PRESSURE

Effectiveness of measures to reduce nutrient inputs

Baltic Marine Environment Protection Commission

Nutrients

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Introduction

Presently the HELCOM Pollution Load Compilation (PLC) database does not include any kind of data on mitigation measures (e.g. what kind of measures have been conducted, how those measures have affected nutrient inputs, what kind of additional measures have been planned and how those measures are projected to affect inputs). Therefore, in order to get a better understanding of these questions the PLC group made a first attempt to gather information from different countries in 2016. That compilation revealed that data concerning measures and their effectiveness was not easily available and the estimates of potential reductions were uncertain. In addition, the estimation methods varied widely between the countries.

A further attempt to evaluate the effectiveness of measures (EOM) was made in the HELCOM ACTION project (2018–2020), in which the evaluation would have been done on the basis of selected river basins exemplifying cases where measures have been particularly effective in reducing nutrient loads as well as those where significant efforts have been made to reduce nutrient inputs, but without apparent success. The idea was to ease the burden of Contracting Parties in gathering all necessary information. However, it became evident, that even at the river-basin level there was no information on mitigation measures available or it was too time-consuming to compile it. Therefore, the original aim of the study had to be redesigned according to the availability of the data. The main emphasis of the redesigned approach was in the estimation of how indirect and direct point source loads have changed during the study period of 2000–2018 on the basis of data extracted from the PLC database. An additional aim was to estimate how reliable and comprehensive this point source data is in regard to nutrient loads.

This report is a compilation of data and information linked to the EOM gathered in the PLC group and two ACTION project's sub-projects. The main purpose of this report is to show how the present status and how evaluating of EOM could be developed in the forthcoming PLC-8 project. It also includes recommendations for further development of the PLC work.

TN

NTOT – total nitrogen

TP

PTOT – total phosphorus

1. Questionnaires to the PLC Contracting Parties

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A specific task to evaluate effectiveness of measures to reduce input of nutrients was included into the PLC-6 project deliverables by the request of HELCOM Gear Group in 2015. Nonetheless, since the very beginning the evaluation was considered as a trial rather than a project deliverable.

Data collection for the evaluation was organized through a questionnaire (Table 1). The evaluation included the estimation of reduction achieved through implementation of reported measures in the period 1995-2014 in comparison with the observed reduction of nutrient inputs (PLC-6 assessment of progress towards national reduction targets). The document also presented the estimation of anticipated reduction, which would be achieved by 2021 by the implementation of already planned measures. National estimates of the effects of measures on load reductions were mainly based on measures included in the River Basin Management Plans (RBMPs) under the EU Water Framework Directive (WFD), national water protection programs as well as the effects of the implementation of the relevant EU directives, e.g. Program of Measures (PoMs) for the development and implementation of the EU Marine Strategy Framework Directive (MSFD) and Urban Waste Water Directive (UWWD).

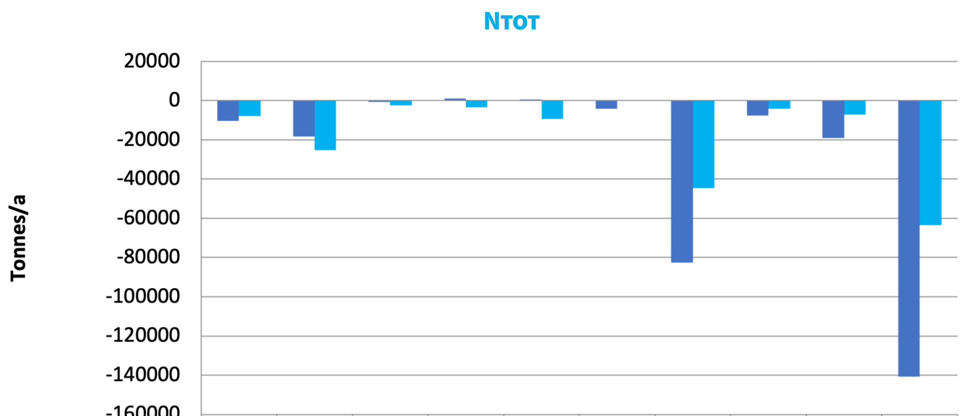
The questionnaire revealed a very high variability of the reported estimates between countries caused by various non-harmonized assessment methods and a remarkable difference in temporal, geographical and sectoral data coverage. Some countries reported the estimated load reductions for all sectors, the majority for only one to three sectors, and some countries merely verbally described the measures aiming at achieving a good ecological status of coastal waters. In general, these data deficiencies and inconsistencies impeded the quantification of the effects of measures across the region enabling only a narrative description of the undertaken and planned measures.

Table 1. The questionnaire sent to PLC–6 project members in 2015.

Country: Sub-basin:	**Reduction during 1995-2014**			**Reduction expected from 2015 onwards**		
	At source/ to inland water	Direct water-borne input to the Baltic Sea	Total Water-borne input to the Baltic Sea	At source/ to inland water	Direct water-borne input to the Baltic Sea	Total Water-borne input to the Baltic Sea
Agriculture Forestry Scattered dwelling Storm-waters Industrial inputs Aquaculture Other (specify)						

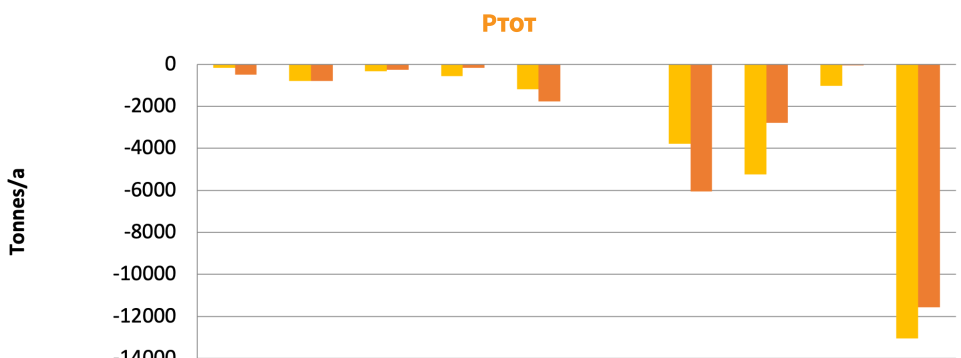
1.1. Reduction from 1995 to 2014

The period of time from which the results were reported, varied by country. Also, the method by which the results were produced varied from country to country. Partially, the results were based on a proven reduction in the load. This is typically the case for point source loads. The reduction of the diffuse load, such as agriculture, is much more difficult to verify. In some countries, modelling was used, in other countries the estimates were based on measures implemented during the first River Basin Management Planning period (2010 - 2015). Comparison with the previous PLC reports was also used as the basis for the evaluation, but this was unreliable since different methodologies were used in different PLCs in many countries. In some cases, information on measures implemented before 2010 were lacking. Sometimes part of the load was reported to inland waters so that the retention had been taken into account. Because of these reasons it was impossible to reliably compare achieved reductions between the countries. The results are shown in Figs.1 and 2.



	DE	DK	EE	FI	LT	LV	PL	RU	SE	BAS
TN PLCs	-10245	-18242	-716	1106	613	-4123	-82628	-7634	-18906	-140775
TN questionnaire	-7875	-25216	-2470	-3498	-9367	-277	-44489	-4196	-7000	-63422

Figure 1. Reductions of NTOT loads from 1995 to 2014 in different countries and as a sum for the whole Baltic Sea (BAS).



	DE	DK	EE	FI	LT	LV	PL	RU	SE	BAS
TP PLCs	-160	-797	-317	-555	-1175	0	-3784	-5246	-1019	-13053
TP questionnaire	-493	-797	-260	-168	-1756	-18	-6045	-2780	-50	-11569

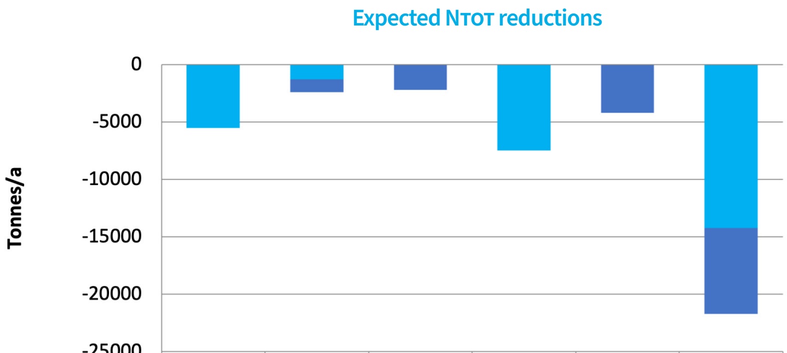
Figure 2. Reductions of PTOT loads from 1995 to 2014 in different countries and as a sum for the whole Baltic Sea (BAS).

1.2. Expected reductions from 2015 to 2021

Nutrient loading from diffuse sources is currently the major source of anthropogenic nutrients in the Baltic Sea catchment area and in most HELCOM countries agriculture is the largest source of inputs of nitrogen and phosphorus to both inland waters and the Baltic Sea. The proportion of agriculture of total loads has constantly increased during recent decades since the water protection measures have mainly addressed and in general have also been the most successful and cost-efficient for point sources. At the same time, the measures taken to reduce the nutrient loading from agriculture have, at least so far, been rather modest in terms of their results.

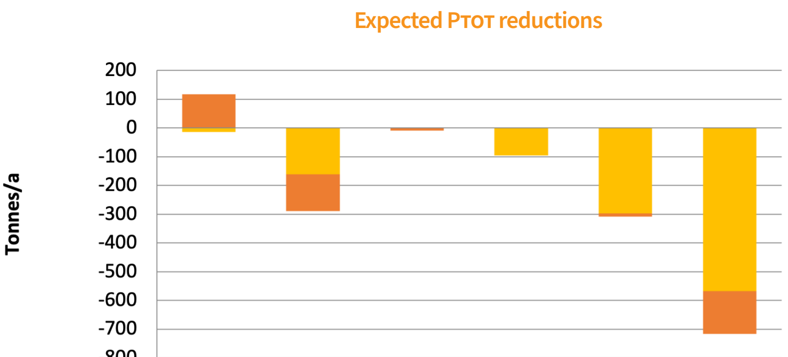
The results above clearly indicate that nutrient load reduction targets set in the BSAP will not be attained with the nutrient reductions obtained by implementing the existing HELCOM Recommendations on improved wastewater treatment for urban and scattered dwellings alone. The additional reductions needed are about 77,000 tonnes of total nitrogen (NTOT) and 6,700 tonnes of total phosphorus (PTOT), and these reductions – especially concerning PTOT – must be achieved mainly in agriculture.

In the PLC-6 questionnaire only four Contracting Parties (Denmark, Finland, Lithuania and Sweden) reported quantitative estimates on the load reductions which are expected to be achieved from 2015 onwards through implementation of water protection measures in agriculture (Fig. 3 and 4).



	DK	FI	GE	LT	SE	BAS
TN other		-1121	-2180		-4190	-7491
TN agriculture	-5500	-1272		-7471		-14243

Figure 3. Reported estimated reduction in agricultural and other NTOT loads from 2015 onwards. The Swedish and German NTOT figures have been reported as unspecified totals. It is assumed that they are largely based on the reductions expected to be achieved in agriculture. Denmark has reported a range. Finland's figure encompasses expected reductions in forestry and reductions expected to be realized after the implementation of several other measures included in the Finnish marine strategy 2016–2021.



