy weather, and drizzly conditions can all contribute to reduced luminosity, even if the total amount of rainfall remains consistent. During the winter solstice, the day is short in the Kymenlaakso region, with a duration of only 5 hours and 43 minutes. The presence of darkness and twilight can impede the efficiency of all activities and often necessitate the wide use of artificial light, which can be viewed as an escalation in light pollution as well. Smart beacon or buoy technology offers the technical capability to monitor local weather conditions (e.g., visibility, rainfall, fog, currents) on a micro level. However, it will take time for this technology to become widespread [31]. This provides a certain degree of assistance in anticipating conditions, particularly in narrow fairways. Heavy rain, snow, or wave conditions can impair marine radar performance, necessitating the use of rain and wave clutters. Filtering out heavy rainfall on the radar display can also result in the erasure of smaller echoes, such as sea marks, rocks, or smaller vessels moving in the area.

Over the past decade, the Safety Investigation Authority of Finland has investigated two incidents in eastern Uusimaa, located near the Kymenlaakso region, both of which involved direct weather-related impacts. The collision between the pilot boat and the missile boat was narrowly avoided [32]. The Safety Investigation Authority determined that several factors contributed to the dangerous situation, including the darkness, the diffuse light from the oil refinery’s spotlights in the background, and the Navy’s desire to operate inconspicuously at times. In the same area, a pilot boat capsized a year earlier, resulting in the deaths of two individuals. This incident also occurred at night, when a south-western wind generated a wave approximately 2 meters high but of particularly sharp character. This wave, in combination with the ship's manoeuvres and its effect on the prevailing wave system, resulted in the pilot boat capsizing [33]. Although the wave’s height did not exceed typical parameters for the region and the time of year, limited visibility may have been a contributing factor to the situation, making rescue operations more difficult.

There have been several reported incidents in low visibility conditions in Finland. The report M2019-03 [34] analyses the incident involving the ROPAX vessel and a road ferry in the Archipelago Sea, where a collision was narrowly avoided. The incident occurred during daylight, but the November day was grey, cloudy, and rainy, with visibility limited to 3-4 miles. Report C4/1997 [35] analyses a collision between the road ferry and the RORO ship in foggy conditions, report C3/2004M [36] a collision between the Navy all-weather craft and the archipelago ferry in icy conditions and fog, and report C7/2005M [37] investigates a collision between the road ferry and the minesweeping equipment at night. The accident was caused by the ferry master’s reduced alertness and fatigue. A thematic study on fatigue [38] in bridge work reveals that this type of work is primarily passive surveillance, where critical actions must be taken in a time-sensitive manner. Long periods of darkness and grey weather do not alleviate fatiguing conditions.

Climate change can have direct or indirect impacts on economic activities. Generally, economic risks are associated with the functioning and characteristics of oil and fuel markets, as well as environmental policies [39-41]. In the past, the risk factor was primarily associated with an increase in fuel prices in the context of a shift to non-fossil fuels. However, in the present day, the situation is much more complex. New regulations, such as FuelEU Maritime [42] and the EU ETS [43], mandate a gradual transition by merchant fleets exceeding 5000 GT to lower greenhouse gas (GHG) intensity fuel and propulsion solutions. The IMO has also set ambitious targets to make maritime transport carbon neutral in the future. This will have a significant impact on the fuel market, which may complicate price forecasting and affect investment profitability. This could result in political pressure that may lead to a reconsideration of previously adopted solutions, creating further uncertainty in the market. This kind of development has been observed in the context of US environmental politics. Conversely, the obligation to distribute biofuels (in road transport) in Finland has been politically adjusted lower, as the price of fuels went up in 2022 due to the impact of Russia's invasion of Ukraine.

Weather conditions can impact different ship types in considerably different ways [44-46]. As such, the operational capabilities of different vessels are contingent upon the prevailing wave conditions. In situations where wind speeds are particularly high, port manoeuvring under these conditions becomes considerably challenging, particularly for ships with large wind surface areas or those otherwise sensitive to wind. Consequently, the vessel's type and operational speed determine the necessity for reserve water under the keel. Ships with a strong ice classification (e.g., 1A or 1A Super) possess the capability to function autonomously, even in relatively challenging ice conditions [47]. Regulations pertaining to the ice classification of vessels permitted to navigate to regional ports during winter have been enacted to ensure the safety of maritime operations in ice-covered waters. In principle, these policies can be continued in the future as well. However, if the number of vessels classified as higher ice-class vessels decreases due to energy efficiency requirements, such a policy could theoretically result in substantial losses in foreign trade if the winter ice proves to be exceptionally severe [48]. This principle similarly applies to investment decisions regarding icebreaking fleet modernization. What is the optimal investment strategy when winters are predominantly mild? However, if a severe and cold winter occurs, are we prepared to face the resulting challenges?

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