CLINSH

SUSTAINABLE WATERWAY TRANSPORT, CLEAN AIR

B 4: Modelling, evaluating and scenario building

Harbour monitoring: Air quality on the Rhine and in the inland ports of Duisburg and Neuss/Düsseldorf.

Part D: Analysis of shipping traffic on the Rhine for the years 2018-2020

CLEAN INLAND SHIPPING

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B.4 Modelling, evaluating and scenario building

Harbour Monitoring Part D:

Analysis of shipping traffic on the Rhine for the years 2018-2020

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CLINSH moves it forward !

(Push boat at Duisburg, Photo: D.Busch, LANUV)

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1. Introduction

A very extensive measurement programme on air pollution on the Rhine and in the ports of Duisburg and Neuss was carried out for CLINSH in 2018. The aim of the measurement programme was to obtain a picture of the air quality in the port areas and to generate a data basis for modelling the pollution components of ship emissions.

In both ports, AIS receivers were additionally installed for the CLINSH project in order to generate information on the respective ship traffic on the Rhine and in the ports. Based on the evaluation of the AIS data, it was possible for the first time to map the real composition of shipping traffic on the Rhine with regard to the length class of the ships (Fig.1) and their real speeds. The classification of the ships was carried out according to the scheme of the Dutch "Buerau Voorlichting Binnenvaart"(1) orientated on the CEMT (European Conference of Ministers of Transport, French: Conférence Européenne des Ministres des Transports (CEMT)).

Size Class	Type of ship
I	 **Spitz, Peniche** **Length** 38,5 m - **width** 5,05 m, **draught** 2,2 m - **cargo capacity** 350 t
II	 **Campine vessel** **Length** 55 m - **width** 6,6 m, **draught** 2,50 - **cargo capacity** 655 t
III	 **Dortmund-Ems-canal vessel** **Length** 67 m - **width** 8,2 m, **draught** 2,50 - **cargo capacity** 1000 t
IV	 **Rhein-Herne-canal vessel** **Length** 85 m - **width** 9,5 m, **draught** 2,50 - **cargo capacity** 1350 t
Va	 **Large Rhine vessel** **Length** 110 m - **width** 11,4 m, **draught** 3,0 m - **cargo capacity** 2750 t
Vb	 **Large Rhine vessel** **Length** 135 m - **width** 11,4 m, **draught** 3,5 m - **cargo capacity** 4000 t

Fig. 1.1: Size classes of cargo ships and tankers in this report, analogous to the classification according to CEMT(4) (Illustration: LANUV, ship graphics: Buerau Voorlichting Binnenvaart).

For "normal" cargo ships and tankers, in many cases the ship sizes can also be used to deduce further parameters, e.g. the period of construction and the originally installed technical equipment (main engine, generators, etc.). Often the current equipment can also be concluded from this.

Since the end of the 19th century, attempts have been made to "standardize" the degree of development of the inland waterways, so that over the years and with an increasing degree of the waters´ development, inland vessels grew in size. The 38.5 m ship (Class 1; < 40 m)) was one of the first "standardized" types, built from 1880 onwards in order to make the optimal use of the French canals. The Dortmund-Ems Canal ship (Class III; 67 m) appeared in the 1950s. The Rhine-Herne-Canal-Ship (Class IV; 85m), also known as the "Europe Ship", was built from the 1970s onwards.

This length classification forms the basis for the description of traffic on the Rhine and in the ports. This classification of shipping traffic is based on the evaluation of AIS signals.

The monitoring of the air quality in the ports of Neuss and Duisburg took place in the year 2018. Unfortunately, there were exceptionally low water levels in the Rhine in the second half of the year, which also led to obstruction of shipping traffic on the Rhine. The calculations of ship emissions for 2018 showed increased emission quantities compared to 2019 and 2020.

Therefore, it became important to investigate these effects on shipping traffic and the changes compared to subsequent years in more detail in order to enable a better assessment of the representativeness of the results of the air quality monitoring. (see LANUV report on *CLINSH "Harbour Monitoring Part A: Air quality on the Rhine and in the inland ports of Duisburg and Neuss/Düsseldorf. Immission-side effect of emissions from shipping and port operations on nitrogen oxide pollution"*)[2].

2. Methodology for the evaluation of AIS signals

The Automatic Identification System (AIS), which is mandatory for inland vessels, serves to exchange navigational and other ship data with the aim of improving the safety and guidance of shipping traffic. This signaling system was adopted as a binding standard by the International Maritime Organization (IMO) in 2000. Inland AIS equipment and use has also been introduced for inland vessels on most European inland waterways. They are therefore obliged to transmit AIS signals permanently. These signals are send at relatively short intervals and contain a lot of information about moving and moored vessels. T These signals contain information about moving and moored vessels, e.g. about its position, its direction of travel, its speed over ground, its length, etc..

Using the AIS-receivers set up for CLINSH in the automatic measuring stations in Duisburg (DURH) and Neuss (NERH), it became possible to obtain a lot of information about the sailing and moored ships in the respective study areas, which enabled further evaluations.

However, the range of these signals is limited. It depends on the respective transmitting power and on the height of the antennas installed on the ships. For example the signals of large container ships that have their cab raised to the maximum can be received on a much longer distance than the signals of smaller ships with low antenna heights. This results in a situation, for example, that downstream of Duisburg, from a certain distance onwards, the number of ships becomes lower and lower as the distance to the receiving station increases, until it drops to a few ships per day. Since most of the ships (approx. 220 per day) reaching the urban area in Duisburg downstream of the harbour entrance must also have sailed in these sections of the Rhine, plausibility checks became necessary.

The checks on the evaluations of the signals from the DURH and NEHR stations showed that on the Lower Rhine in North Rhine-Westphalia, one Rhine section each in the order of approx. 20 km can provide reliable data for determining vessel traffic data on a daily basis. AIS data of the stations Duisburg (km 782) and Neuss (km 741) (validity: +/- 10 km).

The received AIS data was archived and evaluated later. Individual identification with the permission of the ship owners was only carried out for the ships officially participating in the CLINSH project. These data were necessary for special evaluations on the CLINSH emission measurements on board. All other data was processed anonymously.

The following data were evaluated for the CLINSH project on a daily basis.

- Length class of the passing vessels.
- Type of passing ship (cargo ship, tanker, passenger ship, other ship (e.g. official vehicles).
- Direction (upstream or downstream) of the passing vessels.
- Speed over ground.

For the evaluation of the AIS signals, both the project partner HZG and the University of Bremen created corresponding programmes. The HZG used AIS data for the Lower Rhine, being provided by an external provider. The actual location of the receivers remained unknown. A comparison of the data sets for individual Rhine kilometers showed that the listed ship numbers of the AIS data sets of the HZG and the LANUV definitely had sometimes deviations in the ship numbers in the double-digit percentage range. Since the location of the "external receivers" remained unknown, no plausibility check could be carried out.

The focus of the evaluations of the AIS data for Neuss and Duisburg was therefore placed on the AIS data of the LANUV. The final evaluation of the AIS data of the measuring stations DURH and NERH, collected especially for CLINSH, was carried out with the programme of the University of Bremen.

Due to various interfering factors, both the HZG and LANUV data sets had data gaps that had to be closed in order to determine the number of ships actually sailing. In some cases, individual days were not completely recorded, in others entire days or even weeks were missing.

The LANUV has applied the following procedure:

- The data basis is the AIS data of NERH (range approximately from Rhine-km 730-752) and DURH (range approximately from Rhine-km 770-790).
- Data gaps in the LANUV data set are filled by plausible AIS data from the HZG (AIS-Hub), if available.

- If both data sources show incomplete daily data that cannot be filled, a mathematical solution is found: For this purpose, the mean value of the number of ships of the same weekday of the three preceding and the three following weeks is determined (taking into account seasonality, water level, etc.).
- The vessel numbers for Bimmen and Bad Honnef come from the HZG data set.

With the plausibility checks and additions described above, it was possible to obtain a realistic picture of shipping traffic on the Rhine and in the ports.

3. Overview of shipping traffic on the Lower Rhine

Fig. 3.1 shows an overview of the composition of vessel traffic on the entire section of the Rhine in North Rhine-Westphalia in 2019 and 2020. Unfortunately, no complete AIS data were available for the Bimmen/Lobith and Bad Honnef area for 2018, so that the traffic situation for the complete year 2018 can only be presented for the Neuss/Düsseldorf to Duisburg section of the river, studied by the LANUV for CLINSH. (Fig. 3.2 a,b,c).

For the German-Dutch border at Bimmen, the evaluations of the AIS signals can be compared with the data of the ship counts of the German WSV report. It shows a quite good conformity between the data sets.

Ship passages on the German-Dutch border		
Year	**AIS-Signals, km 865**	**WSV-Reports[26]**
2018	**58.200 (2nd half-year) ***	**111.352**
2019	**108.800**	**106.499**
2020	**109.500**	**103.624**

Tab. 3.1: Ship passages at Bimmen
(* due to availability of AIS data)

Since no complete AIS data is available for Bimmen and Bad Honnef for the year 2018, the analysis of the Lower Rhine in North Rhine-Westphalia is based on the example of the data for the year 2019. If the number of ships passing by in Bimmen is set to 100% as a reference value, it can be seen that a ship count of about 74% is detectable in Duisburg in 2019. Below the port of Neuss, the number of ships drops to about 65%. At the border to Rhineland-Palatinate (Bad Honnef, km 640), the number of passing ships drops to about 46%.

Fig. 3.1 and Tab. 3.2 show that the main share of freight traffic on the Rhine in the range of 70-80% is handled by vessels of size classes IV (85 m, share 16-23%), Va (110 m, share 32-42%) and Vb (135 m, share 15-21%). In addition, there are pushed and coupled convoys, which together account for about 7-10 % of the total traffic.

The smaller cargo ships and tankers of classes I, II and III play only a minor role. Only in the Bimmen area is a larger number of size class I ships visible. These are presumably the small bunker boats of the bunker station located in Lobith, which supply the moving inland vessels with fuel in this area and are thus usually detected here several times a day by AIS signal. It was not possible to clarify whether an increased number of authority boats (e.g. river construction, survey boats) was also deployed in this area in 2019. For about 1-4 % of the vessels, no classification by vessel size can be made due to faulty AIS signals.

Location/km	Ship class and percentages in 2019										Total
	I-III	%	IV	%	Va	%	Vb	%	PC+C-U	%	n
HON 640	6,160	12	8,092	16	21,317	42	9,410	19	5,242	10	50,515
NEU 742	6,612	9	12,926	18	28,593	40	14,701	21	5,035	7	70,657
DURH 782	7,099	9	15,409	19	31,234	39	16,842	21	6,593	8	80,554
BIM 865	22,853	21	24,971	23	35,199	32	16,254	15	8,788	8	109,091

I-III > 85 m IV 85 m Va 110 m Vb 135 m PC pushed convoy C-U coupled unit

Tab. 3.2: Percentage share of the different ship length classes in shipping traffic on the Lower Rhine between Bimmen and Bad Honnef in the year 2019.

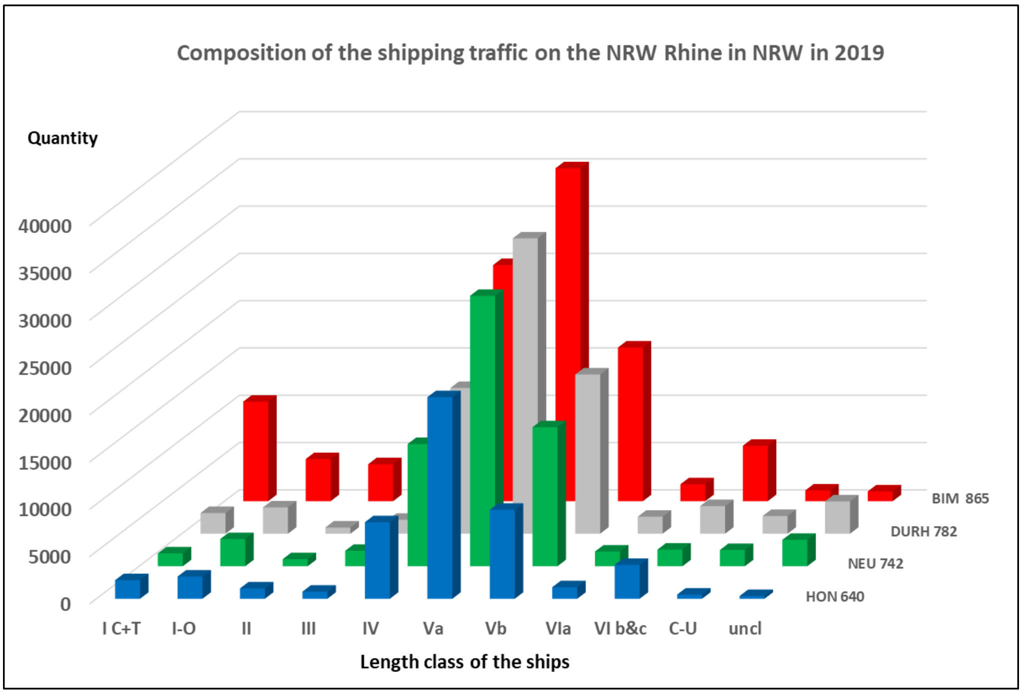


Fig. 3.1: Vessel traffic on the North Rhine-Westphalian section of the Rhine (Rhine-km 640-865) in 2019, composition according to the individual vessel size classes

(For ship classes see Fig. 1.1; I C+T = cargo and tanker ships; I-O = other ships; VI=sheer convoy, VIa=2 barges; VIb&c=4 -6 barges; C-U= coupled unit; uncl=ship not clearly classifiable via AIS signal.

Table 3.3 lists the most important ports/stream quays in North Rhine-Westphalia. In some cases, ships on the Rhine only sail to these ports or canal entrances. Therefore, the shipping traffic may also change at these locations with regard to traffic density and fleet composition.

Rhine-km	640		672		691		696	697		699		687		700		740		743		764		770	771
Ports/Locations/ Current quays / Measuring stations	Bad Honnef		Port Wesseling		Port Köln-Mülheim		Port Köln Niehl 1	Tankerlöschanlage		Port Köln Niehl II		Port Deutz		Bayer Leverkusen, Current quay		Port Neuss **NERH (AIS-Reciever)**		Port Düsseldorf		Port Krefeld		Erzhafen Huckingen	Container Terminal, current quay

Rhine-km		773		775		777		779	780	781	782	790	791		793	794		813		865
Ports/Locations/ Current quays/ Measuring stations		Port Rheinhausen		Current quay- Steel shipping		Innenhafen, Parallelhafen Duisburg		Sachtleben factory	Ruhr mouth	Prot entry Duisburg/ Rhein Herne Channel	**DURH (AIS-Reciever)**	Port Schwelgern	Port Walsum Süd		Port Walsum Nord	Current quay Orsoy		Port Friedrichsfeld/ Wese-Datteln-Channel		Bimmen

Table 3.3: The most important ports, stream quays and channel entrances in North Rhine-Westphalia.

4. Development of water levels in the Rhine

The chosen year of investigation 2018 was unfortunately a year with extremely low water levels in the Rhine. The low fairway depths had a direct impact on shipping traffic, as large vessels could no longer sail fully loaded.

Figures 4.1 a-c show the development of fairway depths in 2018 compared to the years 2017, 2019 and 2020. The respective situation at the river gauges Düsseldorf (Rhine-km 744.2), Duisburg-Ruhrort (Rhine-km 780.2) and at the Lower Rhine near Emmerich (Rhine-km 851.9) is depicted. The red curve shows the fairway depths for the year 2018.