	DK	FI	GE	LT	SE	BAS
TP other	118	-128	-9		-12	-149
TP agriculture	-13,5	-161		-96	-297	-568

Figure 4. Reported estimated reduction/increase in agricultural and other PTOT loads from 2015 onwards. Denmark has reported a range. In the Swedish figure "other" source means storm waters. Germany's PTOT figure is as unspecified total. Finland's figure encompasses expected reductions in forestry and reductions expected to be realized after the implementation of several other measures included in the Finnish marine strategy 2016–2021.

1.3. Concluding remarks

In conclusion, it is clear that good environmental status or the preconditions for good ecological status of the Baltic Sea cannot be achieved by 2021 or at any later stage, if only the targets for municipal wastewater treatment are fulfilled. It is equally clear that additional measures are needed in agriculture. In most HELCOM countries agriculture is at the moment the largest source of inputs of nitrogen and phosphorus to the Baltic Sea. Reliable data on this source are thus necessary in order to assess the effectiveness of different measures to reduce losses from this sector.

The survey conducted during the PLC-6 project showed that the assessment of the effectiveness of agricultural measures is a major challenge for most Contracting Parties. Most countries also had difficulties in producing comprehensive reports on expected reductions for other sectors. The existing total reduction potential can therefore not be assessed on the basis of the questionnaires.

2. Point source data in the PLC database 2000–2018

(updated from a HELCOM ACTION project document)

2.1. Direct point source loads

Direct point source data was collected from the PLC-database for all HELCOM Contracting Parties except Russia. Data from Russia was provided by the Russian PLC-group member.

In 2018 N_{TOT} load into the Baltic Sea from direct point sources was 25,200 t and the main origin was municipalities (Fig. 5, right). Since the year 2000 N_{TOT} load decreased by 12,600 t (33%), though the relative share of input origin remained similar.

In 2018 P_{TOT} load into the Baltic Sea from direct point sources was 1030 t and the main origin was municipalities (Fig. 6, right). Since the year 2000 P_{TOT} load decreased by 1930 t (65%). The relative share of input origin remained similar.

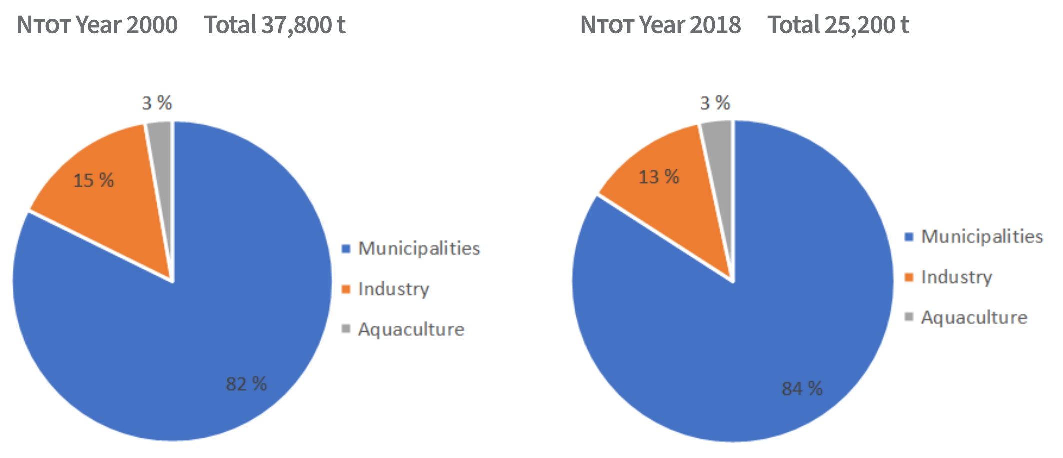


Figure 5. Direct point source N_{TOT} loads by sources in 2000 (left) and 2018 (right).

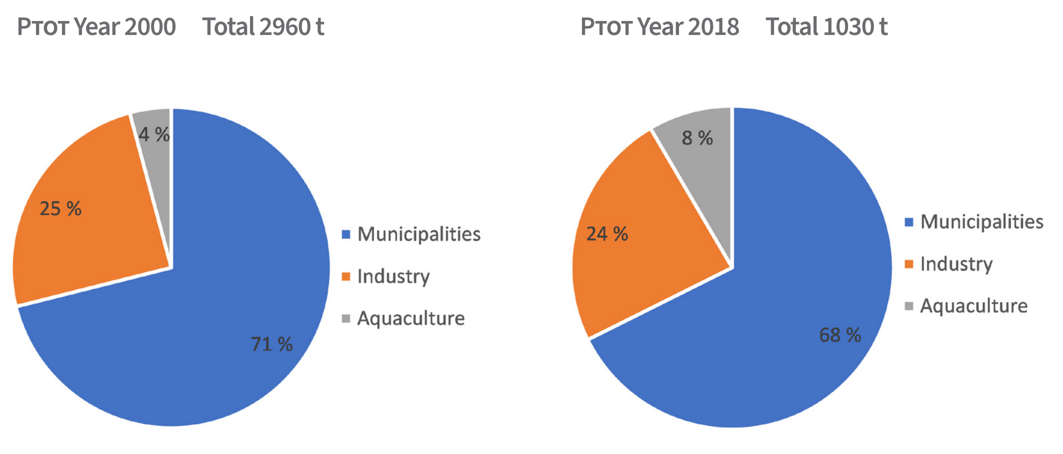


Figure 6. Direct point source P_{TOT} loads by sources in 2000 (left) and 2018 (right).

2.1.1 Direct municipal loads

In 2018 municipal wastewater treatment plants discharged 21,200 t N directly into the Baltic Sea (Table 2a). Sweden had the highest N loads (7300 t), followed by Russia (6700 t), Finland (3200 t) and Denmark (1700 t). Direct municipal NTOT loads decreased markedly between 2000 and 2018: 10,600 t, which equals to a 33% decrease. The biggest reduction in municipal N loads was detected in Germany (3400 t). In addition, N loads were reduced with over 1000 t in five countries: Finland, Latvia, Poland, Russia and Sweden. The reductions could be attributed to large investments in wastewater treatment in the biggest cities.

In 2018 municipal wastewater treatment plants discharged nearly 700 t P directly into the Baltic Sea (Table 2b). Denmark, Sweden and Russia had the highest P loads: from 164 to 177 t in 2018. The direct municipal P loads decreased between 2000 and 2018 with 1405 t and in percentage the decrease was larger than the respective N decrease: 67%. The biggest reduction in municipal P loads was detected in Russia (777 t) followed by Latvia (177 t), Poland 117 t) and Denmark (100 t). The reduction of Russian load was mainly due to enhanced P removal from wastewaters in St. Petersburg. It is noteworthy that in Sweden and Finland P removal percentage from municipal wastewaters was at a high level already before the year 2000.

Table 2a. Direct municipal NTOT loads from 2000 to 2018, presented per country.

Country	Para-meter	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Change (2000-2018)	Change (2000-2018)
		t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	%
DE	NTOT	4215	1628	807	800	759	730	641	538	574	602	643	682	665	538	618	810	776	870	810	-3405	-81
DK	NTOT	1967	1791	2023	1648	1904	1761	1867	2189	1719	2126	1721	1973	1956	1991	1774	1920	1819	1895	1676	-291	-15
EE	NTOT	978	992	946	971	1082	867	756	826	833	714	704	694	569	502	467	438	480	483	423	-555	-56
FI	NTOT	4534	4738	4270	4604	3902	3501	3216	3392	3582	2899	3173	3121	3571	3163	3296	3300	3222	3585	3190	-1345	-30
LT	NTOT	285	78	75	102	269	99	86	241	246	198	48	215	197	166	157	168	171	205	163	-121	-43
LV	NTOT	1551	1613	1539	1914	1561	1656	1786	2437	2477	1292	1155	1179	1086	678	495	551	520	434	410	-1141	-74
PL	NTOT	1794	744	768	1184	1028	888	928	1720	919	880	727	874	565	913	827	496	373	939	560	-1234	-69
RU	NTOT	8038	7942	8490	8668	8529	7566	8653	8653	8016	9549	9375	9989	9614	9562	8940	8924	8690	8191	6663	-1375	-17
SE	NTOT	8463	8334	8447	7662	8049	8017	9191	9344	9447	8751	8577	8511	8347	8252	8080	8325	7905	8029	7303	-1160	-14
Total	NTOT	31824	27859	27365	27554	27083	25085	27123	29340	27813	27012	26123	27236	26570	25764	24655	24932	23957	24632	21196	-10628	-33

Table 2b. Direct municipal PTOT loads from 2000 to 2018, presented per country.

Country	Para-meter	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Change (2000-2018)	Change (2000-2018)
		t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	%
DE	PTOT	52	21	22	21	20	16	12	16	18	14	18	12	13	11	16	25	26	27	26	-26	-50
DK	PTOT	277	254	295	223	238	227	208	267	281	380	247	282	336	310	263	269	222	210	177	-100	-36
EE	PTOT	90	69	62	57	63	58	54	71	69	55	58	59	53	29	24	24	27	27	22	-68	-98
FI	PTOT	113	93	90	82	96	89	78	68	77	58	68	60	68	69	24	59	54	58	57	-56	-50
LT	PTOT	38	8	7	8	30	5	11	19	12	10	4	11	11	6	10	7	9	13	8	-30	-78
LV	PTOT	213	239	223	174	189	212	173	180	154	55	44	34	71	53	58	64	45	41	36	-177	-83
PL	PTOT	149	29	43	50	57	61	71	140	90	52	35	46	37	46	45	32	18	48	32	-117	-79
RU	PTOT	941	1024	1066	1259	1924	1291	1175	1005	943	742	388	260	249	270	521	613	595	403	164	-777	-83
SE	PTOT	228	221	213	177	187	187	247	212	190	150	167	189	171	155	160	158	148	156	174	-54	-24
Total	PTOT	2102	1957	2021	2051	2803	2147	2028	1978	1834	1515	1029	952	1009	950	1122	1251	1143	981	696	-1405	-67

2.1.2 Direct industrial loads

In 2018 industrial wastewater treatment plants discharged 3160 t N directly into the Baltic Sea (Table 3a). Sweden and Finland together contributed 94% of the N inputs, so the proportion from other countries was minor. The high industrial N inputs in Sweden and Finland originated largely from pulp and paper industry. Direct industrial NTOT loads decreased markedly between 2000 and 2018: by 2500 t, which equals a 44% decrease. The biggest reduction in industrial N loads was detected in Sweden (1020 t), Estonia (607 t) and Finland (526 t). There were large gaps in the data coverage of several countries (Table 3a).

In 2018 industrial wastewater treatment plants discharged 246 t P directly into the Baltic Sea (Table 3b). Sweden and Finland together contributed 95% of the P inputs, so the proportion of other countries was minor. The high industrial P inputs in Sweden and Finland originated largely from pulp and paper industry. The direct industrial P loads decreased between 2000 and 2018 with 159 t and in percentage the decrease was 38%. The biggest reduction in industrial P loads was detected in Sweden (107 t). There were large gaps in the data coverage of several countries (Table 3b).