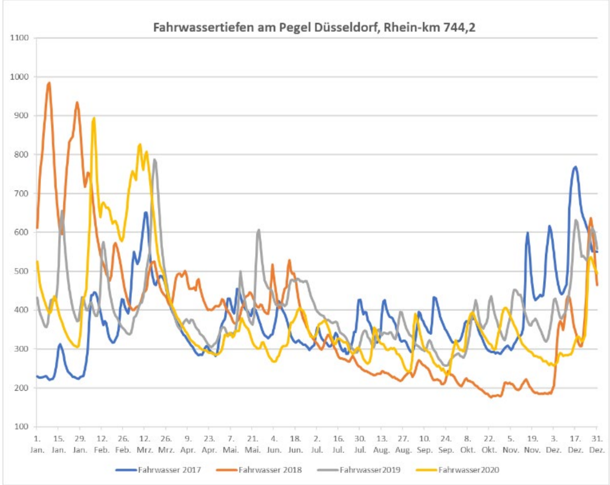


Fig. 4.1a: Fairway depths at the Düsseldorf gauge in 2017-2020

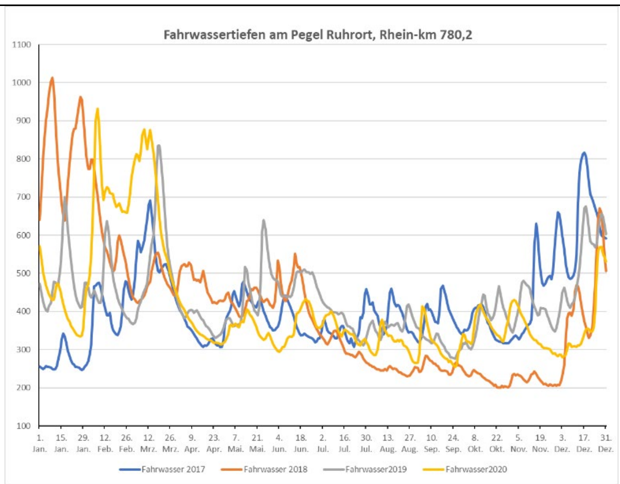


Fig. 4.1b: Fairway depths at the Duisburg-Ruhrort gauge in 2017-2020

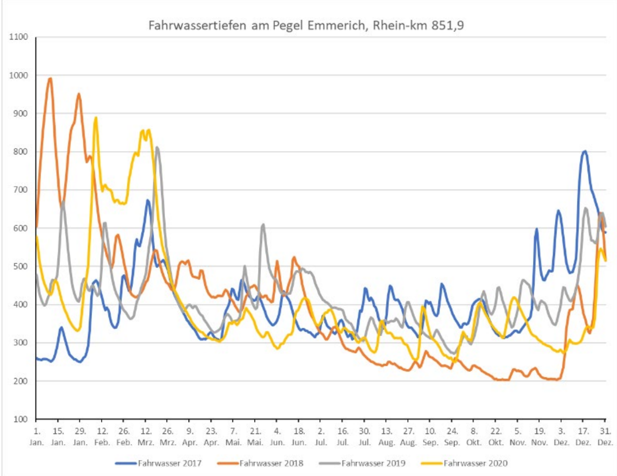


Fig. 4.1c: Fairway depths at the Emmerich gauge in 2017-2020

In 2018, fairway depths decreased significantly from mid-June and remained at an unusually low level until the beginning of December. From mid-June on, the decreasing fairway resulted in increasing restrictions on inland navigation. Already in mid-July, the depth had dropped below the 3.0 mark. A further decrease to 2.5 m occurred by the beginning of August. In the Düsseldorf area, the water level even dropped below the 2.0 m mark from October onwards. The situation did not ease again until the beginning of December. Serious restrictions for the different types of ships are shown in Fig. 4.2 for the Lower Rhine using the example of the three gauges.

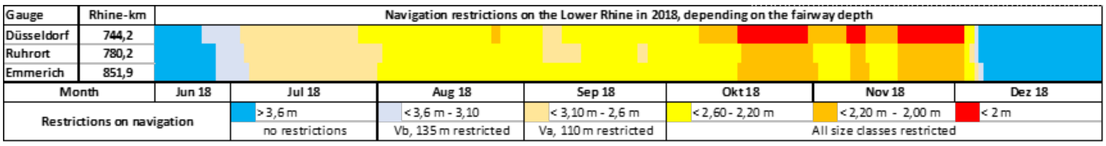


Fig. 4.2: Schematic representation of the course of fairway depths at the Lower Rhine gauges and the restrictions resulting from the fairway depth for the ship classes in 2018.

For the ship classes Va (110 m) and Vb (135 m), the first restrictions on loading depths and also maneuvering ability were already in place in June/July 2018. From August onwards, ships of length class IV (85 m) were also no longer able to sail fully loaded. From mid-October, there were even restrictions on the even smaller ship types. Even the 40 m class with a draught of 2.2 m could no longer be fully loaded on the Lower Rhine in October/November 2018.

Lower loading depths have several possible consequences:

- The total amount of cargo to be transported has to be distributed among a larger number of vessels, which are either significantly smaller or can only be partially loaded.
- Part of the cargo volume has to be transferred to other means of transport (e.g. rail, truck).

For the CLINSH project, the question arose to what extent shipping traffic in 2018 and the associated emissions were also representative for the following years. For this reason, the traffic of the years 2018-2020 was also examined using statistical methods.

Figure 4.3 shows on how many days a given water fairway depth was reached. The upper panel with the data for 2018 clearly shows that in that year there were considerably more days on which only a fairway depth of less than 300 cm was reached than in 2019 and 2020. This circumstance obviously had an influence on the number of ships sailing.

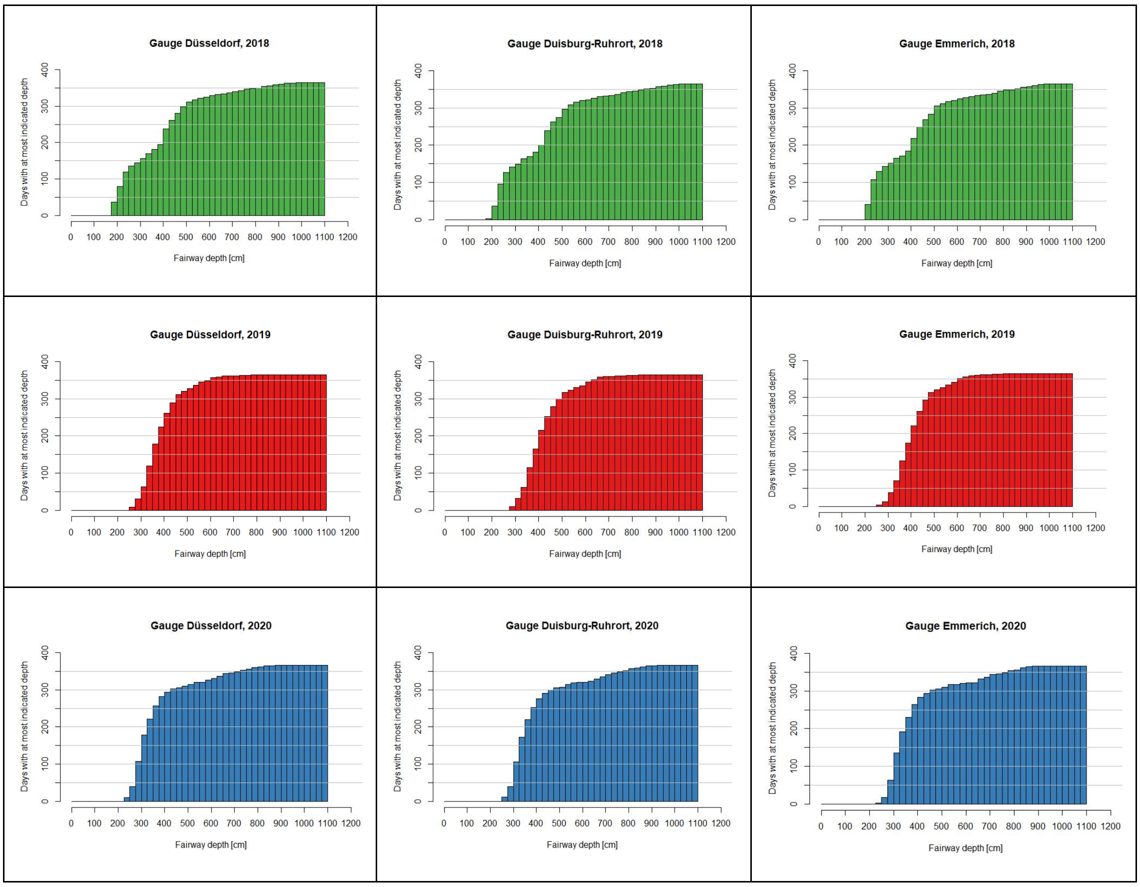


Fig. 4.3: Number of days with a maximum of the fairway depth specified on the horizontal axis

(Düsseldorf gauge (km 744.2), Duisburg-Ruhrort gauge (km 780.2) and Emmerich gauge (km 851.9).

Fig. 4.4: Shipping traffic on the Rhine near Duisburg (Photo: D. Busch, LANUV)

5. Effects of water levels on the composition of shipping traffic

5.1 General overview

In the Duisburg area, complete AIS data from the DURH station are available for every three years. Due to the low water in the 2nd half of the year, more ships (92,225) sailed in the area of the Port of Duisburg (Rhine-km 782) in 2018 than in the following years 2019 (80,554 ships) and 2020 (78,877). It is striking that especially ship classes IV (85 m, increase 22 %) and Va (110 m, increase 16 %) had a significantly higher number in 2018 than in the following years. This is presumably due to the fact that the ships that could no longer be fully loaded had to sail more frequently in order to be able to fulfil their freight contracts in terms of volume. A significant increase in the shares of small vessels in length classes I-III was not detectable (Fig. 5.1).

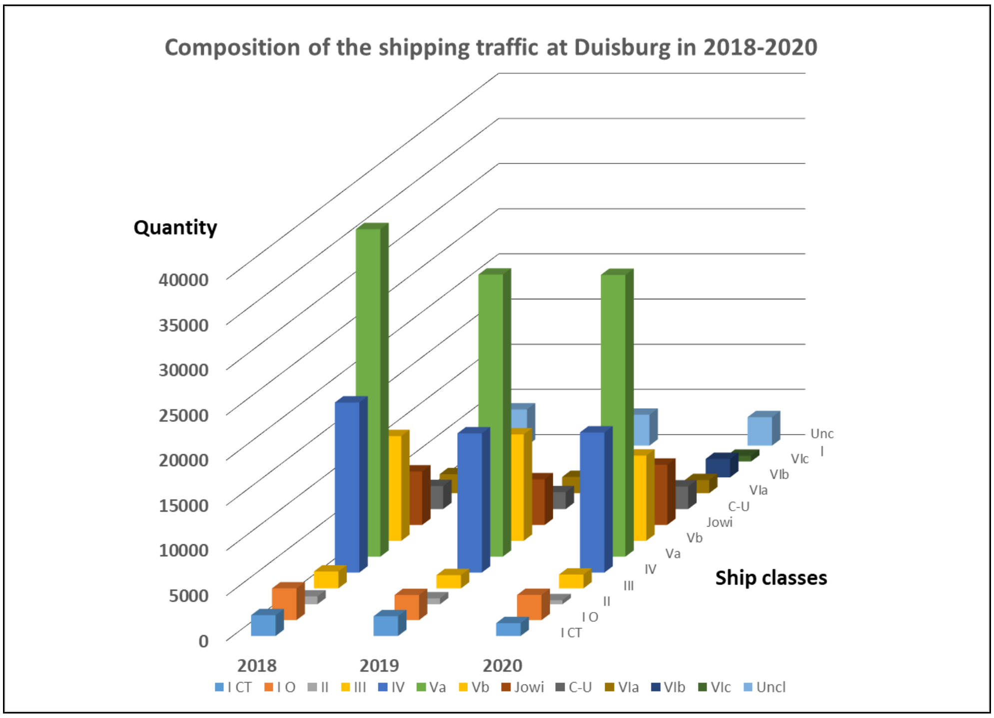


Fig. 5.1: Comparison of the composition of shipping traffic in 2018-2020.

It is also interesting to see the chronological sequence of the vessel numbers in the individual classes in the 2nd half of 2018 compared to the following years. Figure 5.2 gives an overview of the monthly developments in total traffic. The figures in Chapter 6 each contain a representation of the proportions with which the mainly sailing ship classes are represented in the total of all ships. The vertical confidence intervals at each share value shown, describe the statistical dispersion of these shares as a 95% confidence interval. If confidence intervals overlap, there is no significant difference between the shares involved.

For some vessel classes, there is a clear annual variation in the shares of a class (e.g. I-O, Vb, VIa). A conspicuous course of the shares for 2018 (green curve in each case), which would be conceivable due to the water levels at that time, is only recorded for the classes Vb, VIb in NERH and Vb in DURH. In 2018, the proportions of the afore mentioned have increased there over a longer period of time compared to the other years.

The course of the shares of classes VIb, JOWI, and C-U Kop show a fluctuation greater than for other classes over all three years studied. It should be remembered, however, that the proportion of the classes I, II, III to all vessels is relatively small, so that a comparatively small change in numbers produces significant changes in percentages. The month of July 2018 in DURH is striking, with a clear local minimum of JOWI class vessels and coupled units accompanied by a local maximum of VIb class vessels. A similar pattern occurs in September and November 2018 in NERH.

Fig. 5.2 shows the total number of ships sailing on the Rhine for the years 2018, 2019 and 2020. It can be clearly seen that in the second half of 2018, significantly more ships were used than in the two reference years. In 2017, the section above the port entrance at Duisburg (km 772) shows a significantly higher traffic volume than in the reference years. This increase was significantly higher in the section below the harbour (km 790). From September to October, up to 2,000 more ships passed through here than in the reference years.

Fig. 5.1a: Ships passage on the Rhine at Düsseldorf/Neuss (Photo: H. Eckhoff, LANUV)

Fig. 5.2: Total numbers of ships sailing along the section of the Rhine at and around Neuss (km 740) and Duisburg (km 782) in the years in 2018, 2019 and 2020.

5.2 Number and share of individual vessel classes in total traffic in 2018-2020

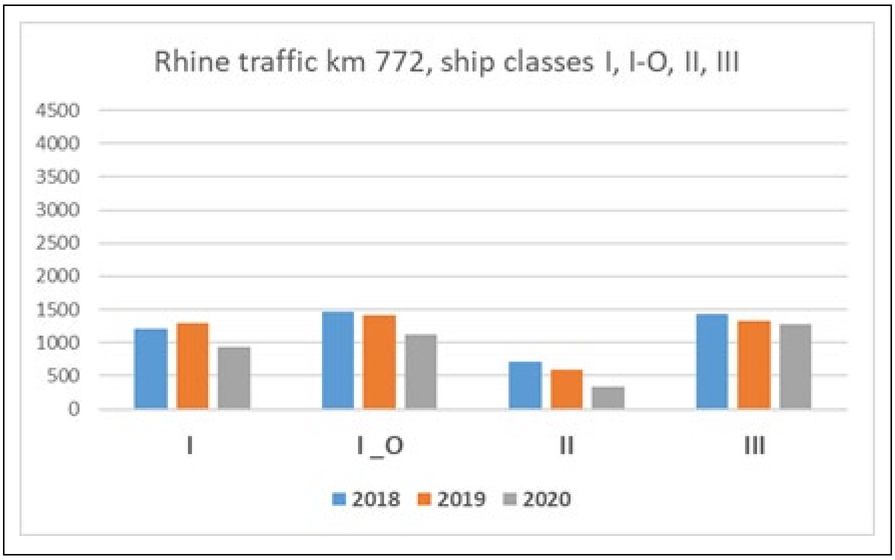
The composition of traffic from the individual vessel classes was influenced by the low water levels in 2018. Below, these influences are described in more detail for the individual vessel classes.

5.2.1 Length classes I, II, III

In Table 5.2, both the number and the respective shares of ship classes I (cargo and tanker vessels), I-O (other ships), II and III in the total traffic on the Rhine are compiled for the years 2018-2020. Fig. 5.4a-c: shows the respective ship numbers, separated by ship class and year.

Jahr	I		I _O		II		III	
km 772	n	%	n	%	n	%	n	%
2018	1209	1,7	1475	2,0	718	1,0	1437	2,0
2019	1290	1,9	1412	2,0	590	0,9	1334	1,9
2020	942	1,5	1117	1,7	343	0,5	1278	2,0
km 782	n	%	n	%	n	%	n	%
2018	2302	2,5	3513	3,8	868	0,9	1871	2,0
2019	2189	2,7	2785	3,5	656	0,8	1469	1,8
2020	1424	1,8	2794	3,5	453	0,6	1538	1,9
km 790	n	%	n	%	n	%	n	%
2018	2098	2,0	4452	4,3	995	1,0	1738	1,7
2019	1682	1,9	3230	3,7	969	1,1	1439	1,6
2020	1163	1,3	2259	2,6	572	0,7	1476	1,7

Tab. 5.1: Number and percentage share of ships in ship classes I, I-O, II and III in total traffic in the area of Duisburg in the years 2018-2020.



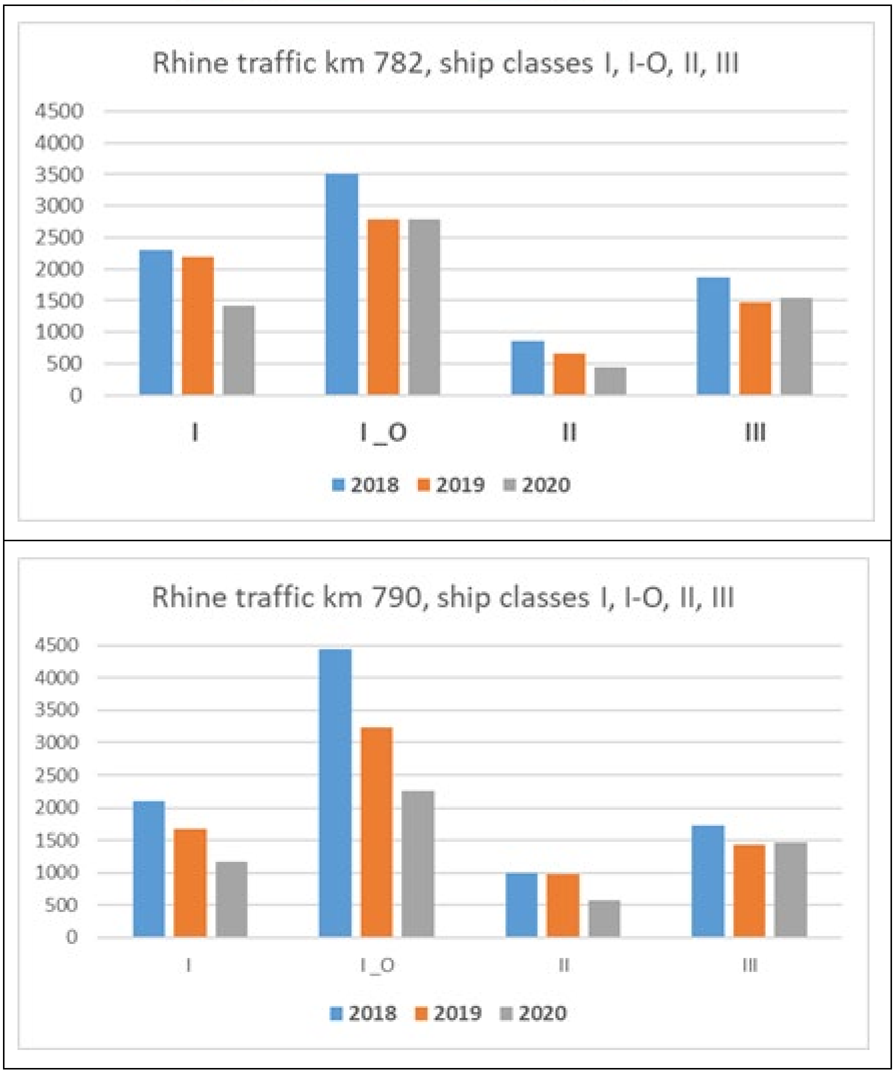


Fig. 5.3: Comparison of the number of vessels of the individual length classes I-III.

Ship class I, (cargo ships and tankers < 40m).

The small cargo vessels are usually very old ships that are still active today for special shipping areas (e.g. small canals with small locks in France). In these waters, only traffic with these very small ships is possible, so that money can still be earned here today.

Tankers in this size class can also be more modern vessels, operating as bunker boats or bilge de-oilers, for example. A station for bunker boats is located in Duisburg at Rhine-km 780.5. The slightly higher share of this ship class in the area of the Port of Duisburg is probably caused by the use of the bunker boats and bilge de-oilers stationed here.

The share of total traffic was around 2% in 2018 and 2019. What is striking is the lower number and also a slightly lower share of total traffic in 2020 for all three river kilometers considered.

Ship class I-O, length up to 40 m, other ships

This ship class includes all ships with lengths of up to 40 m that are not declared as cargo vessels or tankers in their AIS signals. These include water police, fire brigade, public authority vessels, construction and research vessels of port and water and shipping authorities, etc..

The significantly higher numbers of ships of this group at Rhine kilometers 782 and 790 in 2018 are striking. Possibly, considerably more measuring trips were necessary in this low water year to secure the fairway depth than in the following years. In 2018, this is particularly evident in the shares of this ship class in September at Rhine-km 740 (Neuss) (Fig. 5.4).

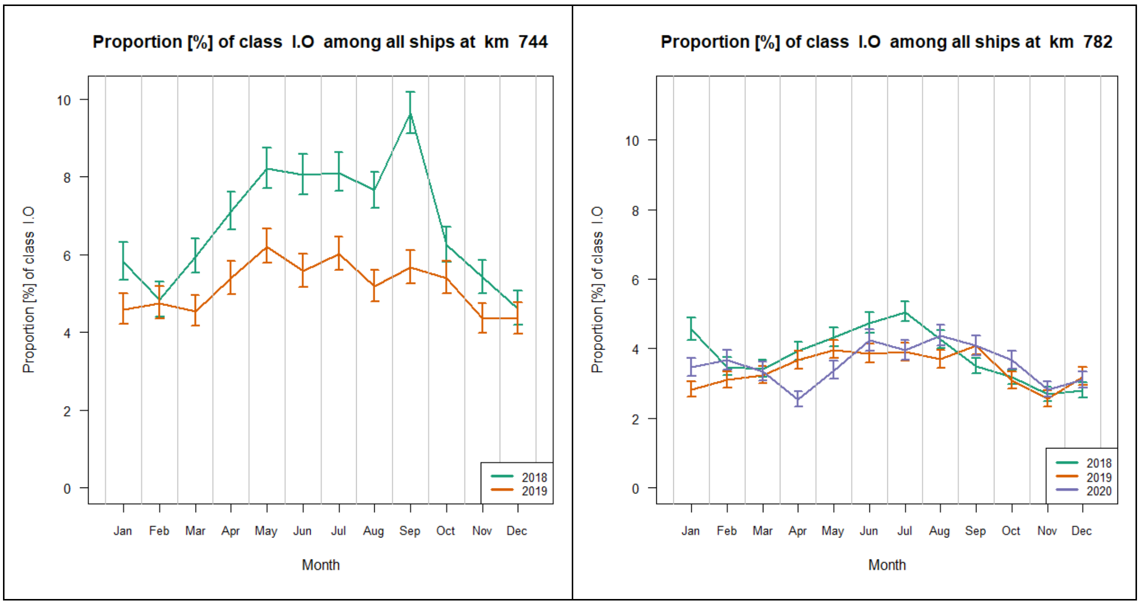


Fig. 5.4: Monthly shares of Class I-O vessels in total traffic at Neuss (km 740) and Duisburg (km 780).

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Fig. 5.5: A bilge de-oiler in the Duisburg harbour canal.

Ship class II (55 m)

The share of vessels of this length class in the total traffic was about 1 % in 2018/2019. In 2020 the share was slightly lower. Vessel numbers at Rhine-km 782 were slightly higher in 2018 (n= 868) than in 2019 (n=656) and 2020 (n=453). At Rhine-km 790, vessel numbers were comparable in 2018 (n=995) and 2019 (n=969), while significantly lower numbers were detected here in 2020 (n=572) (Tab. 5.1; Fig. 5.3). With regard to ship emissions on the Rhine, this ship class plays a subordinate role both in terms of the shares of ship emissions and in terms of the annual changes in the shares of total traffic.

Ship class III (67 m)

Vessel class III accounted for about 2% of total traffic in all three years. Vessel numbers were slightly increased in 2018 (n= 1,871) at Rhine-km 782 compared to 2019 (1,469) and 2020 (n=1,476). A similar development was also evident at Rhine-km 790. (Tab. 5.1; Fig. 5.3). With regard to ship emissions on the Rhine, this ship class plays a subordinate role both in terms of the shares of ship emissions and in terms of the annual changes in the shares of total traffic.

5.2.2 Vessel classes IV (85 m), Va (110 m), Vb (135 m), JOWI (135 m XL)

In Table 5.2, both the number and the respective shares of ship classes I, I-O, II and III in the total traffic on the Rhine are compiled for the years 2018-2020. Fig. 5.6 shows the respective ship numbers, separated by ship class and year.

Ship class	IV		Va		Vb		Jowi-class	
km 772	n	%	n	%	n	%	n	%
2018	13236	18,4	29861	41,5	9204	12,8	4987	6,9
2019	12250	17,7	27960	40,5	10118	14,6	4565	6,6
2020	12025	18,8	26152	40,9	7866	12,3	5550	8,7
Ship class	IV		Va		Vb		Jowi-class	
km 782	n	%	n	%	n	%	n	%
2018	18828	20,4	36259	39,3	11595	12,6	5920	6,4
2019	15409	19,1	31234	38,8	11785	14,6	5057	6,3
2020	15509	19,7	31194	39,5	9440	12,0	6671	8,5
Ship class	IV		Va		Vb		Jowi-class	
km 790	n	%	n	%	n	%	n	%
2018	17537	17,1	36391	35,5	12782	12,5	6352	6,2
2019	15023	17,0	32038	36,3	11957	13,5	4991	5,7
2020	14857	17,2	31206	36,2	9417	10,9	6643	7,7

Tab. 5.2: Number and percentage share of ships in ship classes IV, Va, Vb and JOWI class in total traffic in the area of Duisburg in the years 2018-2020.

Ship class IV (85 m)

Ships in the 85 m size class (European ship) have a significant share in the total traffic on the Rhine. The share of ships of this length class at Duisburg was about 17-20 % in 2018-2020. Vessel numbers on the Rhine-km 782 were about 3,400 vessels higher in 2018 (n= 18,828) than in 2019 (n=15,409) and 2020 (n=15,509). The Rhine-km 790 also shows a similar trend, with about 2,500 more vessels sailing here in 2018 (n=17,537) than in the following years 2019 (n=15,023) and 2020 (n=14,857) (Tab. 5.2; Fig. 5.6).

The percentage share of 85 m vessels in total traffic was also comparable in the course of the year in the three study years (Fig. 5.7).

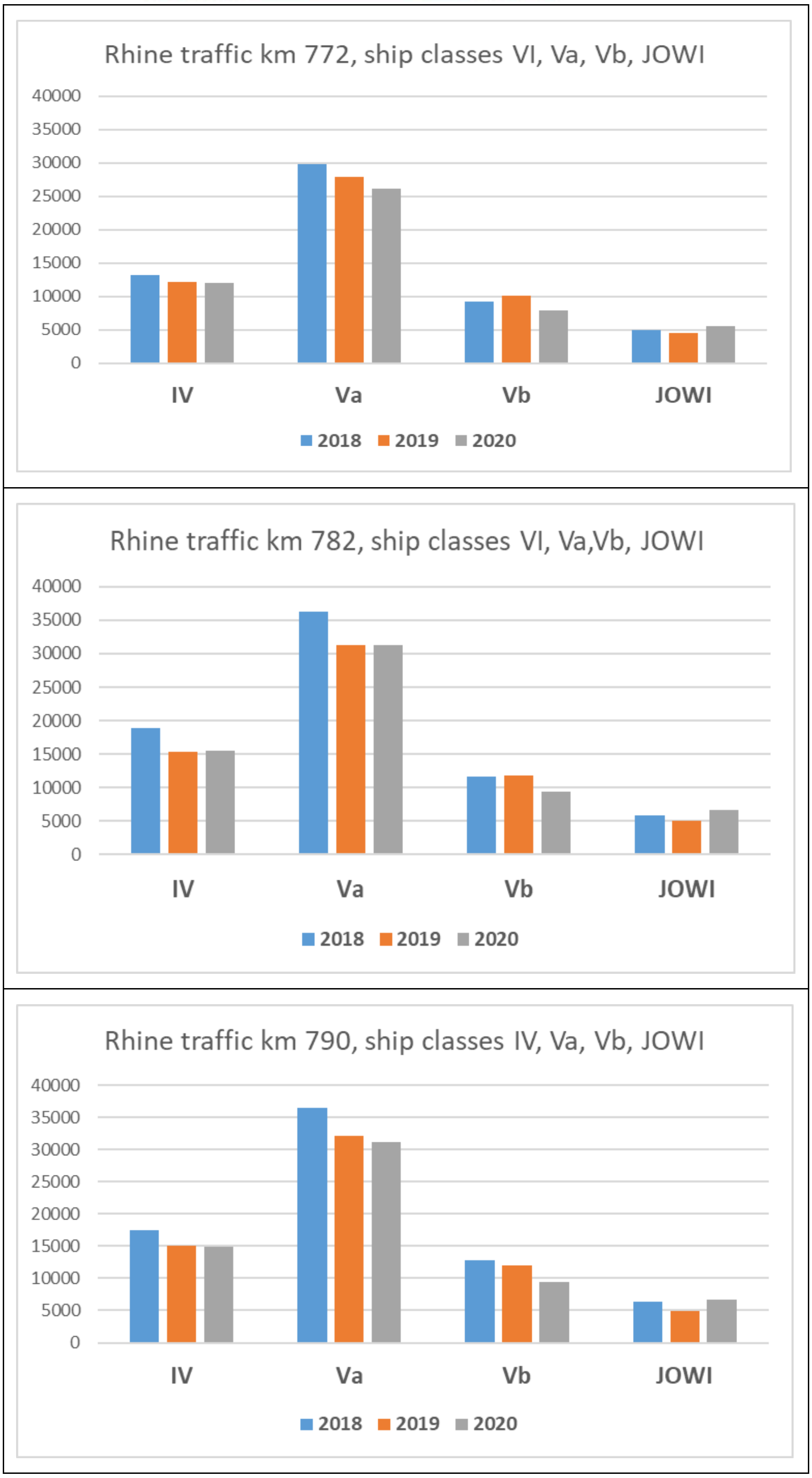


Fig. 5.6: Comparison of the number of vessels of the individual length classes IV, Va, Vb, and JOWI

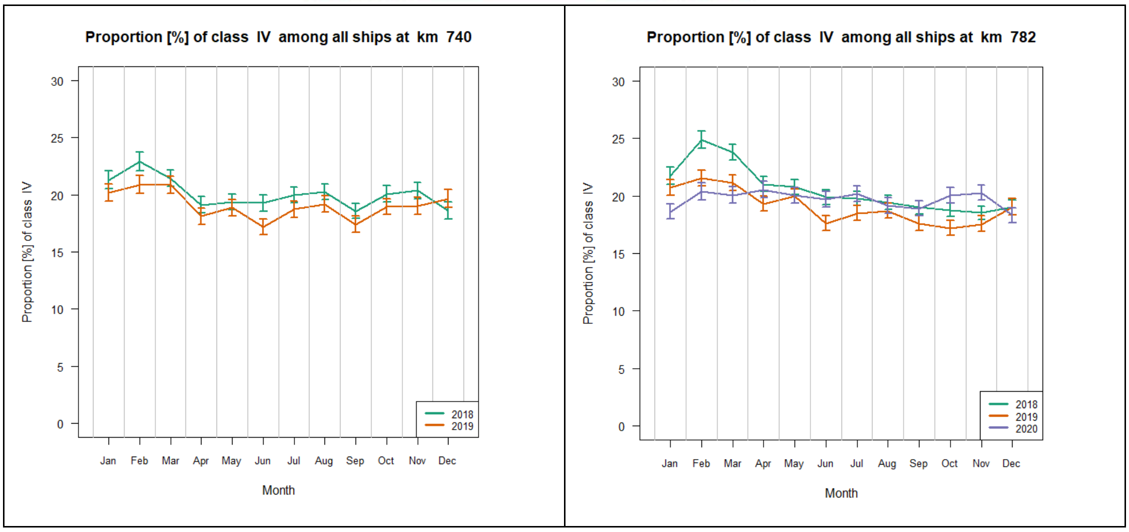


Fig. 5.7: Monthly shares of Class IV vessels (85 m) in total traffic at Neuss (km 740) and Duisburg (km 780).