Table 3a. Direct NTOT loads from industry from 2000 to 2018, presented per country.

Country	Parameter	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Change (2000-2018)	Change (2000-2018)
		t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	%
DE	NTOT	22						25	24	22	11	26	7	36	36	31	38	30	35	31	9	42
DK	NTOT	439	412	358	266	194	144	148	152	178	113	123	150	121	134	127	109	94	104	95	-344	-78
EE	NTOT	626				33	85	61	69	88	41	29	42	42	51	8	8	19	24	19	-607	-97
FI	NTOT	1844	1662	1559	1563	1431	1410	1070	1138	1224	1120	1255	1302	1352	1601	1607	1316	1039	1474	1319	-526	-28
LT	NTOT	8	13	13	9	3	8	4					6	9	7	9	7	11	14	12	3	36
LV	NTOT		21	18	12	10	6	14	21	10	7	8	11	11	11	10	8	4	5	2	2	
PL	NTOT	15	0	0	0	0	0			3							6		23	19	4	28
RU	NTOT	33	29	22	2	1	13	60	16	7	5				9	39	39	36	71	8	-25	-76
SE	NTOT	2672	2274	2559	2592	2517	2585	2622	2209	2198	2007	1895	1864	2006	2100	1987	1971	1833	1751	1653	-1020	-38
Total	NTOT	5661	4412	4530	4444	4189	4251	4004	3628	3730	3305	3336	3381	3576	3950	3819	3502	3067	3501	3158	-2503	-44

Table 3b. Direct PTOT loads from industry from 2000 to 2018, presented per country.

Country	Parameter	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Change (2000-2018)	Change (2000-2018)
		t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	%
DE	PTOT	1						1	1	1	0	1	0	1	2	1	1	1	1	1	0	-3
DK	PTOT	25	24	22	14	12	11	10	10	12	5	9	9	10	10	9	8	7	8	8	-18	-70
EE	PTOT	1				2	8	12	4	9	3	3	3	2	2	1	1	1	1	2	1	39
FI	PTOT	93	100	94	94	95	95	88	100	95	75	83	79	91	89	76	75	50	65	61	-32	-35
LT	PTOT	1	1	1	1	0	1	0					0	0	0	0	0	1	1	1	0	-24
LV	PTOT		4	4	3	4	2	4	5	3	2	3	3	4	3	3	2	0	1	0	0	
PL	PTOT	4	0	0	0	0	0			0							1		2	1	-3	-73
RU	PTOT	10	8	18	1	2	2	10	11	10	6					10	11	9	9			
SE	PTOT	280	250	266	262	280	275	279	254	238	217	219	203	221	227	226	208	218	187	173	-107	-38
Total	PTOT	415	387	406	375	395	394	405	384	368	308	317	298	328	333	326	307	287	276	246	-159	-38

2.1.3 Marine aquaculture

Marine aquaculture in the Baltic Sea is concentrated in three countries: Finland, Denmark and Sweden. In 2018 direct N input from aquaculture was 850 t. Finland's contribution was 46%, Denmark's 41% and Sweden's 12% (Table 4a). Finland managed to reduce N inputs from aquaculture by 49% between 2000 and 2018, whereas the respective N inputs increased by 34% in Denmark. Swedish data starts from the year 2006 and inputs decreased from 2006 to 2018.

In 2018 direct P input from aquaculture was 87 t. Finland's contribution was 44%, Denmark's 45% and Sweden's 13%. Finland managed to reduce P inputs from aquaculture by 59% between 2000 and 2018, whereas the respective P inputs increased by 32% in Denmark. Swedish data starts from the year 2006 and inputs decreased from 2006 to 2018 (Table 4b).

Table 4a. Direct N_{TOT} loads from aquaculture from 2000 to 2018, presented per country.

Country	Parameter	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Change (2000-2018)	Change (2000-2018)
		t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	%
DK	N_{TOT}	262	248	263	270	240	255	270	285	299	255	266	322	324	338	337	335	322	333	352	90	34
EE	N_{TOT}							15												3		
FI	N_{TOT}	769	724	517	481	538	507	530	521	500	489	432	442	479	464	469	463	399	494	391	-378	-49
LT	N_{TOT}							0					0									
SE	N_{TOT}							139	139	139	139	139	93	.	112	90	114	119	99	104		
Total	N_{TOT}	1031	972	781	751	779	762	953	944	938	883	836	857	803	914	896	912	840	926	850	-288	-28

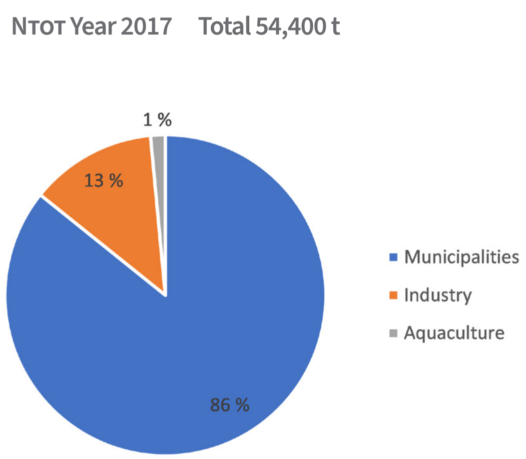
Table 4b. Direct P_{TOT} loads from aquaculture from 2000 to 2018, presented per country.

Country	Parameter	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Change (2000-2018)	Change (2000-2018)
		t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	%
DK	P_{TOT}	29	25	28	29	26	27	29	31	32	28	28	34	35	35	36	35	34	34	38	9	32
EE	P_{TOT}							2												0,3		
FI	P_{TOT}	95	91	64	60	66	63	65	63	62	61	54	55	58	54	50	47	39	55	39	-56	-59
LT	P_{TOT}							0					0									
SE	P_{TOT}							18	18	18	18	18	12		14	10	12	13	11	11		
Total	P_{TOT}	124	116	92	89	92	91	114	112	112	106	100	100	93	103	96	94	86	99	87	-47	-38

2.2. Indirect point source loads

Indirect point source data was collected from the PLC-database, except for Russian data, which was received from the Russian PLC-group member. These indirect point sources are defined as point sources that do not discharge directly to the Baltic Sea, but via relevant pathways and waterways contribute to the total load in the Baltic Sea. Indirect point source loads are reported only during PLC periodical reporting years. PLC periodical reporting years are: PLC-4 2000, PLC-5 2006, PLC-6 2014 (except Poland and Germany 2012) and PLC-7 2017. This data was complemented with supplementary data received directly from the HELCOM Contracting Parties.

In 2017 NTOT load into inland waters from point sources was 54,400 t (Fig. 7, left) and the respective PTOT load was 3970 t (Fig. 7, right). The main origin of the inputs were municipalities, whereas inputs from aquaculture were negligible. Due to gaps in the data coverage, it was not possible to estimate changes in loads.



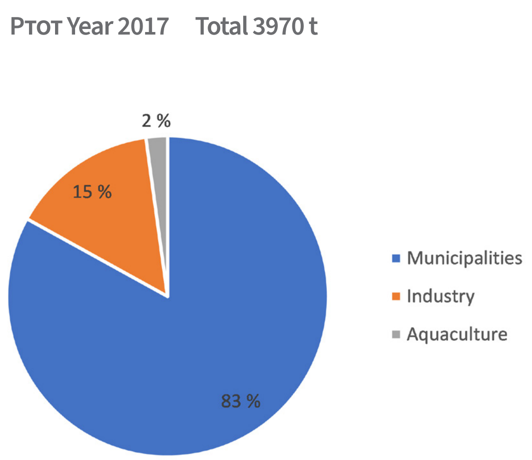


Figure 7. Indirect point source NTOT and PTOT loads by sources in 2017.

2.2.1 Indirect municipal point source loads

In 2017 N inputs from indirect municipal wastewater treatment plants were 46,600 t (Table 5a). Four countries contributed over 90% of the inputs: Poland 42%, Sweden 19%, Russia 17%, and Finland 13%. Denmark, Estonia and Finland managed to reduce their inputs to varying degrees, whereas, according to the reported data, N inputs from indirect municipal wastewater treatment plants increased in other countries. Total municipal N inputs into inland waters increased by 7980 t (21%). Part of the increases might be due to the increased connectivity (i.e. an effort to decrease loads originating from scattered dwellings by increasing the number of people being connected to municipal treatment plants). However, there is high variability in the reported loads between the PLC periodical reporting years for some countries, which might be due to deficiencies in data coverage and indicates that there are large uncertainties in the analysis.

In 2017 P inputs from indirect municipal wastewater treatment plants were 3300 t (Table 5b), of which Poland contributed with 2150 (65%). Russian loads showed the biggest decrease (225 t) and four other countries managed to reduce their P inputs, whereas it increased in three countries. Overall, i.e. at the Baltic Sea scale, the changes indicate a slight decrease. The reported P loads also varied to some extent between the PLC years in some countries, but this variation was minor compared to the respective fluctuation in the reported N inputs.

Table 5a. Indirect municipal N_{TOT} loads from 2000 to 2017, presented per country.

Country	Parameter	PLC-4	PLC-5	PLC-6	PLC-7	Change (2000-2017)	Change (2000-2017)
		t	t	t	t	t	%
DE	NTOT	492	262	209	614	122	25
DK	NTOT	1860	1470	1269	1162	-698	-38
EE	NTOT	411	262	210	264	-147	-36
FI	NTOT	6491	6890	7748	5909	-582	-9
LT	NTOT	996	1909	1332	1781	784	79
LV	NTOT	396	527	515	886	490	124
PL	NTOT	15591	31788	25148	19343	3752	24
RU	NTOT	4910		3546	7840	2930	60
SE	NTOT	7503	10450	8823	8834	1331	18
Total	NTOT	38650	53558	48799	46633	7983	21

Table 5b. Indirect municipal P_{TOT} loads from 2000 to 2017, presented per country.

Country	Parameter	PLC-4	PLC-5	PLC-6	PLC-7	Change (2000-2017)	Change (2000-2017)
		t	t	t	t	t	%
DE	PTOT	21	16	24	52	31	148
DK	PTOT	184	124	113	99	-84	-46
EE	PTOT	57	18	7	9	-48	-83
FI	PTOT	114	103	74	66	-48	-42
LT	PTOT	76	228	112	138	62	82
LV	PTOT	65	110	68	115	50	76
PL	PTOT	2096	3183	2793	2148	52	2
RU	PTOT	785		728	560	-225	-29
SE	PTOT	122	161	127	111	-12	-10
Total	**PTOT**	**3520**	**3942**	**4047**	**3299**	**-221**	**-6**

2.2.2 Indirect industrial point source loads

In 2017 N inputs from indirect industrial wastewater treatment plants were 6930 t (Table 6a). Finland, Sweden and Russia contributed together 6060 t, nearly 90% of the total inputs. Polish industrial inputs dropped dramatically between 2014 to 2017, otherwise Denmark and Estonia were the only countries shown to reduce their indirect industrial N loads. However, there is high variability in the reported loads between the PLC periodical reporting years for some countries, which might be due to deficiencies in data coverage and indicates that there are large uncertainties in the analysis.

In 2017 P inputs from indirect industrial wastewater treatment plants were 588 t (Table 6b). Russia contributed with nearly 70% of the total inputs. Many countries were able to decrease their loading and the total P inputs into inland waters decreased with 21% from 2000 to 2017.

Table 6a. Indirect N_{TOT} loads from industry from 2000 to 2017, presented per country.

Country	Parameter	PLC-4	PLC-5	PLC-6	PLC-7	Change (2000-2017)	Change (2000-2017)
		t	t	t	t	t	%
DE	NTOT			231	207		
DK	NTOT	231	183	101	11	-219	-95
EE	NTOT	70	345	168	22	-48	-68
FI	NTOT	2177	2749	2463	2261	83	4
LT	NTOT	57	132	134	219	163	286
LV	NTOT	66	135	40	186	119	179
PL	NTOT	1316	5069	4173	230	-1087	-83
RU	NTOT	2282	1366	1761	1634	-648	
SE	NTOT	2150	2601	2334	2162	12	1
Total	**NTOT**	**8350**	**12580**	**11403**	**6932**	**-1624**	**-19**

Table 6b. Indirect P_{TOT} loads from industry from 2000 to 2017.

Country	Parameter	PLC-4	PLC-5	PLC-6	PLC-7	Change (2000-2017)	Change (2000-2017)
		t	t	t	t	t	%
DE	PTOT			18	7		
DK	PTOT	13	5	3	1	-12	-90
EE	PTOT	3	10	4	2	-1	-28
FI	PTOT	137	130	113	85	-53	-38
LT	PTOT	10	9	7	9	-1	-9
LV	PTOT	4	21	4	20	16	375
PL	PTOT	80	148	75	12	-68	-85
RU	PTOT	390	328	767	399	9	2
SE	PTOT	93	75	60	53	-39	-43
Total	**PTOT**	**731**	**726**	**1051**	**588**	**-150**	**-21**

2.2.3 Indirect aquaculture

In 2017 NTOT inputs from inland aquaculture were 809 t (Table 7a). Sweden, Finland and Denmark had the biggest shares of the total inputs. Three countries were able to decrease their loading and the total inputs into inland waters decreased substantially (35%) from 2000 to 2017. Swedish load data from 2000 was missing, thus hindering a full estimation of changes.

In 2017 PTOT inputs from inland aquaculture were 86 t (Table 7b). Sweden, Finland and Denmark had the biggest shares of the total inputs. Three countries were able to decrease their loading and the total inputs into inland waters decreased substantially (30%) from 2000 to 2017. Swedish load data from 2000 was missing, thus hindering the estimation of changes.

Table 7a. Indirect NTOT loads from aquaculture from 2000 to 2017.

Country	Parameter	PLC-4	PLC-5	PLC-6	PLC-7	Change (2000-2017)	Change (2000-2017)
		t	t	t	t	t	%
DK	NTOT	437	326	221	227	-210	-48
FI	NTOT	235	170	135	173	-62	-26
LT	NTOT	29	69	7	5	-24	-83
LV	NTOT		62	0	1		
PL	NTOT	141	17	250			
SE	NTOT			363	403		
Total	**NTOT**	**843**	**644**	**976**	**809**	**-296**	**-35**

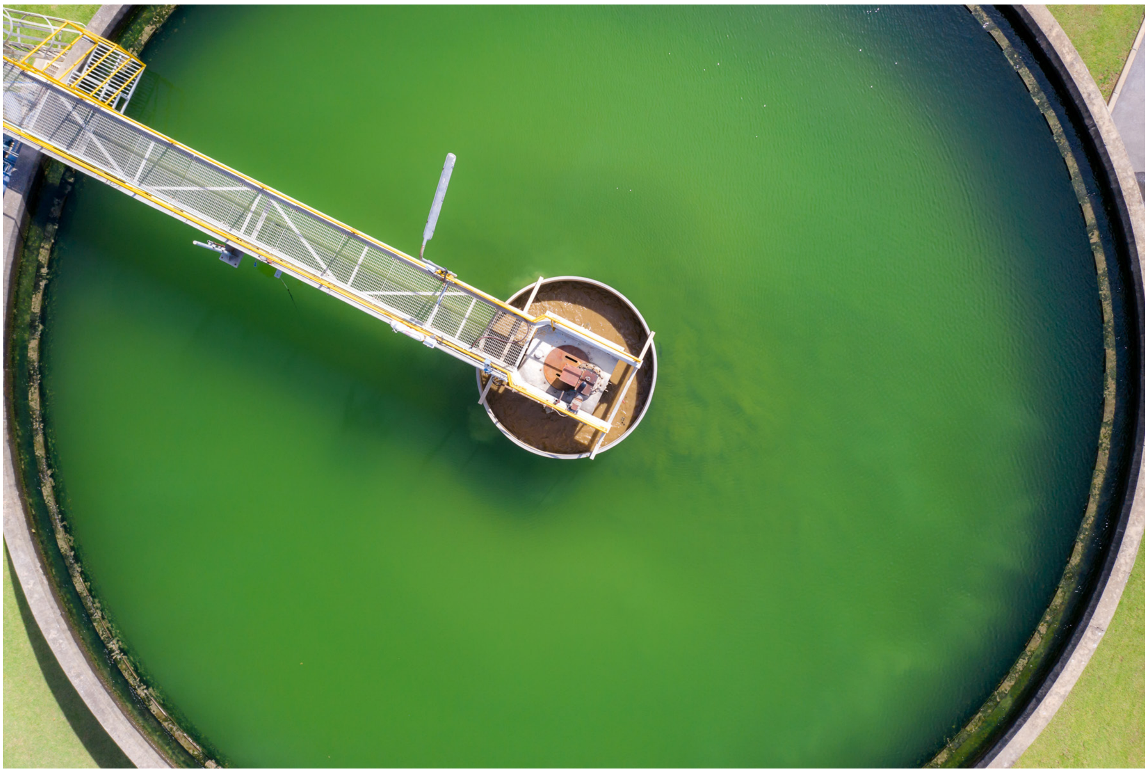
Table 7b. Indirect PTOT loads from aquaculture from 2000 to 2017.

Country	Parameter	PLC-4	PLC-5	PLC-6	PLC-7	Change (2000-2017)	Change (2000-2017)
		t	t	t	t	t	%
DK	PTOT	34	27	22	21	-13	-39
FI	PTOT	29	22	13	18	-11	-37
LT	PTOT	2	3	1	1	-1	-70
LV	PTOT		8	0	0		
PL	PTOT	19	2	30			
SE	PTOT			60	46		
Total	**PTOT**	**84**	**62**	**127**	**86**	**-25**	**-30**

2.3. Conclusions

Direct point source loads have decreased substantially from 2000 to 2017/2018: N loads with 33% and P loads with 65%. Municipalities were the dominant source of nutrient inputs originating from point sources into the Baltic Sea. Even though municipal wastewater treatment has improved substantially during the last decades there is still clear potential to reduce the nutrient load from this sector. There are gaps in the data coverage, especially in indirect loads in the PLC-database, which is reflected in the uncertainty of the results.

3. Development of inputs of nutrients from nine big municipal wastewater treatment plants



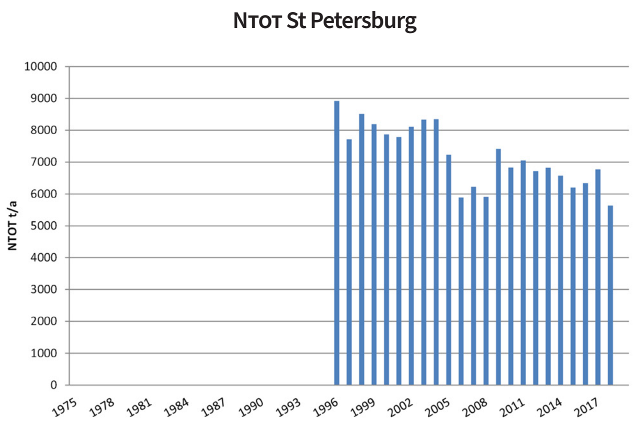
Contributors: Antti Räike, Damian Bojanowski, Katarina Hansson, Ilga Kokorite, Piotr Kwiatkowski, Julian Mönnich, Natalia Oblomkova, Svajunas Plunge, Michael Pohl, Lars M. Svendsen, Henrik Tornbjerg, Kristi Uudeberg

The time-series of nutrient inputs from point sources in the PLC database were in many cases incomplete making it impossible to reliably estimate the development of nutrient inputs originating from municipal wastewater plants (MWWTP). In order to get a more temporally comprehensive overview of the development, PLC group members contacted authorities of the largest MWWTP in their countries to get as long time-series as possible. This study includes time-series of nutrient inputs from the biggest municipal wastewater treatment plants of every HELCOM country: St. Petersburg, Warsaw, Stockholm, Copenhagen, Helsinki, Riga, Vilnius, Tallinn and Rostock. The time-series varied in length: The longest was for Helsinki (starting from the year 1975) and the shortest for Vilnius (starting from the year 1997).

3.1. St. Petersburg

Vodokanal St. Petersburg supplies water and wastewater services to a population of 5.3 million people and to tens of thousands of city companies and organizations. Nowadays there are altogether 13 wastewater treatment plants of which 8 discharge wastewaters directly into the Gulf of Finland. At present, 99% of wastewater is treated in St. Petersburg. The total flow rate of the treatment plants is around 2,100,000 m^3 in a day, most of the treated water is discharged to Neva Bay. All the wastewater treatment plants provide wastewater treatment in full compliance with the recommendations of the Baltic Marine Environment Protection Commission. One of the biggest environmental projects focused on closing untreated wastewater discharges into the water bodies was the construction of the Northern Collector Tunnel completed in October 2013. After opening of the tunnel untreated wastewaters totaling 334,000 m^3/day were directed to the sewerage system. In 2018, the efficiency of wastewater treatment in St. Petersburg was more than 98% for suspended solids and BOD, 95% Ptot and 74% Ntot.

Before 1978, St. Petersburg's wastewaters were discharged to the sea almost without any treatment. From then on wastewater treatment capacity has increased, and phosphorous and nitrogen inputs to the sea have further declined during the past decades as the result of the measures implemented by the Vodokanal. Dramatic reduction of phosphorus inputs after 2005 was related to the enhanced biological treatment and introduction of chemical phosphorus precipitation in wastewater treatment plants (Fig. 8). More gradual reduction can be seen in direct nitrogen inputs in the corresponding period. During the last two decades direct Ptot inputs from St. Petersburg WWTPs were reduced by 90%, Ntot inputs by 50%.