Ship class Va (110 m)

Vessels in the 110 m size class (large Rhine vessel) have by far the largest share of shipping traffic in the Duisburg area. The share of ships of this length class near Duisburg was about 35-41% in 2018/2020. Vessel numbers on the Rhine-km 782 were about 5,000 vessels higher in 2018 (n= 36,259) than in 2019 (n=31,234) and 2020 (n=31,194). The Rhine-km 790 also shows a similar pattern with about 2,500 more vessels in 2018 (n=36,391) than in the following years 2019 (n=32,038) and 2020 (n=31,206) (Tab. 5.2; Fig. 5.6). The percentage share of 110 m vessels in total traffic was comparable in the course of the year in the three study years, but showed a slightly increased share in the 2nd half of 2018 (Fig. 5.8).

Fig. 5.8: Monthly shares of Class Va vessels (110 m) in total traffic at Neuss (km 740) and Duisburg (km 780).

Ship class Vb (135 m, width 11.4 m)

Ships in the 135 m size class also have a significant share of shipping traffic in the Duisburg area. The share of vessels in this length class near Duisburg was around 11-14% in 2018-2020. The number of 135 m vessels at km 782 in 2018 (n= 11,595) was at the same level as in 2019 (n=11,785). In 2020, there were significantly fewer 135 m vessels (km 782: 9,440; km 790: 9,417) in the Duisburg area. A clearly different trend in the shares of total traffic for 2018 compared to 2019 and 2020 cannot be determined (Fig. (Tab. 5.2; Fig. 5.6 Fig. 5.9).

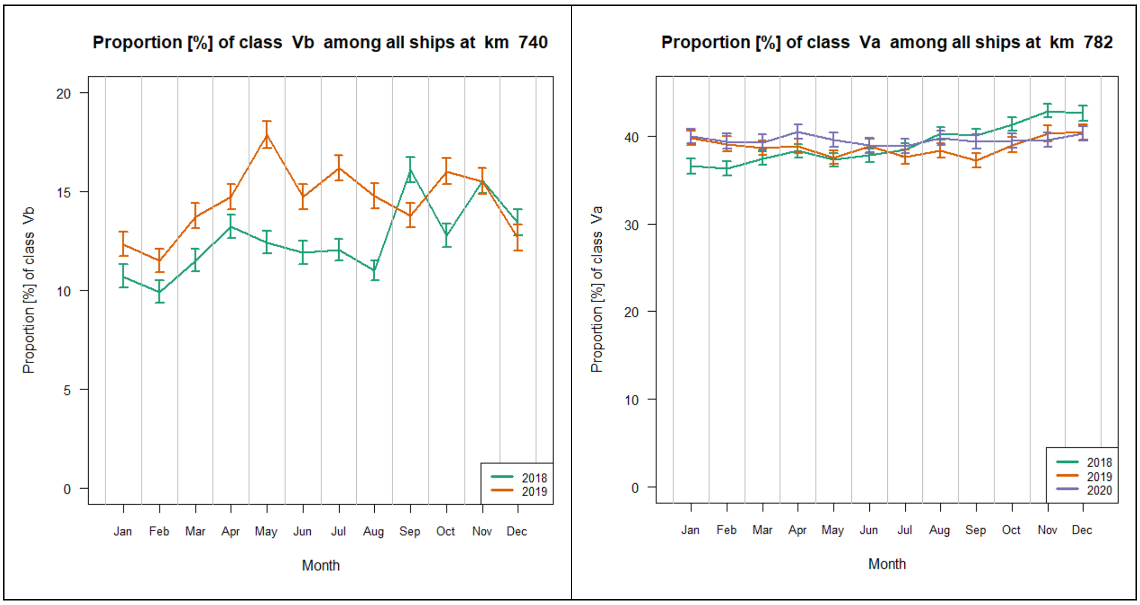


Fig. 5.9: Monthly shares of Class Vb (135 m) vessels in total traffic at Neuss (km 740) and Duisburg (km 780).

JOWI class: (135 m, "XL" width up to 17.5 m).

The particularly wide 135 m vessels (width up to 17.5 m) of the JOWI class also have an important share in shipping traffic in the Duisburg area with 6-8%. The number of ships on the Rhine at km 782 in 2018 (n= 5,920) was about 900 ships higher than in 2019 (n=5,057) while 5,571 ships were detected in 2020. A similar trend can be seen at Rhine-km 790, where in 2018 (n=6,352) about 1,300 more vessels passed than in the following year 2019 (n=4,991). In 2020, a similar level as in 2018 was reached with 6,643 (Tab. 5.2; Fig. 5.6).

The percentage share of the JOWI class showed a clear decrease at Rhine-km 740 (Neuss) in the 2nd half of the year 2018. At Rhine-km 782, the lowest share of the JOWI class (2%) in the total traffic was in July (Fig. 5.10).

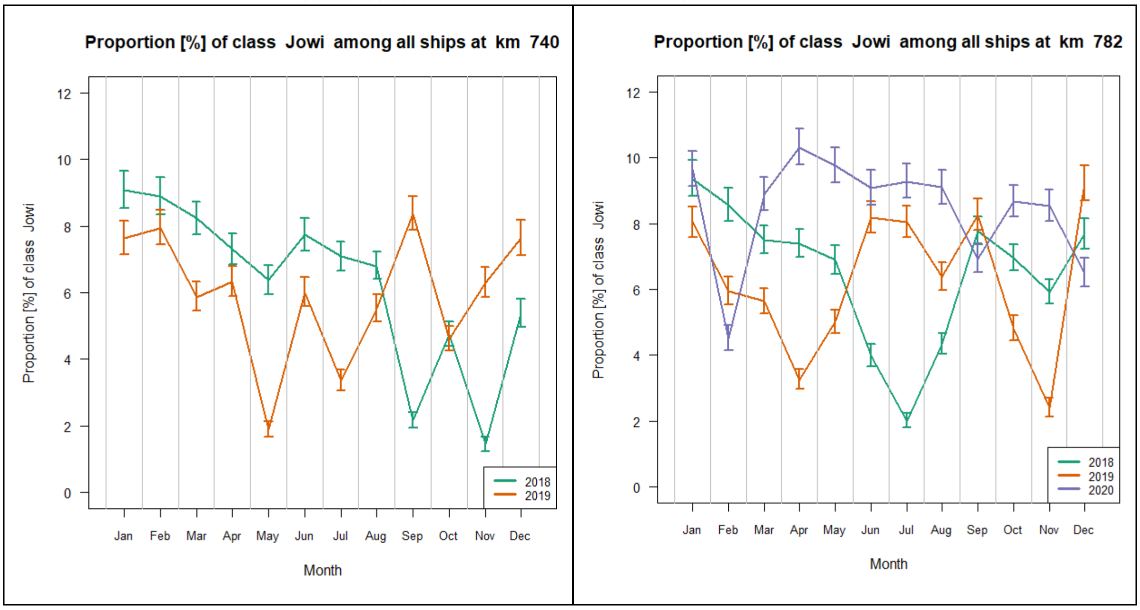


Fig. 5.10: Monthly shares of Jowi vessels (135 m, "XL"width) in total traffic at Neuss (km 740) and Duisburg (km 780)

Fig. 5.11: The container vessel "IVERNA" (length:135 m, width 14.2 m) belongs to the Jowi class.

5.2.3 Ship classes C-U (coupled units) and VIa, VIb and VIc (pushed units)

In Table 5.3, both the number and the respective shares of the coupled units (C-U) and the pushed convoys (VIa = 2 barges; VIb = 4 barges; VIc = 6 barges) in the total traffic on the Rhine are compiled for the years 2018-2020. Fig. 5.12 shows the respective number of coupled units and pushed convoys.

Ship class	Coupled unit		VIa		VIb		VIc	
km 772	n	%	n	%	n	%	n	%
2018	1989	2,8	2088	2,9	2076	2,9	382	0,5
2019	1646	2,4	1795	2,6	2647	3,8	633	0,9
2020	2088	3,3	1514	2,4	1992	3,1	477	0,7
Ship class	Coupled unit		VIa		VIb		VIc	
km 782	n	%	n	%	n	%	n	%
2018	2552	2,8	2108	2,3	2107	2,3	392	0,4
2019	1872	2,3	1799	2,2	2371	2,9	552	0,7
2020	2508	3,2	1454	1,8	2043	2,6	635	0,8
Ship class	Coupled unit		VIa		VIb		VIc	
km 790	n	%	n	%	n	%	n	%
2018	3111	3,0	2437	2,4	3982	3,9	1323	1,3
2019	1918	2,2	1742	2,0	3355	3,8	1912	2,2
2020	2620	3,0	1497	1,7	3175	3,7	2213	2,6

Tab. 5.3: Number and percentage share of pushed convoys (2, 4, 6 barges) of ship classes VIa, VIb, VIc and coupled units in the Duisburg area in the years 2018-2020.

Fig. 5.13: Coupling unit consisting of a 110 m vessel (Va) and two barges (Photo: D. Busch, LANUV)

Fig. 5.12: Comparison of the number of coupled units (C-U) and pushed convoys with 2, 4 or 6 barges

Coupled units (C-U)

A coupled unit usually consists of a larger vessel and a barge. The vessel is usually coupled lengthwise with a barge. However, a barge can also be driven sideways. On the Rhine, it is also possible to observe three-ship convoys in which one barge is coupled lengthwise and a second barge is driven sideways. (Fig. 5.13).

The most commonly used barge is the Europa-Barge Type IIa with a length of 76.50 m, a width of 11.40 m, a draught of up to 3.7 m and a cargo capacity of up to 2,850 tonnes. Thus, coupled convoys can reach a length of up to 200 m.

The share of coupled vessels in the total traffic was in the order of 2-3 % with about 2,000 to 3,000 vessels and shows different fluctuations in the course of the year. The number of coupled convoys on the Rhine at km 782 were at a similar level in 2018 (n= 2,552) as in 2020 (n=2,508). In 2019, the number was about 25 % lower with 1,872 dressings. At Rhine-km 790, a total of 3,111 coupling associations were registered in 2018. The number decreased to 1,918 in 2019 (reduction 37%) and increased again in 2020 (Tab. 5.3; Fig. 5.12).

In 2018, the highest number of coupled convoys sailed at Rhine-km 782 in the months of October to December. The increased number of coupled convoys at Rhine-km 782 in 2018 might have been an effect of the low water levels in 2018, when larger pushed convoys could not navigate. In 2018, there was an increase in the percentage of coupled convoys in the total traffic (Fig. 5.14).

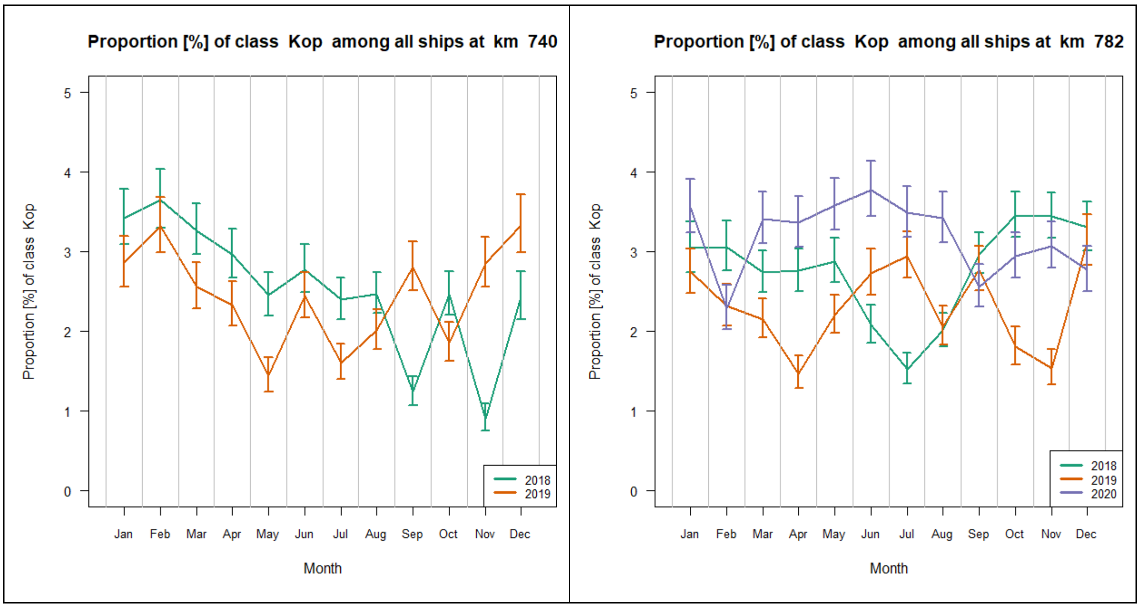


Fig. 5.14: Monthly shares of coupled units in total traffic at Neuss (km 740) and Duisburg (km 782).

Kop = Coupled units (C-U)

Pushed convoys

In pushed convoys, the barges are pushed by a special push boat without its own loading capacity. When sailing upstream, two barges are usually driven side by side. When going downstream, one tries to keep the convoy, which is more difficult to steer, as short as possible and then drives three barges next to each other in a convoy of six.

The largest possible dimensions for pushed convoys with six barges are 269.5 m × 22.8 m when travelling upstream and 193.0 m × 34.2 m when travelling downstream.

Fig. 5.15: Pushed convoy with 6 barges loaded full of iron ore and coal near Duisburg (Photo: D. Busch, LANUV NRW)

Pushed convoys with 2 barges (VIa)

Fig. 5.16: Schematic of a pushed convoy with 2 barges, upstream and downstream travel

On the Rhine near Duisburg, about 1500 to 2500 push boats per year travel with 2 barges. The share of the total traffic is about 2-3 %. In 2018, the number of 2-barge pushed convoys (n=2,088) at km 782 was increased compared to 2019 (n=1,795) and 2020 (n=1,514). At km 790, this increase was even more pronounced in 2018 (n=2,437) compared to 2019 (n=1,742) and 2020 (n=1,497). Presumably, the larger pushed convoys were significantly impeded at very low water levels in 2018, so that only a few barges could be used (Tab. 5.3; Fig. 5.12).