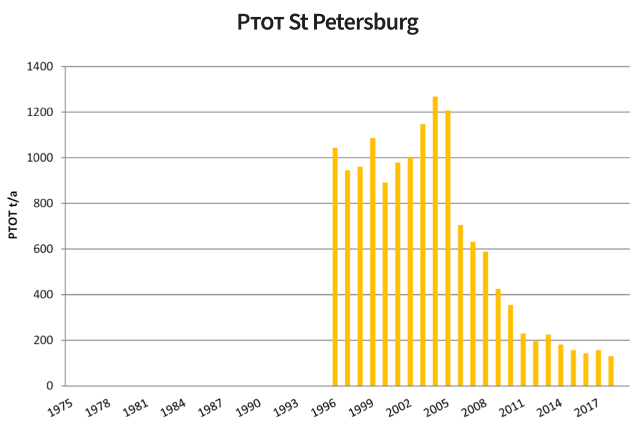
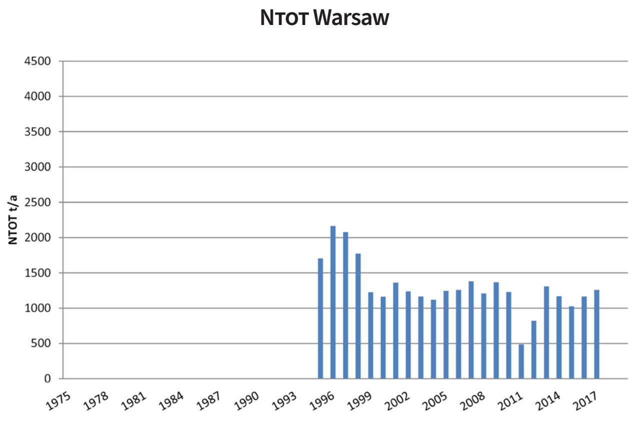


Figure 8. Nitrogen and phosphorus loads from St Petersburg MWWTPs (altogether 8 treatment plants) 1996–2018. Note: The scale of the y-axis differs between the cities.

3.2. Warsaw

Czajka MWWTP in Warsaw receives a BOD load of more than 1,900,000 PE (1 PE = 60 g BOD_5/d). The plant was originally designed in the early 1970s and construction began in 1976, but the plant was first completed in 1991. It received wastewater from the right-bank part of Warsaw and from the surrounding smaller right-bank towns. The original MWWTP had classical closed sludge digestion tanks. Between 2008 and 2012 the plant was modernized and extended to receive the wastewaters from the left-bank Warsaw, including storm waters. At the same time, sludge management was completely re-designed and sludge digestion was replaced by sludge incineration.

Before 2008 the average loads from Czajka MWWTP were 1500 tonnes per year of NTOT 130 tonnes of PTOT per a year with maximum at 2200 tonnes of NTOT and 275 tonnes of PTOT during 1996-1998 period (Fig. 9). Back then, the MWWTP did not meet the EU and HELCOM requirements for urban wastewater treatment, and therefore Warsaw urban area was on the HELCOM Hot Spot list. This was the reason for modernization of the plant, which ended in 2012. After the modernization nitrogen treatment efficiency increased from 65% to 85% and loads discharged into the Vistula River decreased. The increase of NTOT and PTOT loads after 2012 was caused by the increased amount of wastewater after the modernization. Compared to the period 1995-1998 NTOT load decreased by a half and PTOT load by 75%. As a result, Warsaw urban area was deleted from the HELCOM Hot Spot list in 2015. After 2012 the NTOT and PTOT loads have been relatively constant: 1200 t NTOT and 60 t PTOT annually.



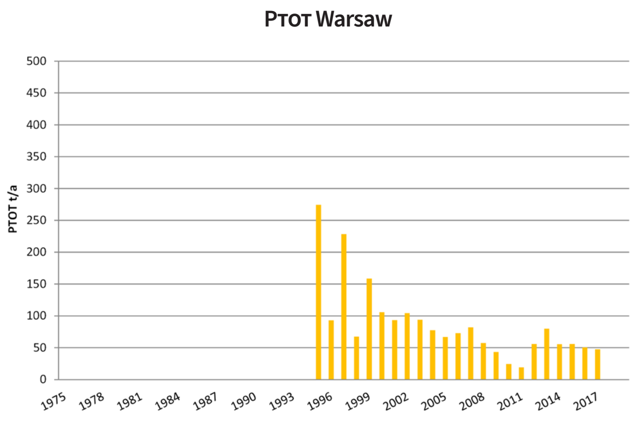


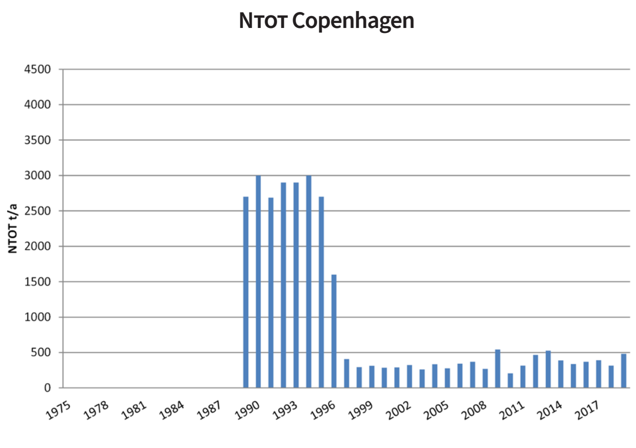
Figure 9. Nitrogen and phosphorus loads from Warsaw Czajka WWTP 1996–2017.
Note: The scale of the y-axis differs between the cities.

3.3. Copenhagen

Lynetten, the largest sewage treatment plant in Denmark, treats industrial and municipal wastewater of approx. 750,000 PE from 535,000 inhabitants, corresponding to 3.2 million liters of wastewater every day. The maximum capacity is 41,500 m^3 per hour. The wastewater originates from the center and parts of the suburbs of the city of Copenhagen altogether 76 km^2 urban catchment. Lynetten was founded in 1980 with mechanical separation and removal of organic matter by injection of pure oxygen, and before that there was no real treatment of the wastewater. In 1985, about 100 million m^3 wastewater was treated generating about 25,000 tonnes sludge.

By 1997, the treatment plant was expanded and inaugurated including biological (e.g. nitrification and denitrification), and chemical treatment of the sludge (e.g. application of iron and aluminum) and sludge incineration with two multiple-hearth furnaces for nitrogen and phosphorus removal. It resulted in marked reduced nitrogen and phosphorus discharges from the treatment plant by 1997 (Fig. 10). In recent years, the focus on operation optimization has ensured higher nutrient removal.

In 2019 about 1.36 billion m^3 untreated diluted wastewater was discharged from Lynetten to the Sound when rainwater amounts exceeded the capacity of the wastewater treatment plant. By 2027, the treatment capacity will be increased reducing discharged annual amounts of untreated diluted wastewater to less than 1 billons m^3 annually



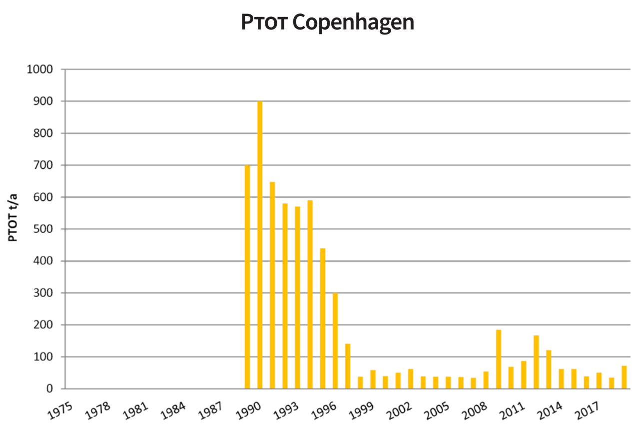


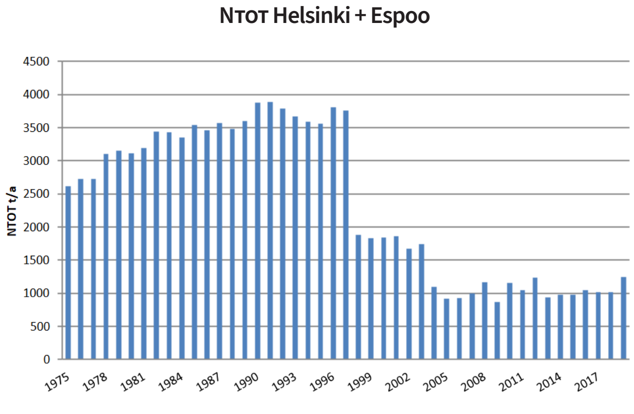
Figure 10. Nitrogen and phosphorus loads from Copenhagen Lynetten WWTP 1989–2019. Note: The scale of the y-axis differs between the cities.

3.4. Helsinki and Espoo

The Viikinmäki wastewater treatment plant in Helsinki is the largest treatment plant in Finland. It processes wastewaters of around 800,000 residents as well as the wastewaters of the region's industry. The plant was taken into use in 1994 and it replaced several small-scale water treatment plants. The total flow rate of the treatment plant is around 270,000 m^3 per day, and an average of 100 million m^3 of wastewater is treated at the plant every year. The treated wastewater is discharged through a tunnel in the bedrock into the sea eight kilometers away from Helsinki shoreline into a depth of 20 meters.

The Suomenoja wastewater treatment plant processes wastewaters of 310,000 residents in Espoo, Kauniainen ja West-Vantaa. Construction of a new plant started in 2016 and like the treatment in Helsinki the plant in Espoo is inside the bedrock. The Blominmäki wastewater treatment plant in Espoo will be opened in 2022 and replace the old Suomenoja treatment plant. It will have a capacity to process wastewaters of 400,000 residents. The goal is to remove more than 96% of the phosphorus and over 90% of the nitrogen it receives.

In Helsinki and Espoo improvements in wastewater treatment started in late 1970s, when investments led to more efficient phosphorus removal (Fig. 11). Nitrogen removal improved first when the new plant in Helsinki was opened in 1994 and further improvements took place in 2005, when new technologies were taken into use. Since the mid-2000s the inputs have stayed quite stable (on average 1050 t NTOT and 33 t PTOT). Nowadays over 95 % of phosphorus and 90 % of nitrogen is removed from the wastewater.



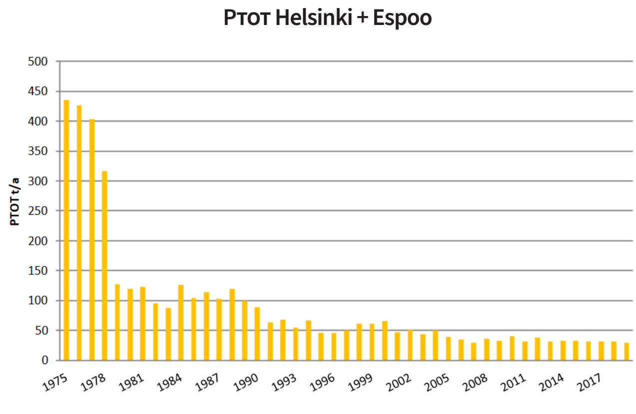


Figure 11. Nitrogen and phosphorus loads from Helsinki and Espoo WWTPs 1975–2019. Note: The scale of the y-axis differs between the cities.

3.5. Stockholm

Bromma and Henriksdal waste water treatment plants, both operated by Stockholm Vatten och Avfall, are two of Sweden's largest WWTPs. Bromma WWTP, which was taken into operation in 1934, receives wastewater from around 360,000 residents, while around 860,000 residents are connected to Henriksdal (in operation since 1941). The two plants treat around 450,000 m^3 of wastewater per day. More than 95% of the phosphorus and 75% of the nitrogen is removed from the wastewater and the organic contaminants are converted into 57 000 m^3/d of biogas, equivalent to 120 GWh annually, which is used to fuel busses for public transport in the city.