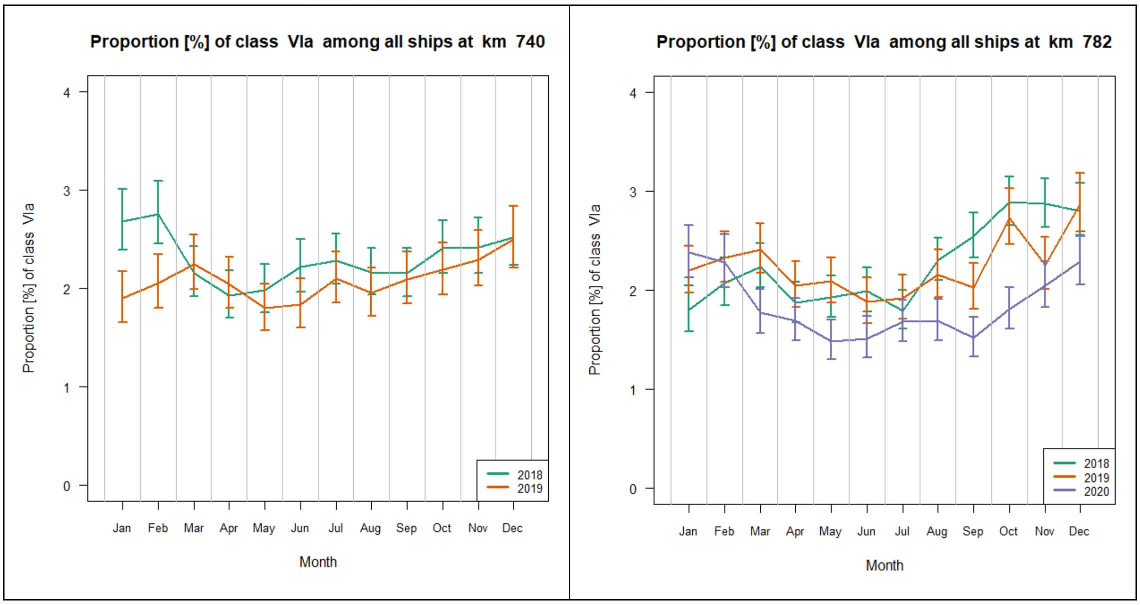


Fig. 5.17: Monthly shares of pushed convoys with 2 barges in total traffic at Neuss (km 740) and Duisburg (km 782)

The number of push boats with two barges is similar at Rhine-km 740 (Neuss) in 2018 and 2019. In the Duisburg area (Rhine-km 782), the number of push boats with 2 barges increases more significantly in the course of 2018 in the 2nd half of the year than observed in the following two years.

Pushed convoys with 4 barges (VIb)

Fig. 5.18: Schematic of a pushed convoy with 4 barges

The share of pushed convoys with four barges in the total traffic is between 2.5% and 4% at Rhine-km 772 and 782 and about 4% at Rhine-km 790. At Rhine-km 782, lower proportions were observed in 2018 (n=2,107) for pushed convoys with four barges than in 2019 (n=2,371). In 2020, only 2,043 pushed convoys with four barges were detected here (Tab. 5.3; Fig. 5.12)

Fig. 5.19 shows the course of the numbers of the four-barge convoys. The mean numbers of thrust units with four barges fluctuate greatly over the course of the year. A common rhythm of the three years is not recognizable. In 2018, there was a clear increase in the shares of total traffic between May and July, after which the shares fell sharply again until October and remained constant at a low level in November and December.

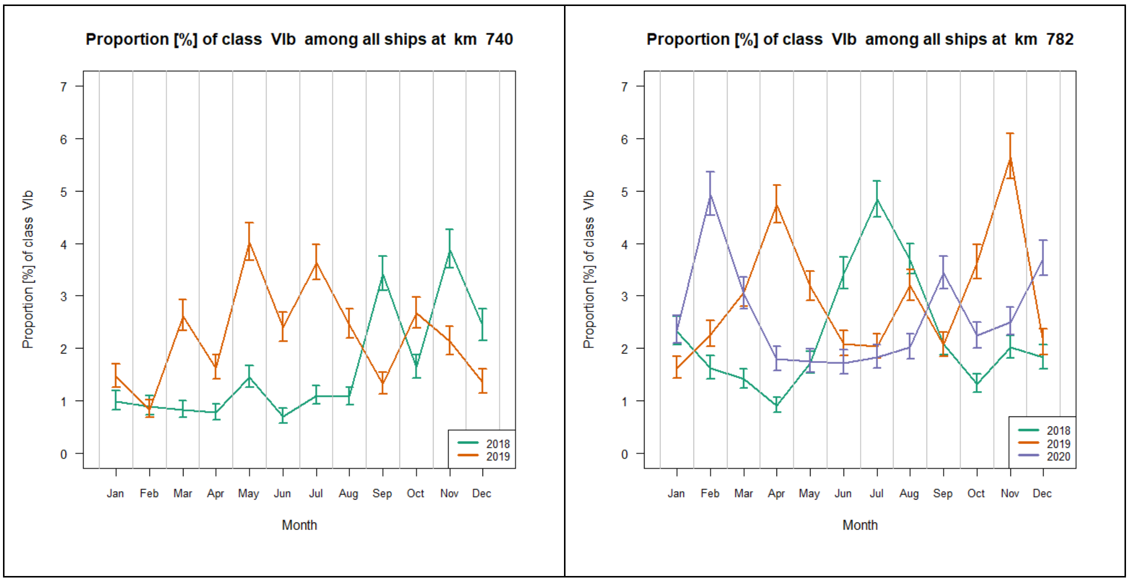


Fig. 5.19: Monthly shares of pushed convoys with 4 barges in total traffic at Neuss (km 740) and Duisburg (km 782).

Pushed convoys with 6 barges (VIc)

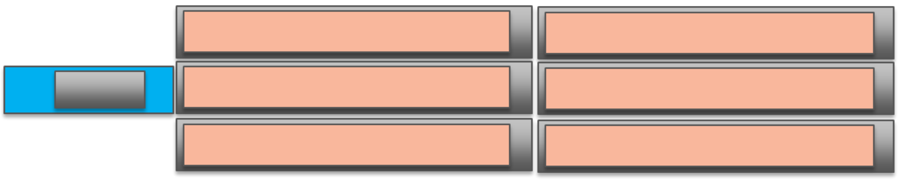


Fig. 5.20: Schematic of a pushed convoy with 6 barges, downstream travel

The share of push boats with 6 barges in the total traffic at Rhine-km 782 was about 0.7-0.9 % in 2019 (n=552) and 2020 (n=635). In the low water year 2018 (n=392), this share was roughly halved with 0.4-0.5 %. Downstream of the port of Duisburg, the share of 6 barges convoys was about 2.2-2.6 % in 2019 (n=1.912) and 2020 (n=2.213). Again, the share of total traffic in 2018 (n=1.323) was roughly halved with 1.3%.

Due to their length, pushed convoys with six barges require a considerable fairway width when travelling upstream, especially in curves. Not only because of the draft of the barges but also due to the reduced width of the fairway at low water, these 6-barge pushed convoys were significantly restricted in 2018. Particularly in the 2nd half of 2018, the number of 6 barges convoys declined sharply. (Fig. 5.21)

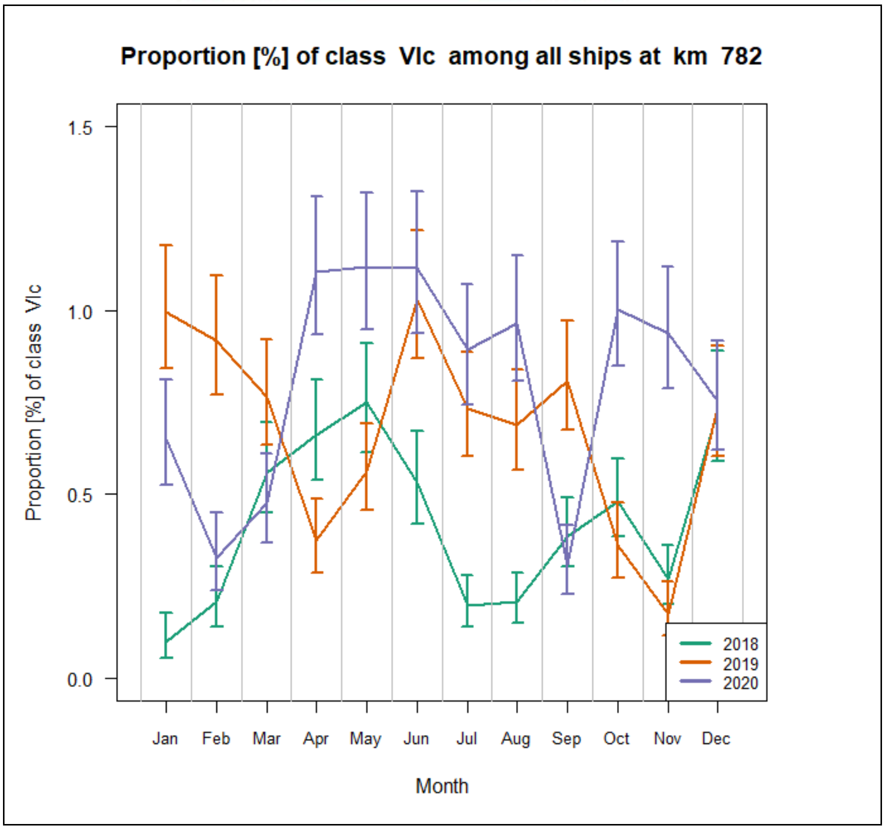


Fig. 5.21: Monthly shares of pushed convoys with 6 barges in total traffic at Duisburg (km 782).

-no pushed convoys with 6 barges at Neuss-

Fig. 5.22: A new butan gas tanker (110 m) on the Rhine, equipped with SCRT-System
(Photo: D. Busch, LANUV)

6. Statistical evaluation of the shares of ship classes in total traffic and fairway depths

Figs. 6.1a-i show the relationship between fairway depth and the shares of selected ship classes in the total number of ships. The fairway depth and the share of the ship class shown is represented by a gray symbol for each individual day. Because the daily values show considerable fluctuation that makes it difficult to discern a systematic pattern, the daily values have been smoothed by a spline function (solid lines). This shows the mean course of a year freed from random fluctuations. Since this mean course was derived from variables subject to random fluctuations, the mean course is also still subject to a certain degree of uncertainty. This is indicated by a dashed line, the 95% confidence band.

This is to be interpreted in such a way that 95% of all future courses, which develop under the same conditions as in the represented year, are to be expected within this band. The practical use of the confidence band is that it can be used to compare trajectories from different years: if the confidence bands of two trajectories overlap throughout the trajectory, they are not statistically significantly different. If they do not overlap anywhere, they are to be considered completely different (the difference can no longer be explained by random effects). If they partially overlap, then neither of these two extreme statements can be made, but partial differences exist in some phases and are not present in other phases.

First of all, it is striking that the trajectories in 2018 (green curves) show considerable proportions of ships at fairway depths significantly below 300 cm. This applies not only to vessels with correspondingly shallow drafts, but to all size classes. This fact can be interpreted to mean that larger vessels load correspondingly less deep at low water and continue to participate in traffic. For some size classes (VIa at km 744 and 780, VIa, JOWI, and C-U at km 780), there is even a certain tendency for some size classes to be represented with a larger share at low fairway depths. Most other size classes are represented with correspondingly smaller proportions at low water levels.

Fig. 6.1.a: Tanker vessels at the „Oil Island“ in the port of Duisburg (Foto: D. Busch, LANUV)

Fig. 6.1: Relationship between the shares of a ship class in the total traffic and the fairway depth at km 744 and 780.
Daily observations (grey symbols) and the temporal course in smoothed form (spline with 95% confidence interval) are shown, separately per year.

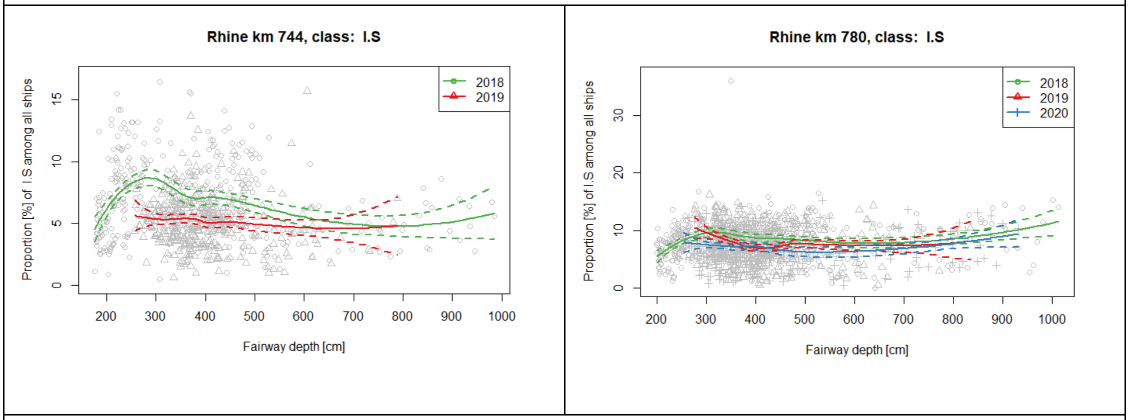


Fig. 6.1.a: Share of class I-O (I.s) in all vessels at km 744 (Düsseldorf gauge) and at km 780 (gauge Duisburg-Ruhrort) as a function of fairway depth.

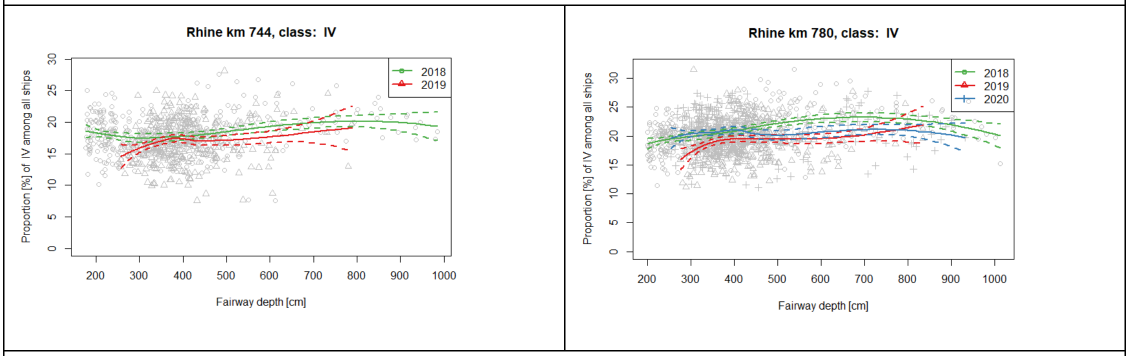


Fig. 6.1.b: Share of class IV (85 m) in all vessels at km 744 (Düsseldorf gauge) and at km 780 (gauge Duisburg-Ruhrort) as a function of fairway depth.

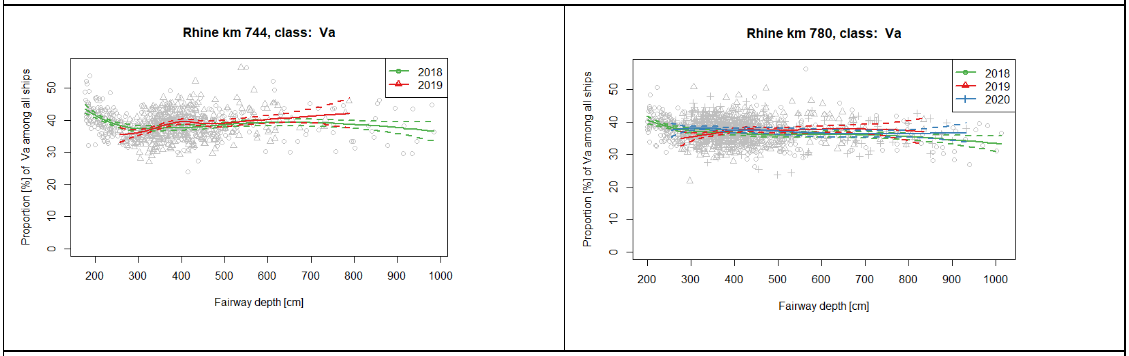


Fig. 6.1.c: Share of class Va (110 m) in all vessels at km 744 (Düsseldorf gauge) and at km 780 (gauge Duisburg-Ruhrort) as a function of fairway depth.