Since 1992 the load of nitrogen from Stockholm WWTPs (Bromma and Henriksdal) decreased from approximately 3000 tonnes to today's level of 1400 tonnes (Fig. 12). For phosphorus, a corresponding decrease in load is from approximately 140 tonnes in 1975 to 32 tonnes in 2019. An increased load to the WWTPs, some operational problems and the modernisation and expansion of the Henriksdal WWTP, can explain the small variations in load during the latest years.

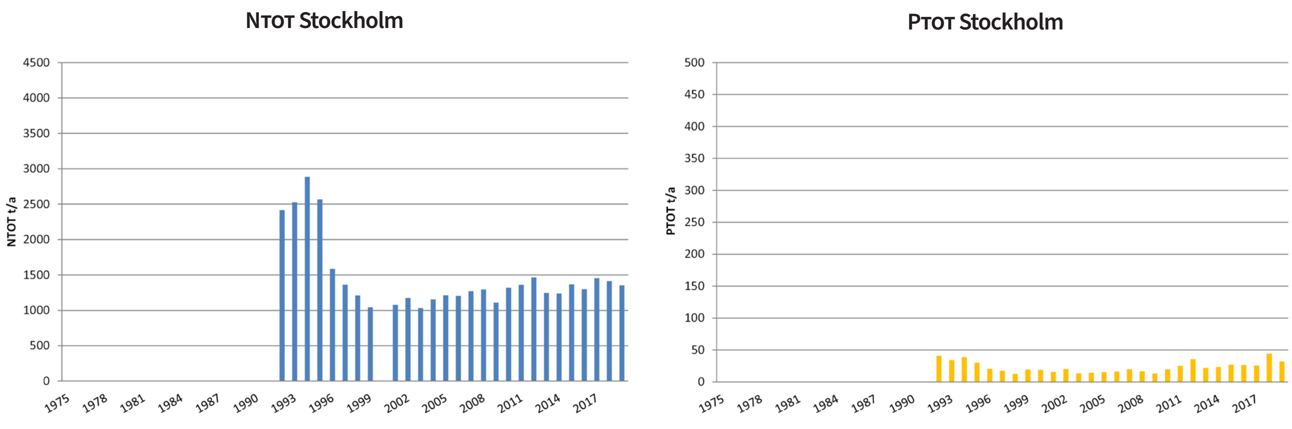
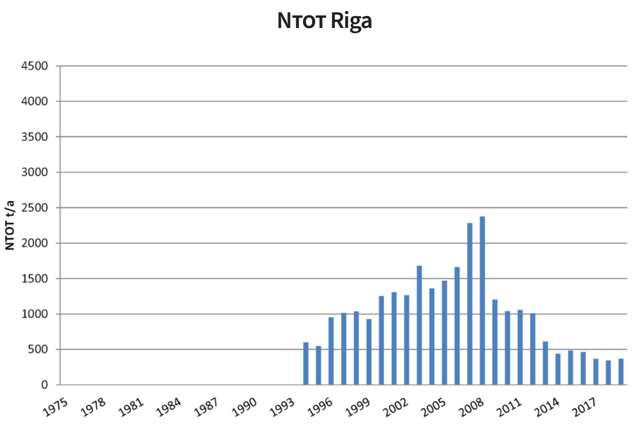


Figure 12. Nitrogen and phosphorus loads from Stockholm WWTPs (Bromma and Henriksdal) 1992–2019. Note: The scale of the y-axis differs between the cities.

3.6. Riga

Daugavgrīva biological wastewater treatment plant in Rīga is the largest treatment plant in Latvia. The first phase of the new biological WWTP in Riga was completed in 1991. At later stages, the sewerage network was considerably extended, and the infrastructure and technologies were improved. Today, about 650,000 inhabitants of Rīga and several nearby municipalities as well as industrial facilities are connected to the Daugavgrīva treatment plant (approximately 27-30% of the total wastewater is generated by industrial facilities). The total flow rate of the treatment plant is around 140,000 m^3 in a day, and an average of 50 million m^3 of wastewater is treated at the plant every year. Treated wastewater is discharged into the Gulf of Rīga at a depth of 15 meters and in a distance of 2.4 km from the shore. Nowadays 90% of phosphorus and 87% of nitrogen is removed from the wastewater, respectively.

Since the 1990s large investments have been made to modernize Riga WWTP in Daugavgrīva. In 2014, major reconstruction works were finished. During these projects, BioDenitroTM technology was introduced, dosing equipment for chemical precipitation of phosphorus were purchased and the control of the wastewater treatment process was improved. Moreover, nowadays the company strictly controls the quality of received industrial wastewater in order to ensure the stability of biological treatment process. The largest industrial enterprises must have their own pre-treatment facilities to remove toxic substances. Improvement in the treatment process has resulted in a significant reduction of nutrient concentrations in wastewater. During 2014-2019, NTOT load discharged into the environment varied between 484-344 t/y and that for PTOT was 59-31 t/y (Fig. 13). Since 2013, the efficiency of Rīga WWTP meets the requirements of HELCOM Recommendation 28E/2, where at least a 70-80% reduction of NTOT load is required. Since 2016, efficiency in PTOT removal is above 90% and complies with HELCOM standards.



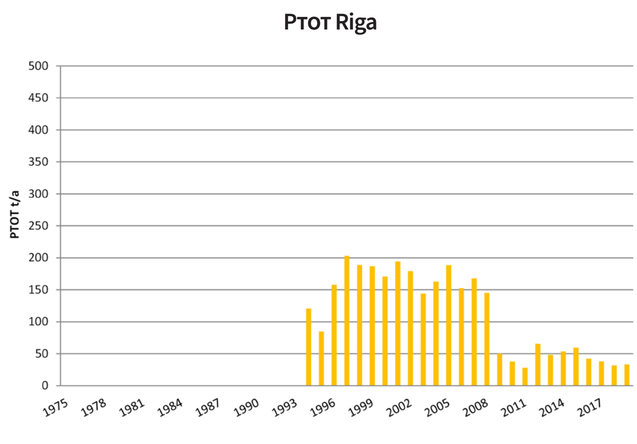


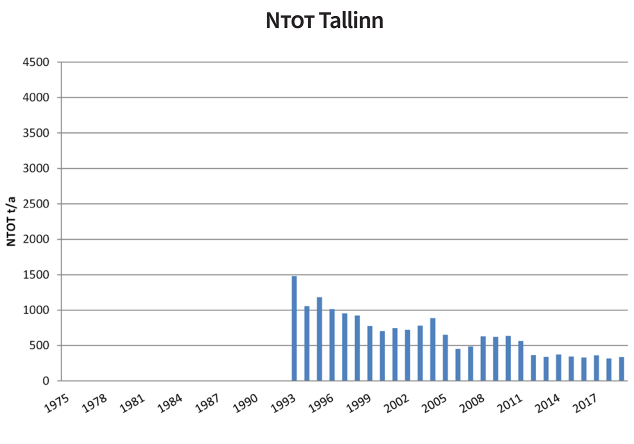
Figure 13. Nitrogen and phosphorus loads from the Daugavgrīva WWTP 1994–2019 in Riga. Note: The scale of the y-axis differs between the cities.

3.7. Tallinn

The Paljassaare wastewater treatment plant in Tallinn is the largest treatment plant in Estonia. It processes wastewaters of around 463,000 residents as well as wastewaters of the region's industry. The plant was taken into use in 1980. The hydraulic capacity of the plant is 350,000 m^3 per day, average flow is 120,000 m^3 per day and an average of 50 million m^3 of wastewater is treated at the plant every year. The treated wastewater is discharged into the sea 3 kilometers away from the Tallinn shoreline. Nowadays over 93% of phosphorus and 86% of nitrogen is removed from the wastewater.

Over the years, the wastewater treatment plant has made various investments to increase the efficiency of the wastewater treatment process, and the decreased nutrient loads as a result can be seen in Fig. 14. The nitrogen and phosphorus loads to the sea have decreased from 1464 t to 338 t and from 137 t to 20 t, respectively, in the years 1993—2019. The biological treatment stage was established as classical activated sludge process in the wastewater treatment plant during 1993—1997. Between 2004 and 2006, the wastewater treatment plant was further modified and it achieved a total nitrogen concentration of 10 mg N/l in the effluent. As part of these modifications, methanol was dosed to the biological treatment process to affect the denitrification. In 2012, the load of nitrogen discharged to the sea reduced by almost 40% due to extensive reconstruction of the first treatment stage (mechanical treatment) and added additional treatment stage, biofilter. The main aim of the biofilter was to reduce the load of nitrogen, however, the load of phosphorus discharged to the sea decreased as well. In the end of the year 2015, new coagulant dosing system was launched to help better control the chemical removal of phosphorus and to achieve a total phosphorus concentration of 0.50 mg P/l in the effluent.

Additional investments in the wastewater treatment are planned in order to further reduce nutrient loads discharged into the Baltic Sea.



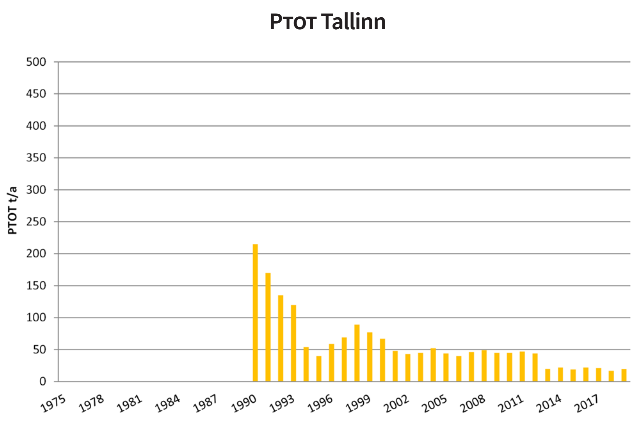


Figure 14. Nitrogen and phosphorus loads from Tallinn WWTP 1993–2019. Note: The scale of the y-axis differs between the cities.

3.8. Vilnius

Vilnius wastewater treatment plant is the largest treatment plant in Lithuania. Situated downstream from the capital on the Neris River, it processes wastewaters from around 500,000 residents and surrounding industries. The plant was built in 1975 and nowadays treats around 115,000 m^3 of sewage a day. Nitrogen and phosphorus removal rates are around 85% and 91% correspondingly. The plant has installed mechanical, biological treatment and additional chemical removal of phosphorus and nitrogen. However, a large EU financed project to upgrade its capacity and treatment effectiveness started in 2020 and should be finished in the middle of 2023. Results of it would allow improving many aspects of the treatment plant's operation including increasing its treatment capacity by 30%, tackling stormwater overflows and removing pollutants not properly addressed currently, like microplastics.