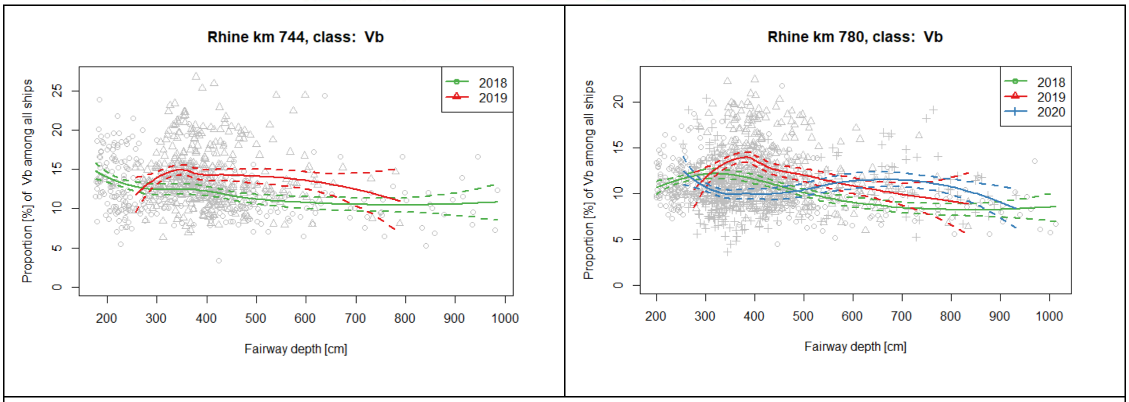


Fig. 6.1.d: Share of class Vb (135 m) in all vessels at km 744 (Düsseldorf gauge) and at km 780 (gauge Duisburg-Ruhrort) as a function of fairway depth.

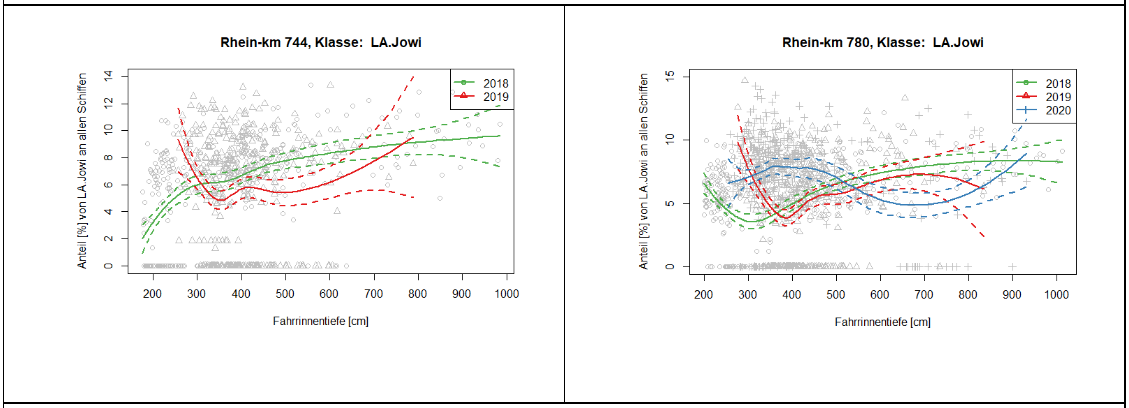


Fig. 6.1e: Share of the JOWI-class (135 m) in all vessels at km 744 (Düsseldorf gauge) and at km 780 (gauge Duisburg-Ruhrort) as a function of fairway depth.

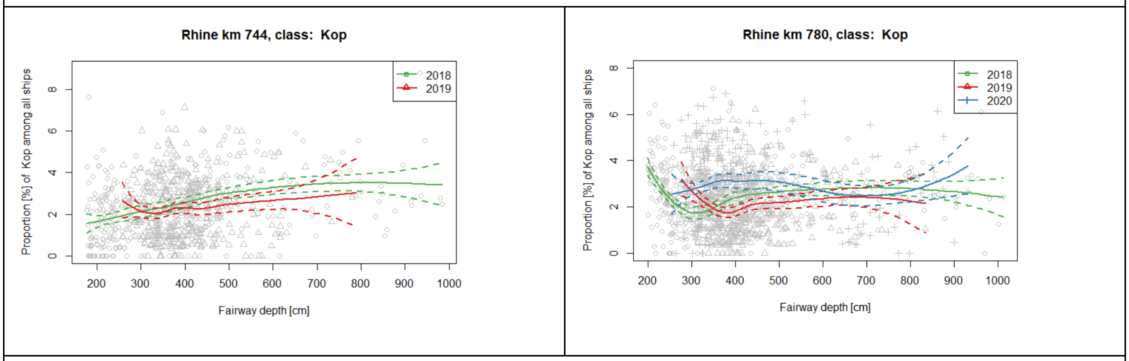
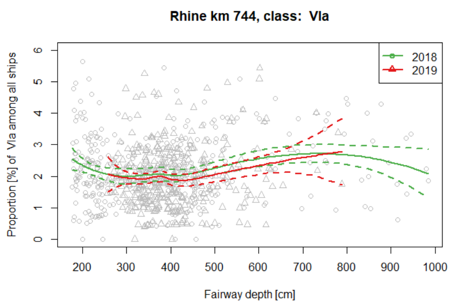


Fig. 6.1f: Share of coupled units in all vessels at km 744 (Düsseldorf gauge) and at km 780 (gauge Duisburg-Ruhrort) as a function of fairway depth.



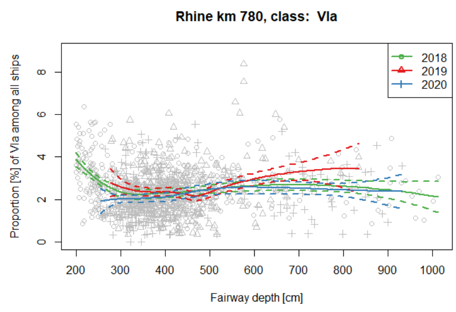
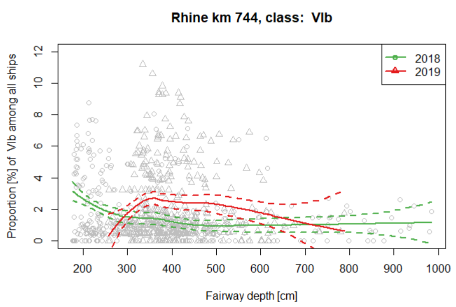


Fig. 6.1g: Share of pushed convoys with two barges (VIa) in the shipping traffic at km 744 (Düsseldorf gauge) and at km 780 (Duisburg-Ruhrort gauge) as a function of fairway depth.



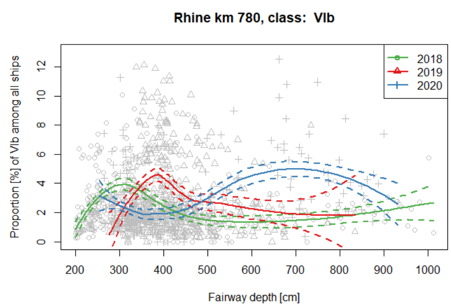


Fig. 6.1h: Share of pushed convoys with four barges (VIb) in the shipping traffic at km 744 (Düsseldorf gauge) and at km 780 (Duisburg-Ruhrort gauge) as a function of fairway depth.

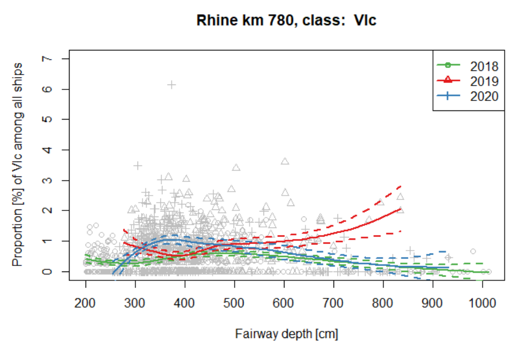


Fig. 6.1.i: Share of pushed convoys with six barges (VIc) in the shipping traffic at km 780 (Duisburg-Ruhrort gauge) as a function of fairway depth.

The analyses presented show for Rhine kilometers 744 and 780 that the structure of inland navigation in terms of vessel numbers and the annual course of distribution among the vessel classes in 2018 differs from that in 2019 and 2020 due to the lower water levels. Therefore, a generally equal distribution of moving ships among the different size classes over all years cannot be assumed for emission calculations and modelling. It is therefore recommended to use the actual shipping traffic recorded for the year of analysis as a basis for emission modelling.

7. Speed analyses

There is a close correlation between a ship´s journey through the water, the diesel consumption and the NO_X and particulate matter (PM) emissions generated from the burnt diesel. In addition to the number of ships travelling on the Rhine, the determination of the respective ship speeds is therefore also an essential basis for the estimation of the emissions caused.

Due to the different river morphology (shallows, width of the river bed, bends, tributary mouths), port and canal entrances, river quays, etc. as well as the different water levels and traffic densities, the speed of the ships can be very variable in the different river sections. Therefore, in addition to the distribution of moving vessels among the different size classes, it is also advisable to consider the speed distributions for each individual river kilometer separately.

The speed over ground can be derived from the AIS signals. When travelling upstream, the ship must sail against the current. The velocity speed is then added to the speed over ground. If the ship is going downstream, the velocity speed can be subtracted from the speed over ground. The average flow velocity of the Lower Rhine in the fairway is in the range of 1.6-1.8 m/s (6-6.5 km/h). It is closely correlated with the changing water levels or discharge rates.

The evaluation of the ships' speeds was carried out separately according to ship classes and upstream and downstream navigation. Since the whole year was considered in each case, an indirect averaging of the influences of the different water levels or flow velocities results over the year under investigation. In the following, the speed distributions on the Lower Rhine are shown, using the example of ship classes IV (85 m), Va (110 m); Vb (135 m), coupled convoys and pushed convoys with two or four barges, which also have the highest percentage shares of traffic and transport volume on the Rhine.

The comparison of the speed distributions in 2018 and 2019 shows a fairly similar picture for the upstream travelling ships. Almost all vessel sizes and coupled units mainly travel in the speed range of 2-3 m/s over ground (7.2-10.8 km/h). Despite the similar picture, however, the percentage shares in the respective speed classes vary in a year-on-year comparison. Only at kilometer 730 the majority of vessels travel in the speed range 3-4 m/s (10.8-14.4 km/h). The average speed of upstream going vessels over ground on the Lower Rhine in North Rhine-Westphalia is in the range of 9-10 km/h range.

The pushed convoys also predominantly travel in the speed range of 2-3 m/s. For the pushed convoys with four barges, it is noticeable that below Duisburg the center of gravity of the speeds travelled is somewhat lower in the range of 1-2 m/s (3.6-7.2 km/h) in 2018 .

A comparison of the years 2018 and 2019 shows a clear difference for the downstream travelling vessels. In 2018, the center of gravity of speeds in the range of 4-5 m/s (14.4-18 km/h) was on average slower than in 2019. For vessel classes IV-Vb, the speeds´ center of gravity is more frequently 5-6 m/s (18.8-21.6 km/h). The average speed of the downstream riders over ground in the Lower Rhine area of North Rhine-Westphalia is around 20 km/h.

Pushed convoys and coupled units generally travelled mainly at 4-5 m/s in both years. The speed reduction observed in 2018 for the upstream going pushed convoys with four barges below Duisburg could not be observed for the downstream drivers.

Percentage shares of the various-**upstream-** travel speeds of the most important ship classes on selected river kilometers in the Neuss/Düsseldorf/Duisburg area in 2018											
Class	Rhine-km	Year	Travel	< 1 m/s	1-2 m/s	2-3 m/s	3-4 m/s	4-5 m/s	5-6 m/s	6-7 m/s	> 7 m/s
IV	730	2018	up	0,5	1,3	28,5	**48,2**	8,7	9,7	2,9	0,1
IV	740	2018	up	0,1	5,2	**59,8**	24,1	4,7	4,5	1,2	0,2
IV	750	2018	up	0,2	1,2	**57,6**	25,1	5,4	6,9	3,2	0,5
IV	772	2018	up	--	1,0	**49,7**	31,2	8,3	7,3	2,4	0,1
IV	782	2018	up	1,8	3,8	**42,5**	28,3	9,2	11,4	2,9	0,2
IV	790	2018	up	0,2	2,2	**51,7**	23,7	8,7	10,1	3,1	0,4
Va	730	2018	up	0,4	1,3	36,3	**46,5**	6,9	6,5	1,9	0,1
Va	740	2018	up	--	4,2	**64,9**	20,6	4,5	4,4	1,2	0,1
Va	750	2018	up	0,2	0,8	**65,1**	22,6	3,5	5,2	2,1	0,5
Va	772	2018	up	0,1	1,2	**54,8**	28,9	7,7	5,0	2,2	0,2
Va	782	2018	up	0,7	2,5	**56,7**	28,2	6,2	4,7	0,9	0,1
Va	790	2018	up	0,6	4,4	**64,3**	19,2	5,5	4,7	1,2	0,1
Vb	730	2018	up	--	0,8	33,0	**49,2**	7,6	6,8	2,4	0,3
Vb	740	2018	up	--	3,8	**61,3**	24,7	4,4	4,3	1,58	0,1
Vb	750	2018	up	0,1	1,0	**57,6**	30,6	3,8	3,9	2,6	0,4
Vb	772	2018	up	0,1	2,4	**51,3**	30,7	7,8	5,7	2,0	0,1
Vb	782	2018	up	0,2	1,8	**57,3**	30,7	5,6	4,0	0,5	0,1
Vb	790	2018	up	1,5	9,8	**58,5**	20,4	5,0	3,6	1,1	0,2
Jowi	730	2018	up	0,1	0,8	38,9	**48,6**	6,9	3,8	0,8	--
Jowi	740	2018	up	--	10,8	**63,0**	16,8	3,8	5,3	0,2	--
Jowi	750	2018	up	--	1,7	**61,6**	26,0	3,8	5,8	1,0	--
Jowi	772	2018	up	0,2	4,7	**56,7**	28,0	6,2	3,2	0,9	0,1
Jowi	782	2018	up	0,1	2,4	**62,4**	23,9	6,8	4,1	0,3	--
Jowi	790	2018	up	1,9	10,8	**60,8**	16,4	6,3	3,3	0,5	--
VIa	730	2018	up	--	1,4	**54,3**	29,4	8,1	5,8	0,9	--
VIa	740	2018	up	0,1	14,8	**69,0**	6,1	6,7	3,1	--	--
VIa	750	2018	up	--	4,2	**75,4**	9,8	4,6	5,2	0,9	--
VIa	772	2018	up	0,5	14,3	**60,3**	14,9	5,9	3,4	0,7	--
VIa	782	2018	up	0,1	14,5	**64,5**	11,1	5,4	3,5	0,7	--
VIa	790	2018	up	8,0	22,7	**55,9**	5,0	4,8	3,0	0,5	--
VIb	730	2018	up	--	0,5	**67,0**	25,9	4,6	2,0	--	--
VIb	740	2018	up	0,4	14,6	**68,6**	10,0	4,6	1,7	--	--
VIb	750	2018	up	--	5,4	**78,5**	9,5	4,5	2,1	--	--
VIb	772	2018	up	5,5	**40,5**	40,3	6,9	4,2	2,3	0,2	--
VIb	782	2018	up	2,8	**46,4**	41,5	5,0	2,8	1,5	0,2	--
VIb	790	2018	up	16,4	**60,3**	19,2	1,6	1,6	0,8	0,1	--
C-U	730	2018	up	0,3	1,0	**55,0**	27,3	7,6	8,5	0,4	--
C-U	740	2018	up	0,1	15,7	**66,6**	5,6	8,5	3,3	0,1	--
C-U	750	2018	up	0,2	1,9	**72,2**	12,0	4,9	7,8	1,0	--
C-U	772	2018	up	1,2	8,5	**63,6**	17,1	5,6	3,6	0,5	--
C-U	782	2018	up	0,8	7,5	**70,2**	11,6	6,7	3,0	0,2	--
C-U	790	2018	up	10,9	18,7	**54,4**	6,6	5,8	3,4	0,2	--

Tab. 7.1a: Distribution of the percentage shares of the various travel -upstream- speeds of the most important ship classes on selected river kilometers in the Neuss/Düsseldorf/Duisburg area in 2018