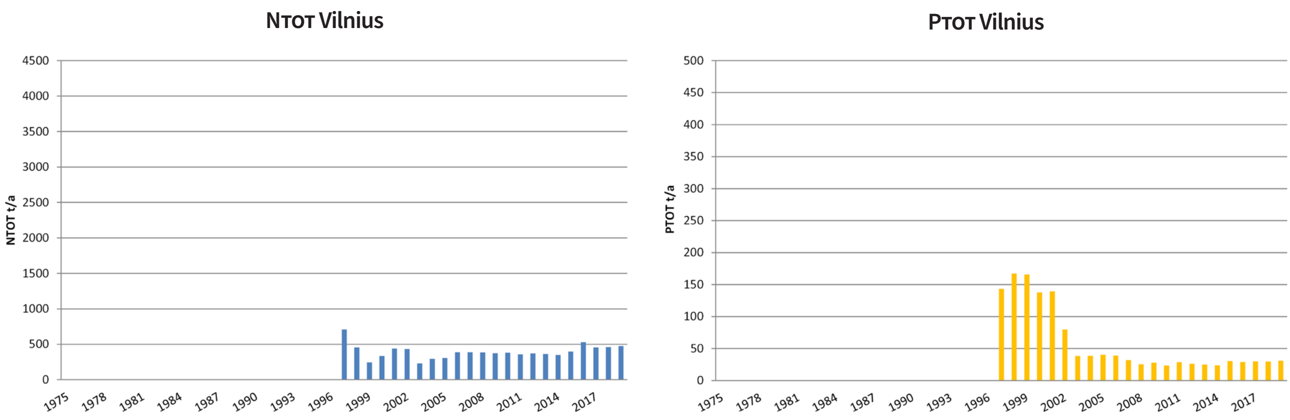
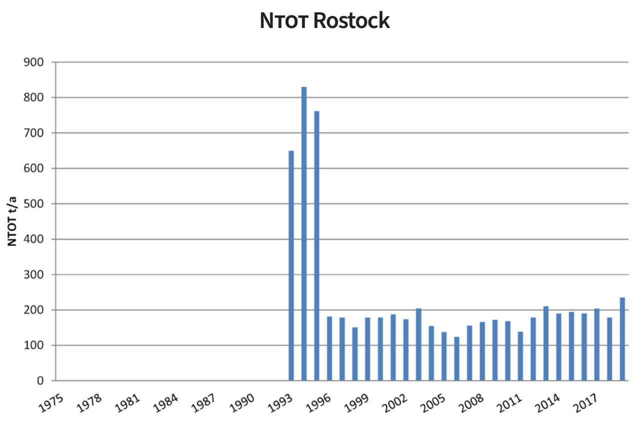


Figure 15. Nitrogen and phosphorus loads from Vilnius WWTP 1997–2019. Note: The scale of the y-axis differs between the cities.

3.9. Rostock

The Rostock-Bramow wastewater treatment plant is the largest in Mecklenburg-Vorpommern. It processes the wastewaters of around 240,000 residents from the city of Rostock and 17 surrounding communities as well as the wastewaters of the region's industry and the seaport. The plant was taken into use in 1996 and has been upgraded several times afterwards. The total flow rate of the treatment plant is around 44,000 m³ per day, and an average of 16 million m³ of wastewater is treated every year. The cleaned water is discharged directly to the estuary of the River Warnow.

In Rostock, improvements in wastewater treatment started in mid 1950s, when the first central wastewater treatment plant was built for around 150,000 residents and industry from the city of Rostock. Nitrogen and Phosphorus removal improved both when the new plant in Rostock was opened in 1996 and further improvements happened several times after the opening (Fig. 16). Since the opening of the central wastewater treatment plant in Rostock-Bramow in the mid-1990s the inputs have stayed quite stable (on average 200 t NTOT and 2 t PTOT). Nowadays about 98% phosphorus and 80% of the nitrogen is removed from the wastewater.



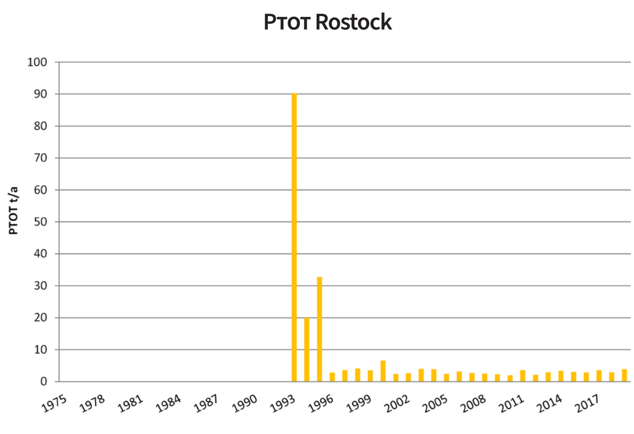


Figure 16. Nitrogen and phosphorus loads from the Rostock-Bramow WWTP 1993–2019. Note: The scale of the y-axis differs between the cities.

4. Municipal wastewater treatment, connectivity and scattered dwellings

Finland and Sweden were the first countries to start more efficient wastewater treatment and in 1990 tertiary treatment was applied nearly in all wastewater treatment plants, followed by Denmark and Germany (Fig 17). A remarkable improvement in wastewater treatment has happened during the last decade in the Baltic countries and Poland. St Petersburg also is a good example of improved wastewater treatment: Before 1978, almost all wastewaters from St Petersburg were discharged untreated into the Gulf of Finland or the River Neva, but nowadays the capacity has increased to 98.5% (Vodokanal, 2015) and the nitrogen load has decreased by 60% and the phosphorus load by 90% (Knuuttila et al. 2017). However, there are several wastewater treatment plants (WWTPs) that still require upgrading in many countries.

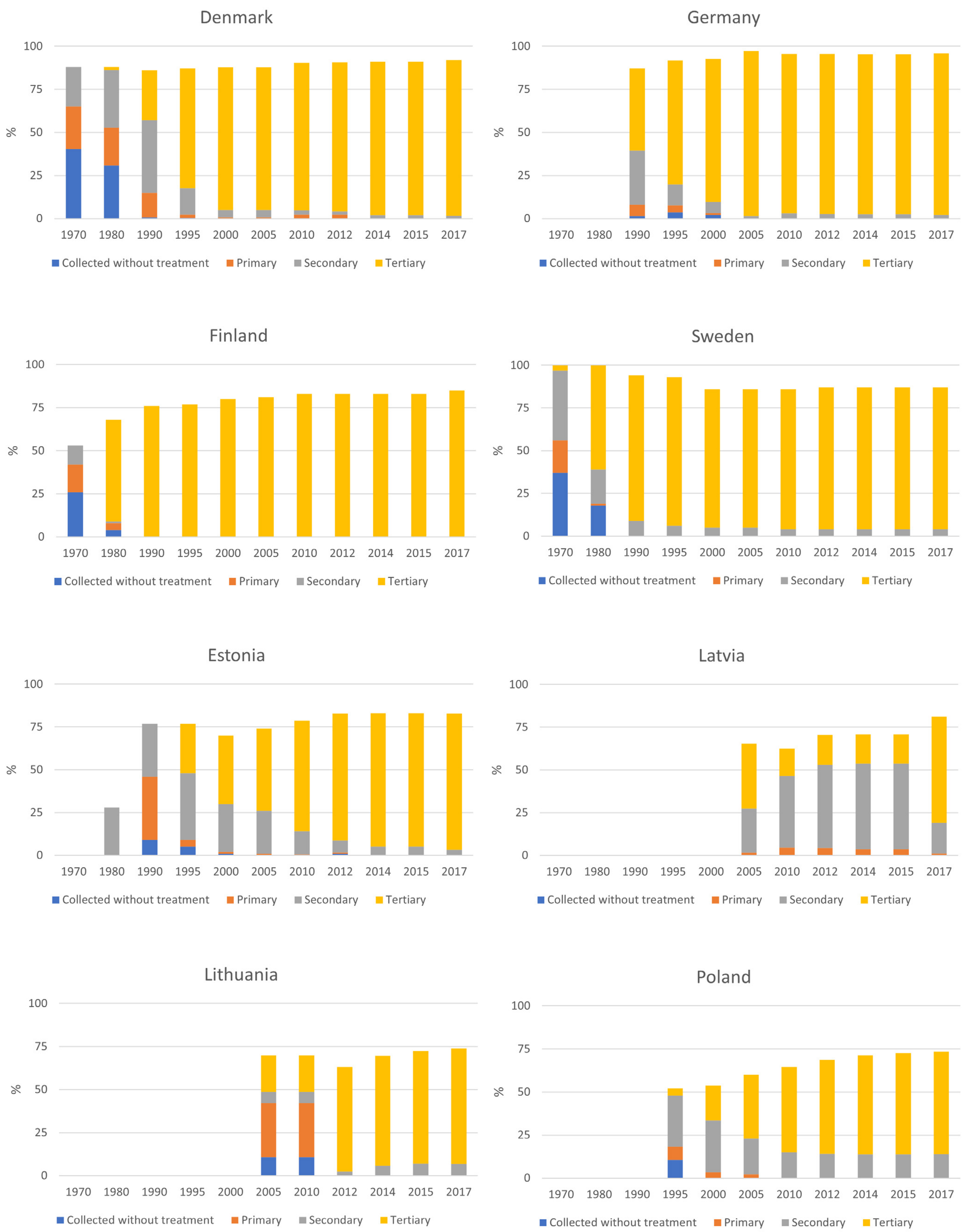


Figure 17. Connectivity and treatment status in municipal wastewater treatment plants of eight HELCOM Contracting Parties from 1970–2017. Note: data for Denmark, Germany and Sweden also include treatment plants outside the Baltic Sea catchment. Source: EEA.

There has been a steady increase in the percentage of the population connected to secondary and tertiary wastewater treatment systems (Table 8). In 2017 the connectivity was highest in Denmark and Germany where it was over 90%. During the last decade connectivity to wastewater treatment systems has especially increased in Lithuania, Poland and Russia, which has been reflected in a decreased nutrient load from scattered dwellings.

Table 8. Percentage of population connected to urban wastewater collection and treatment systems. Source of the data for the year 2004: PLC-5 Report. 2014 and 2017 information collected under the PLC-6 and PLC-7 projects respectively.

Country	2004	2014	2017
Denmark	89	85	94
Estonia	72	82	83
Finland	81	82	83
Germany	94	92	93
Latvia	70	76	75
Lithuania	59	80	82
Poland	58	72	71
Russia	60	83	89
Sweden	86	87	87

In 2017 in the Baltic Sea catchment area the number of scattered dwellings was nearly 17 million, but over 60% of them were connected to wastewater systems. The number of scattered dwellings not connected to wastewater treatment plants was 6.6 million (Table 9). Nearly 70% of them were in the Baltic Proper catchment area, mainly in Poland. Furthermore, in the Russian Gulf of Finland catchment the number of scattered dwellings not connected to wastewater systems was over one million.

Table 9. Number of scattered dwellings not connected to wastewater treatment plants in 2017. Source: PLC-7 project.