Percentage shares of the various-**upstream-** travel speeds of the most important ship classes on selected river kilometers in the Neuss/Düsseldorf/Duisburg area in 2019											
Class	Rhine-	Year	Travel	< 1 m/s	1-2 m/s	2-3 m/s	3-4	4-5 m/s	5-6	6-7 m/s	> 7 m/s
IV	730	2019	up	0,2	1,0	34,9	**39,4**	5,5	12,8	3,1	3,0
IV	740	2019	up	0,5	4,9	**59,4**	19,5	6,2	7,9	1,6	0,0
IV	750	2019	up	0,2	1,3	**58,0**	20,1	3,8	12,7	3,9	0,1
IV	772	2019	up	0,0	0,9	**46,6**	29,0	5,3	13,9	4,2	0,1
IV	782	2019	up	0,8	4,1	**43,8**	23,6	10,4	14,7	2,4	0,1
IV	790	2019	up	0,0	2,4	**49,9**	20,7	7,4	16,3	3,2	0,1
Va	730	2019	up	0,3	1,0	42,1	**42,1**	4,1	8,6	1,8	0,0
Va	740	2019	up	0,0	2,9	**68,9**	15,9	4,1	7,2	1,0	0,0
Va	750	2019	up	0,2	0,8	**64,2**	20,9	2,5	8,4	3,0	0,1
Va	772	2019	up	0,1	0,5	**54,2**	27,0	4,3	10,6	3,2	0,2
Va	782	2019	up	0,3	1,9	**56,9**	24,2	5,9	9,3	1,5	0,0
Va	790	2019	up	0,2	2,9	**62,0**	17,9	5,2	9,5	2,1	0,1
Vb	730	2019	up	0,3	0,8	28,4	**51,9**	6,0	9,4	2,7	0,4
Vb	740	2019	up	0,0	2,4	**58,8**	26,1	5,1	5,9	1,3	0,4
Vb	750	2019	up	0,1	0,5	**51,0**	34,2	2,6	8,5	2,1	0,9
Vb	772	2019	up	0,0	0,7	**42,2**	35,2	7,0	11,9	2,9	0,1
Vb	782	2019	up	0,0	0,8	**50,7**	31,2	7,8	8,3	1,3	0,0
Vb	790	2019	up	0,0	1,9	**58,0**	23,6	6,1	8,9	1,0	0,4
Jowi	730	2019	up	0,1	0,7	38,7	**49,5**	3,8	6,4	0,8	0,0
Jowi	740	2019	up	0,0	5,1	**68,2**	18,8	3,7	3,8	0,4	0,0
Jowi	750	2019	up	0,0	1,3	**56,5**	32,0	2,9	5,2	1,9	0,1
Jowi	772	2019	up	0,3	2,2	**51,2**	31,5	4,8	8,6	1,4	0,0
Jowi	782	2019	up	0,1	2,0	**56,1**	27,4	6,7	6,6	1,0	0,0
Jowi	790	2019	up	0,0	3,7	**61,6**	20,5	6,5	7,0	0,7	0,0
VIa	730	2019	up	0,0	1,5	**50,8**	27,5	11,9	7,9	0,4	0,0
VIa	740	2019	up	0,0	11,6	**60,8**	11,0	11,2	5,0	0,2	0,0
VIa	750	2019	up	0,0	4,2	**75,4**	9,8	4,6	5,2	0,9	0,0
VIa	772	2019	up	0,5	14,3	**60,3**	14,9	5,9	3,4	0,7	0,0
VIa	782	2019	up	0,1	14,5	**64,5**	11,1	5,4	3,5	0,7	0,0
VIa	790	2019	up	8,0	22,7	**55,9**	5,0	4,8	3,0	0,5	0,0
VIb	730	2019	up	0,0	2,4	**68,6**	17,9	5,8	5,3	0,0	0,0
VIb	740	2019	up	0,4	11,1	**73,0**	4,9	8,4	2,2	0,0	0,0
VIb	750	2019	up	0,0	2,6	**79,7**	9,1	4,3	3,9	0,4	0,0
VIb	772	2019	up	6,0	28,8	**48,8**	8,6	3,9	3,7	0,2	0,0
VIb	782	2019	up	1,2	**42,8**	38,0	6,9	8,8	2,4	0,0	0,0
VIb	790	2019	up	8,8	**58,7**	22,6	2,8	4,5	2,6	0,0	0,0
C-U	730	2019	up	0,4	2,2	**53,4**	31,9	7,0	5,1	0,0	0,0
C-U	740	2019	up	0,1	11,7	**70,4**	7,9	8,1	1,8	0,0	0,0
C-U	750	2019	up	0,3	1,0	**69,2**	18,4	4,8	6,1	0,1	0,0
C-U	772	2019	up	0,2	0,8	**55,6**	24,6	6,8	11,4	0,8	0,0
C-U	782	2019	up	0,1	3,7	**65,5**	14,1	11,1	5,2	0,3	0,0
C-U	790	2019	up	0,8	5,9	**65,8**	11,6	8,8	6,8	0,3	0,0

Tab. 7.1b: Distribution of the percentage shares of the various travel -upstream- speeds of the most important ship classes on selected river kilometers in the Neuss/Düsseldorf/Duisburg area in 2019

Percentage shares of the various -**downstream**- travel speeds of the most important ship classes on selected river kilometers in the Neuss/Düsseldorf/Duisburg area in 2018											
Class	Rhine-km	Year	Travel	< 1 m/s	1-2 m/s	2-3 m/s	3-4 m/s	4-5 m/s	5-6 m/s	6-7 m/s	>7m
IV	730	2018	down	0,2	0,9	18,6	13,0	**34,7**	29,1	3,5	0,1
IV	740	2018	down	0,2	6,8	29,9	14,8	21,9	**22,5**	3,7	0,1
IV	750	2018	down	0,2	2,9	16,7	8,8	26,8	**35,2**	9,1	0,4
IV	772	2018	down	0,1	1,1	16,1	8,2	**42,8**	28,1	3,6	0,1
IV	782	2018	down	1,7	2,7	14,6	9,6	**33,2**	32,5	5,5	0,2
IV	790	2018	down	0,2	2,7	16,4	9,1	**35,2**	32,1	4,1	0,2
Va	730	2018	down	0,1	0,6	13,2	10,1	**39,5**	32,1	4,3	0,1
Va	740	2018	down	0,1	4,3	17,2	9,5	**34,9**	30,0	3,8	0,1
Va	750	2018	down	0,2	0,6	11,1	6,3	**31,2**	39,9	10,3	0,5
Va	772	2018	down	0,1	0,5	11,8	7,8	**45,8**	29,7	4,3	0,1
Va	782	2018	down	0,8	1,6	8,4	6,7	**43,5**	33,6	5,2	0,3
Va	790	2018	down	0,6	3,0	10,8	6,8	**42,0**	32,5	4,2	0,2
Vb	730	2018	down	0,1	0,7	10,7	13,8	**41,3**	28,4	4,8	0,2
Vb	740	2018	down	0,2	4,0	16,5	10,8	**38,8**	26,0	3,8	0,1
Vb	750	2018	down	0,2	0,3	8,6	8,0	33,4	**38,3**	10,8	0,4
Vb	772	2018	down	0,1	0,6	10,8	10,6	**47,8**	25,7	4,4	0,1
Vb	782	2018	down	0,3	0,9	7,4	8,9	**46,9**	30,4	5,0	0,1
Vb	790	2018	down	1,8	7,1	9,2	6,6	**43,0**	29,1	3,0	0,1
JOWI	730	2018	down	0,1	0,4	11,2	12,4	**48,6**	25,2	2,1	0,1
JOWI	740	2018	down	0,1	7,5	26,7	10,2	**35,3**	18,7	1,5	0,1
JOWI	750	2018	down	0,0	2,0	6,1	6,3	**39,8**	38,1	7,3	0,5
JOWI	772	2018	down	0,2	1,5	13,0	12,6	**50,6**	20,2	1,7	0,1
JOWI	782	2018	down	0,1	1,2	8,6	7,1	**53,7**	27,0	2,2	0,1
JOWI	790	2018	down	2,0	9,3	8,4	4,9	**49,0**	24,4	2,0	0,1
VIa	730	2018	down	0,0	1,7	14,3	12,8	**43,8**	26,5	0,8	0,0
VIa	740	2018	down	0,1	5,1	12,2	9,4	**49,7**	23,0	0,4	0,0
VIa	750	2018	down	0,2	2,0	7,4	4,8	**41,2**	40,2	3,9	0,3
VIa	772	2018	down	2,1	2,6	9,8	17,0	**45,0**	22,7	0,9	0,0
VIa	782	2018	down	0,1	1,6	8,3	11,0	**55,1**	22,3	1,4	0,1
VIa	790	2018	down	5,2	10,3	8,9	10,6	**46,5**	17,3	1,1	0,0
VIb	730	2018	down	0,0	1,3	14,2	18,9	**48,5**	16,7	0,4	0,0
VIb	740	2018	down	0,0	11,6	10,8	11,9	**51,9**	13,8	0,0	0,0
VIb	750	2018	down	0,0	0,0	9,6	8,0	**47,4**	33,1	2,0	0,0
VIb	772	2018	down	1,6	6,3	10,9	19,3	**41,5**	19,9	0,5	0,0
VIb	782	2018	down	0,0	0,9	7,6	16,8	**54,9**	18,5	1,1	0,2
VIb	790	2018	down	8,4	21,1	9,0	11,6	**34,2**	14,7	1,1	0,0
C-U	730	2018	down	0,3	4,8	12,1	11,3	**50,4**	20,1	1,0	0,0
C-U	740	2018	down	0,5	11,5	13,3	9,8	**50,5**	14,1	0,2	0,0
C-U	750	2018	down	0,1	5,9	8,6	4,5	**44,2**	33,5	3,2	0,0
C-U	772	2018	down	0,3	1,1	14,4	13,7	**49,1**	20,2	1,3	0,0
C-U	782	2018	down	0,5	0,7	8,9	11,5	**57,8**	19,2	1,2	0,2
C-U	790	2018	down	8,3	13,4	8,8	7,1	**47,1**	14,1	1,2	0,0

Tab. 7.1c: Distribution of the percentage shares of the various travel –downstream- speeds of the most important ship classes on selected river kilometers in the Neuss/Düsseldorf/Duisburg area in 2018

Percentage shares of the various -**downstream-** travel speeds of the most important ship classes on selected river kilometers in the Neuss/Düsseldorf/Duisburg area in 2019											
Class	Rhine-km	Year	Travel	< 1 m/s	1-2 m/s	2-3 m/s	3-4 m/s	4-5 m/s	5-6 m/s	6-7 m/s	>7m
IV	730	2019	down	0,2	0,7	16,1	12,0	24,2	**42,6**	4,0	0,2
IV	740	2019	down	0,2	6,4	28,7	17,0	16,9	**27,6**	3,1	0,1
IV	750	2019	down	0,2	0,4	21,4	7,5	13,1	**47,3**	9,7	0,4
IV	772	2019	down	0,0	1,1	17,3	7,5	23,2	**43,4**	7,0	0,4
IV	782	2019	down	0,9	1,6	19,1	9,5	24,3	**38,9**	5,5	0,2
IV	790	2019	down	0,1	2,0	19,5	8,0	23,7	**41,0**	5,5	0,2
Va	730	2019	down	0,1	0,5	11,3	7,8	25,4	**49,1**	5,7	0,1
Va	740	2019	down	0,0	2,7	17,2	9,1	24,9	**41,4**	4,4	0,1
Va	750	2019	down	0,1	0,3	12,8	6,4	13,8	**53,9**	12,4	0,4
Va	772	2019	down	0,0	0,4	15,4	5,9	19,9	**49,2**	8,9	0,4
Va	782	2019	down	0,3	0,7	12,9	7,3	26,5	**45,9**	6,0	0,2
Va	790	2019	down	0,3	2,0	15,1	6,4	24,2	**46,0**	5,8	0,2
Vb	730	2019	down	0,1	1,1	9,3	9,6	28,6	**45,8**	5,6	0,0
Vb	740	2019	down	0,0	2,1	16,9	10,5	29,5	**37,3**	3,6	0,0
Vb	750	2019	down	0,2	0,2	10,0	7,4	15,7	**54,3**	11,9	0,3
Vb	772	2019	down	0,0	0,2	14,8	9,2	24,3	**43,7**	7,5	0,2
Vb	782	2019	down	0,2	0,4	11,2	9,4	31,4	**41,5**	5,7	0,2
Vb	790	2019	down	0,2	0,8	12,5	8,5	28,3	**45,2**	4,4	0,0
JOWI	730	2019	down	0,0	2,2	8,9	8,0	**41,8**	37,5	1,6	0,0
JOWI	740	2019	down	0,0	5,8	25,2	11,0	**34,4**	22,8	0,8	0,0
JOWI	750	2019	down	0,0	2,7	9,4	4,2	24,3	**53,7**	5,7	0,1
JOWI	772	2019	down	0,1	0,8	14,7	6,8	35,0	**39,3**	3,2	0,0
JOWI	782	2019	down	0,1	2,8	12,8	6,8	**42,1**	33,1	2,3	0,2
JOWI	790	2019	down	0,2	3,1	12,3	6,0	**39,6**	36,2	2,7	0,1
VIa	730	2019	down	0,0	1,4	21,3	5,7	**46,3**	24,4	0,8	0,0
VIa	740	2019	down	0,0	11,3	12,5	4,6	**48,1**	22,7	0,7	0,0
VIa	750	2019	down	0,2	1,0	18,4	2,1	30,0	**45,3**	3,1	0,0
VIa	772	2019	down	0,0	4,2	17,8	3,2	37,9	35,3	1,6	0,0
VIa	782	2019	down	0,2	9,2	14,8	3,3	**46,8**	24,5	1,1	0,2
VIa	790	2019	down	0,6	12,6	15,4	4,3	**40,5**	25,7	0,9	0,0
VIb	730	2019	down	0,4	0,4	24,5	13,4	**46,8**	14,5	0,0	0,0
VIb	740	2019	down	0,0	11,0	21,7	5,3	**50,7**	11,3	0,0	0,0
VIb	750	2019	down	0,0	0,4	22,7	2,9	**39,2**	34,2	0,7	0,0
VIb	772	2019	down	1,6	5,4	13,6	10,8	**38,9**	29,1	0,6	0,0
VIb	782	2019	down	0,0	3,0	9,1	4,1	**61,0**	22,6	0,2	0,2
VIb	790	2019	down	1,9	19,6	11,1	2,5	**46,4**	17,7	0,8	0,0
C-U	730	2019	down	0,3	0,9	15,7	6,4	**49,8**	26,8	0,1	0,0
C-U	740	2019	down	0,4	6,1	19,5	6,9	**51,1**	16,0	0,1	0,0
C-U	750	2019	down	0,0	0,7	17,0	4,8	31,8	**44,4**	1,4	0,0
C-U	772	2019	down	0,0	2,0	20,0	5,1	**34,6**	36,3	2,0	0,0
C-U	782	2019	down	0,0	1,0	15,2	8,2	**54,1**	20,8	0,7	0,2
C-U	790	2019	down	1,0	3,3	16,5	6,1	**47,6**	24,1	1,3	0,0

Tab. 7.1d: Distribution of the percentage shares of the various travel –downstream- speeds of the most important ship classes on selected river kilometers in the Neuss/Düsseldorf/Duisburg area in 2019

The evaluation shows that the individual ship classes also have different percentage shares of the different speed classes in the river kilometers shown. In addition, there are also different percentages when comparing the years 2018 and 2019.

Different speeds through the water also require different amounts of energy from the ships. This is directly related to the required fuel quantities, whose combustion processes in turn are the starting point for the resulting emission quantities. For this reason, it is necessary to calculate the ship emissions for individual sections in kilometer steps (proposal: according to river kilometers) for a more realistic estimate of the emission quantities.

Figures 7.1 and 7.3 give an overview of the shares of the respective ship classes in the total traffic. Figures 7.2 and 7.4 visualize the speed distributions of vessel classes IV (85m), Va (110m), Vb (135m) as well as of pushed convoys with 2 (VIa) and 4 barges (IVb) and of coupled convoys on the Rhine near Neuss (km 740) and below the port of Duisburg (km 782).

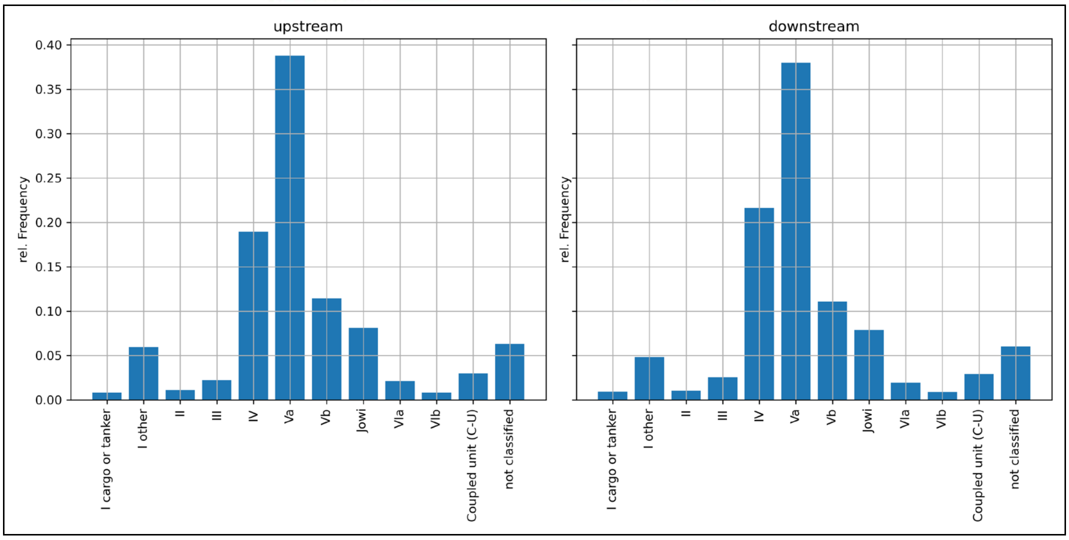


Fig. 7.1: Traffic shares (%) of the different ship classes at Neuss (Rhine-km 740)

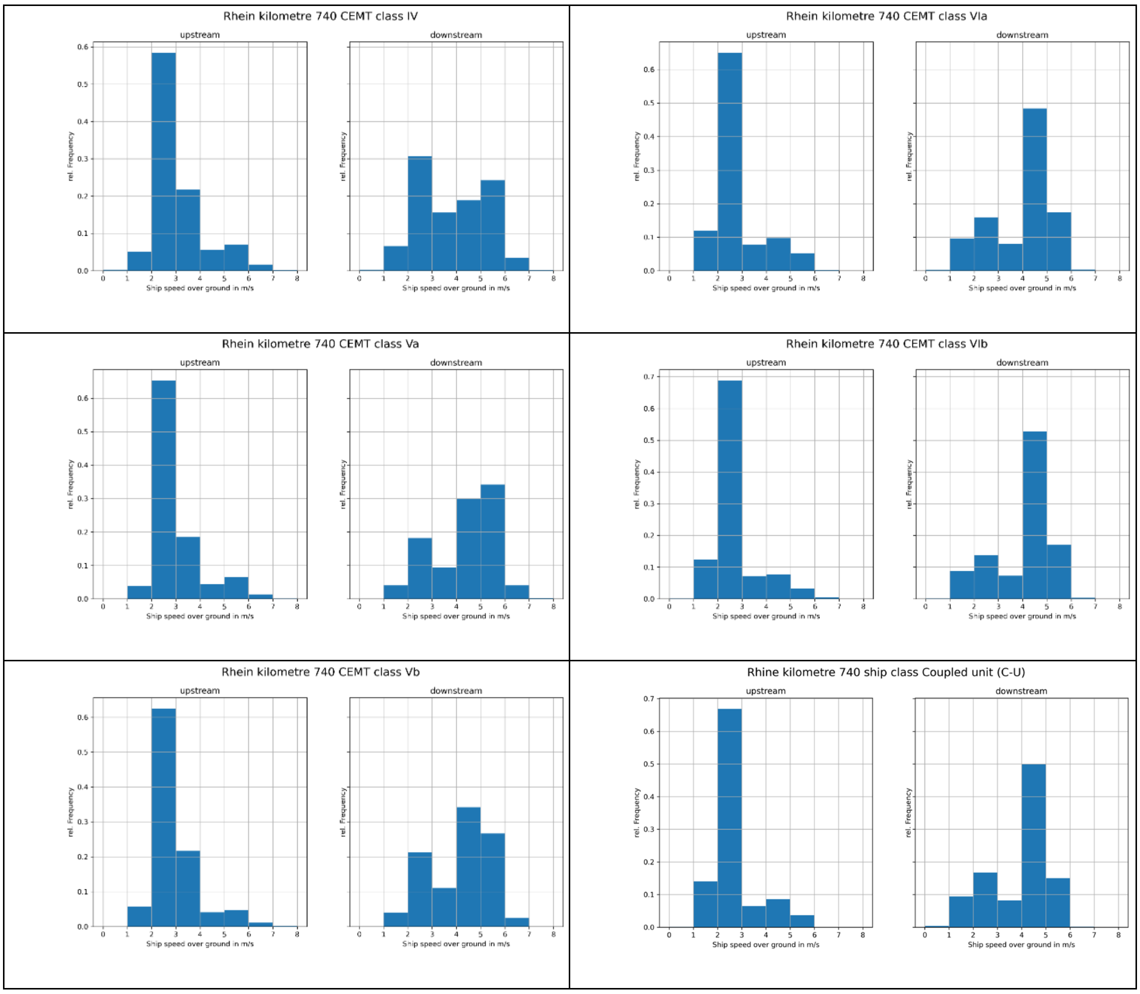


Fig. 7.2 Speed distributions of vessel classes IV, Va, Vb, VIa and VIb at Neuss (Rhine-km 740).

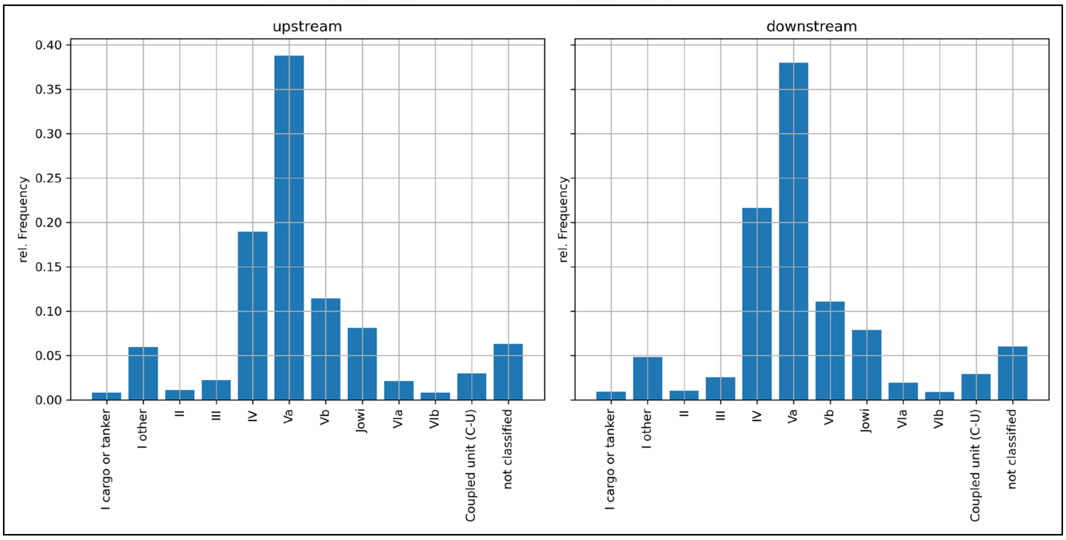


Fig. 7.3: Traffic shares (%) of the different ship classes at Duisburg (Rhine-km 782)

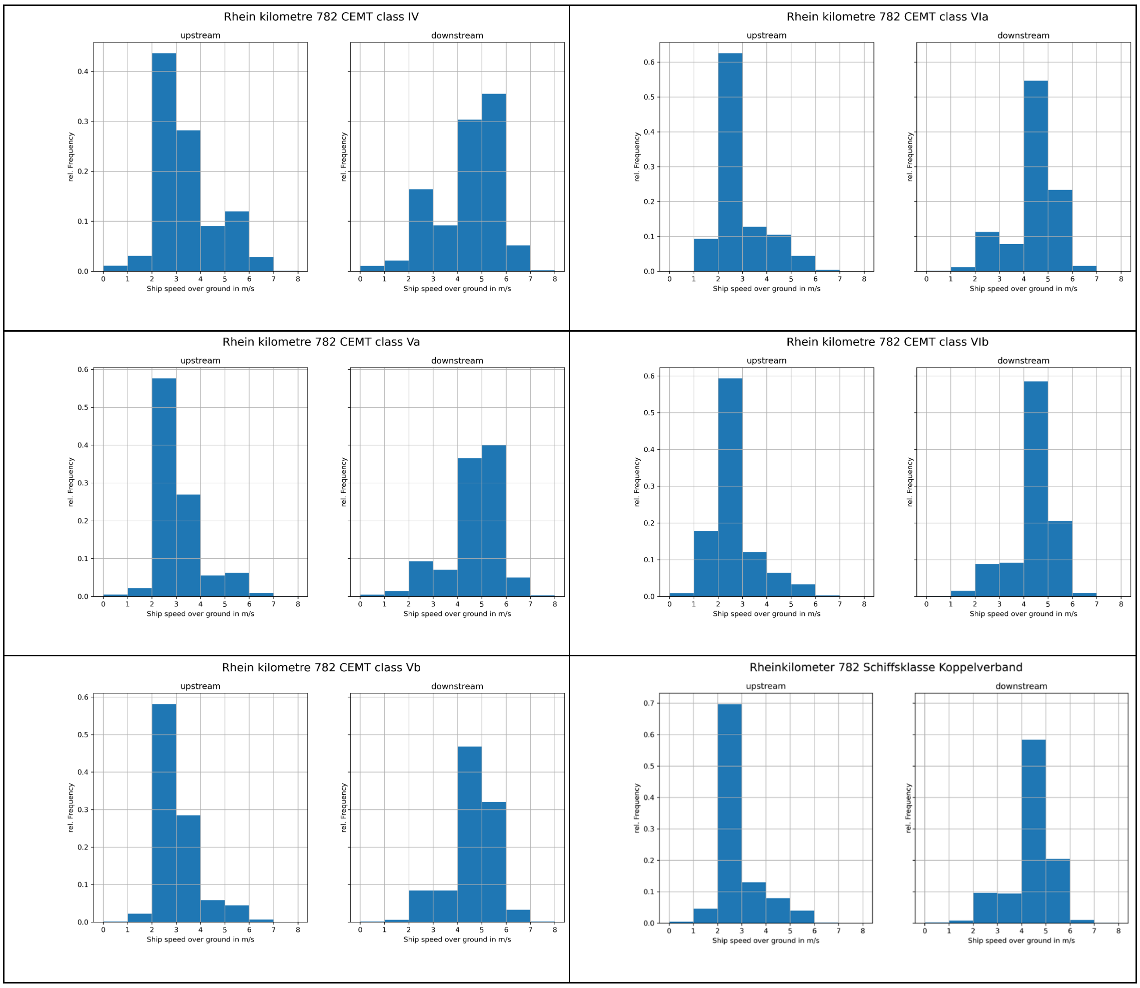


Fig. 7.5 Speed distributions of vessel classes IV, Va, Vb, VIa and VIb below the port of Duisburg at Rhine-km 782.

8. Conclusions from the fleet analyses

The CLINSH project dealt with ship emissions and their effect on air quality. The extensive measurement programmes, carried out in Neuss and Duisburg in 2018, should therefore provide results that are as representative as possible in order to be able to answer these questions in detail. Therefore, a most representative fleet should have sailed in the year of the study.

When analyzing the number of ships, it turns out that in 2018 (n=92,225) about 15 % more ships travelled on the Rhine at Rhine-km 782 than in the following year 2019 (n=80,554). The emission densities for NO_X were also slightly higher in the study year 2018 than in 2019.

Due to the low water levels of the Rhine in 2018, the question arose whether this may also have caused a shift of freight transport to smaller vessels. It is known that the smaller cargo ships and tankers in length classes I-III are generally significantly older than the larger ships in the classes VI, Va and Vb. As a result, a higher average engine age and, as a rule, poorer emission behaviour of the engines can be expected.

It was therefore necessary to clarify whether the emissions of the ships in 2018 were also seriously influenced by a different composition of the fleet. For this reason, the composition of the operating fleets of the years 2018-2020 was analyzed and compared intensively.

The fleet analyses have shown that the compositions of the operating fleets are comparable for the dominant ship classes. The ships of size classes IV, Va, Vb and JOWI have a similar share of traffic (km 782 : 79-80 %; km 790 71-72 %) and thus also of emissions in 2018 as well as in the two following years (Tab. 7.1). The low percentage share of the older cargo and tanker ships, ship classes I-III, was not significantly increased in 2018 compared to the following years.

The analyses of individual ship classes with regard to the percentage distribution of their speeds on the individual river kilometers showed that the speed distributions of ships on the Rhine can vary significantly in the individual sections. The speed of the ships through the water is closely correlated with the therefore required energy demand and thus, via fuel consumption, also with the amount of emissions.

In addition, it has been shown that the speed distribution in the individual ship classes can also vary over the year in a comparison of different years. A significant factor for these variations is likely to be the variation in discharge volumes and, related to this, in flow velocities and water levels.

Therefore, for a more realistic emission estimate, it is necessary to perform a finer-scale calculation in small sections, e.g. on the basis of river kilometers, with the parameters number of ships per ship class and direction of travel as well as the respective associated speed distributions in the analysis year.

An increased number of moving ships, as in 2018, also causes an increase in emissions [(3,4)]. The analysis of ship traffic in comparison to the years 2019 and 2020 did not indicate an untypical increase of emissions in the CLINSH analysis year 2018 due to a significant increase of the share of smaller and thus older ships in the traffic on the Rhine.

It can therefore be assumed that the emissions in 2018 were proportionally influenced by the proportional increase in the number of ships in the different ship classes and a variation in travel speeds, but not by a significant change in the fleet composition.

It can therefore be assumed that the higher emission densities in 2018 were proportionally influenced by the increase in the number of ships, but not mainly through a change in the fleet composition.

Rhine-km	Ship class	IV (85 m)	Va (110 m)	Vb (135 m)	JOWI class
	Percentage of total traffic				
km 782	2018	20,4	39,3	12,6	6,4
	2019	19,1	38,8	14,6	6,3
	2020	19,7	39,5	12	8,5
km 790	2018	17,1	35,5	12,5	6,2
	2019	17,0	36,3	13,5	5,7
	2020	17,2	36,2	10,9	7,7

Tab. 7.1: Percentage share of different ship classes in Rhine traffic near Duisburg in the years 2018-2020

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Thank you for the good cooperation regarding the CLINSH project

(White water rafting at Neuss, Photo: D.Busch, LANUV)

9. Literature

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(2) CLINSH "Harbour Monitoring Part A: Air quality on the Rhine and in the inland ports of Duisburg and Neuss/Düsseldorf. Immission-side effect of emissions from shipping and port operations on nitrogen oxide pollution"

(3) CLINSH "Harbour Monitoring Part C: Emission inventories for the ports of Duisburg and Neuss/Düsseldorf"

(4) CLINSH "Harbour monitoring part E: Onshore measurements: Identification of passing inland vessels based on AIS signals and determination of the associated emission factors for NO_X based on onshore measurements"

10. List of Tables

11. List of figures

Even a port can show beautiful views (Photo: T.Zang, LANUV)

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