Sea-region	DE	DK	EE	FI	LV	LT	PL	RU	SE	BAS
Bothnian Bay				91022					36580	**127602**
Bothnian Sea				78504					122420	**200924**
Archipelago Sea				27169						**27169**
Gulf of Finland			1723	150296				1084640		**1236659**
Gulf of Riga			2129							**2129**
Baltic Proper	15000	9830					4194213	38968	273646	**4531657**
Western Balitc	350	85750								**86100**
The Sound		10288							12482	**22770**
The Kattegat		108505							189840	**298345**
Per country	**15350**	**214373**	**3852**	**346991**			**4194213**	**1123608**	**634968**	**6533355**

5. Potential to reduce nutrient inputs from point sources

(published as a HELCOM ACTION-project document)

5.1. Aim of the study

HELCOM Recommendation 28E/5 and the EU Urban Wastewater Treatment Directive set maximum nutrient concentrations for municipal wastewaters discharged into natural waters. This study estimated how much phosphorus and nitrogen loads would decrease if municipal wastewater treatment plants (MWWTP) followed those recommendations. The study was part of the European Union funded HELCOM ACTION project.

To estimate the reduction capacity of municipal wastewater treatment plants PLC-7 data was collected from the PLC-database. The data includes both treatment plants discharging wastewaters directly to marine waters and to inland plants. Total phosphorus (PTOT) and total nitrogen (NTOT) loads of individual plants were divided by flows to get concentrations, which were compared to the limit values of the HELCOM Recommendation 28E/5 and the EU Urban Wastewater Treatment Directive (Table 10). Since the HELCOM limit values are stricter for PTOT than the respective EU values, the comparison was done with HELCOM recommendation values. If the calculated concentration was above the limit value, the difference in mg/l was calculated back to tonnes for the estimation of the remaining reduction potential. Also, retention of nutrients in inland waters was taken into account to get the estimate of the actual reduction potential benefitting the Baltic Sea.

Table 10. Municipal wastewater treatment requirements according to HELCOM Recommendation 28E/5 and the respective requirements of the EU Urban Wastewater Treatment Directive. PE = population equivalent.

	HELCOM				EU			
PE	PTOT		NTOT		PTOT		NTOT	
	mg/l	%	mg/l	%	mg/l	%	mg/l	%
300-2000	2	70	35	30				
2001-10000	1	80	35	30				
10001-100000	0,5	90	15	70-80	2	80	15	70-80
> 100000	0,5	90	10	70-80	1	80	10	70-80

5.2. Data sources and calculation methods

Data of MWWTPs for the year 2017 (PLC-7 data) was collected from the PLC-database. Russia had only aggregated data, and also Swedish data concerning inland MWWTPs was aggregated, but for this study Sweden submitted data of individual plants. The data consisted of altogether 3990 plants (Table 11).

Population equivalent numbers (PE) were mostly missing in the database, but some countries (Denmark, Finland, Germany, Poland and Sweden) could submit this information enabling the classification of plants according PE numbers. Since there is a high correlation between wastewater flow and PE (r^2 0.81, n = 1741) in 2017, flow to estimate missing PE values was used according to this formula:

$$PE = flow\ (m^3/a) * 0.00904 + 4265$$

To be able to estimate the actual loads reaching the Baltic Sea, retention in inland surface waters has to be taken into account. For that purpose, MWWTPs were first divided into two categories: direct (zero retention) and indirect (variable retention depending on e.g. distance from sea and lake area). Since there is no estimate of retention of individual plants in the PLC-database other ways of retention were applied: A) for Danish plants 25% Ntot retention and 10% Ptot retention were used (Lars Svendsen personal communication). B) To estimate the retention for other countries MWWTP loads per sub-catchments were summed and the sums were compared with source apportionment figures (MWWTP loads reaching the Baltic Sea) derived from the PLC-7 data. C) Many countries (LT, LV, PL, RU) were lacking MWWTP loads in their source apportionment figures and for those countries published retention estimates were applied (Stålnacke et al. 2015, and Stålnacke Excel spreadsheet with P retention coefficients).

Table 11. Number of MWWTPs in the PLC-database in 2017 by countries and subregions. BAP = Baltic Proper, WEB = Western Baltic, KAT = Kattegat, SOU = Sound, GUF = Gulf of Finland, GUR = Gulf of Riga, ARC = Archipelago Sea, BOB = Bothnian Bay, BOS = Bothnian Sea.

COUNTRY	BAP	WEB	KAT	SOU	GUF	GUR	ARC	BOB	BOS	Sum
DE	52	64								**116**
DK	44	319	217	42						**622**
EE					44	13				**57**
FI					162		36	113	83	**394**
LT	556					75				**631**
LV	9				1	28				**38**
PL	1685									**1685**
RU	4				16					**20**
SE	163		120	14				29	101	**427**
Sum	**2513**	**383**	**337**	**56**	**223**	**116**	**36**	**142**	**184**	**3990**

5.3. Results

In 2017 the reported sum of MWWTP Ntot load in the PLC-database was 69,800 t including both indirect and direct loads without retention taken into account (Table 11). Three countries contributed more than 20% of the Ntot loads: Poland 28%, Russia 23% and Sweden 23%.

Loads were divided by country-wise population numbers to get concentrations (mg/l per inhabitants) enabling comparison of wastewater treatment (Table 12). Based on this comparison Russia, Finland and Sweden had the highest per capita nitrogen concentrations. Germany and Denmark are known for their efficient nitrogen removal, which was reflected in low per capita nitrogen concentrations in outflowing wastewaters. Estonia, Latvia, Lithuania and Poland had low per capita nitrogen concentrations, which indicates that treatment is at a high level also in those countries.

In 2017 the reported sum of MWWTP Ptot load in the PLC-database was 4220 t including both indirect and direct loads without retention taken into account (Table 13). Over half of the total municipal phosphorus loads originated from Poland, which also has the biggest population. Finland, Germany, Sweden and Estonia had the lowest per capita Ptot concentrations in outflowing wastewater. Russia had clearly the highest respective Ptot concentrations, which shows that there is still great potential in Ptot reduction.

Table 12. Ntot load of MWWTPs in 2017. BAP = Baltic Proper, WEB = Western Baltic, KAT = Kattegat, SOU = Sound, GUF = Gulf of Finland, GUR = Gulf of Riga, ARC = Archipelago Sea, BOB = Bothnian Bay, BOS = Bothnian Sea.

COUNTRY	BAP	WEB	KAT	SOU	GUF	GUR	ARC	BOB	BOS	Sum	%	Population	Population* connectivity	mg/ inhabitant
	t	t	t	t	t	t	t	t	t	t				
DE	543	875								**1419**	**2**	2700000	2484000	571
DK	48	1065	850	1047						**3010**	**4**	5100000	4335000	694
EE					659	87				**746**	**1**	1300000	1066000	700
FI					3932		550	2809	2275	**9566**	**14**	5500000	4510000	2121
LT	1823					163				**1986**	**3**	2900000	2320000	856
LV	119				20	1181				**1320**	**2**	2200000	1672000	789
PL	19903									**19903**	**28**	38500000	27720000	718
RU[1)]	525				15506					**16031**	**23**	8400000	6972000	2299
SE	6387		3457	1005				1393	3614	**15855**	**23**	9500000	8265000	1918
Sum	**29348**	**1940**	**4307**	**2052**	**20118**	**1431**	**550**	**4202**	**5889**	**69836**	**100**	**76100000**	**59344000**	

[1)] Russian figures are based on aggregated data.

Table 13. Ptot load of MWWTPs in 2017. BAP = Baltic Proper, WEB = Western Baltic, KAT = Kattegat, SOU = Sound, GUF = Gulf of Finland, GUR = Gulf of Riga, ARC = Archipelago Sea, BOB = Bothnian Bay, BOS = Bothnian Sea.

COUNTRY	BAP	WEB	KAT	SOU	GUF	GUR	ARC	BOB	BOS	Sum	%	Population	Population* connectivity	mg/ inhabitant
	t	t	t	t	t	t	t	t	t	t				
DE	37	27								**64**	**2**	2700000	2484000	24
DK	5	108	77	115						**305**	**7**	5100000	4335000	60
EE					31	5				**36**	**1**	1300000	1066000	28
FI					74		9	23	19	**124**	**3**	5500000	4510000	23
LT	136					15				**151**	**4**	2900000	2320000	52
LV	13				3	141				**157**	**4**	2200000	1672000	71
PL	2180									**2180**	**52**	38500000	27720000	57
RU[1)]	20				943					**963**	**23**	8400000	6972000	115
SE	104		70	26				11	31	**243**	**6**	9500000	8265000	26
Sum	**2495**	**136**	**147**	**142**	**1051**	**160**	**8,6**	**33,6**	**50,4**	**4223**	**100**	**76100000**	**59344000**	

[1)] Russian figures are based on aggregated data.

If all MWWTPs would follow HELCOM Recommendation 28E/5, NTOT loads discharged into inland waters or directly to the Baltic Sea would decrease by 13,600 t (Table 14). The largest reduction potential is in Russia, Finland and Sweden.

If all MWWTPs would follow HELCOM Recommendation 28E/5, PTOT loads discharged into inland waters or directly to the Baltic Sea would decrease by 2050 t (Table 15). In Estonia and Sweden there is no potential for further PTOT reductions, whereas the largest possibilities for reductions are in Poland and Russia.

Table 14. NTOT reduction potential in MWWTPs at source. BAP = Baltic Proper, WEB = Western Baltic, KAT = Kattegat, SOU = Sound, GUF = Gulf of Finland, GUR = Gulf of Riga, ARC = Archipelago Sea,

COUNTRY	BAP	WEB	KAT	SOU	GUF	GUR	ARC	BOB	BOS	Sum	
	t	t	t	t	t	t	t	t	t		%
DE	26	78								**103**	**0,8**
DK		4	3	0						**7**	**0,1**
EE					5					**5**	**0,0**
FI					1326		89	1703	1297	**4415**	**32,5**
LT	119					0				**119**	**0,9**
LV	8				9	207				**224**	**1,7**
PL	1375									**1375**	**10,1**
RU[1)]					4638					**4638**	**34,2**
SE	377		83	104				618	1498	**2680**	**19,8**
Sum	**1904**	**82**	**86**	**105**	**5978**	**207**	**89**	**2322**	**2795**	**13567**	**100**

[1)] Russian figures are based on aggregated data.

Table 15. PTOT reduction potential in MWWTPs at source. BAP = Baltic Proper, WEB = Western Baltic, KAT = Kattegat, SOU = Sound, GUF = Gulf of Finland, GUR = Gulf of Riga, ARC = Archipelago Sea, BOB = Bothnian Bay, BOS = Bothnian Sea.

COUNTRY	BAP	WEB	KAT	SOU	GUF	GUR	ARC	BOB	BOS	Sum	
	t	t	t	t	t	t	t	t	t		%
DE	11	2,6								**14**	**0,7**
DK	1,0	21	14	29						**65**	**3,2**
EE					0,1	0,0				**0**	**0,0**
FI					3,3		0,2	2,3	3,2	**9**	**0,4**
LT	48					4,9				**53**	**2,6**
LV	7,5				2,3	81				**91**	**4,4**
PL	1250									**1250**	**61,0**
RU[1)]	0,8				573					**573**	**28,0**
SE	0,1								0	**0**	**0,0**
Sum	**1319**	**24**	**14**	**29**	**578**	**86**	**0**	**2**	**3**	**2055**	**100**

[1)] Russian figures are based on aggregated data.

The reduction potential of loads discharged into inland waters would not totally benefit the Baltic Sea, since part of the loads would be retained along the route towards the sea. Approximately 17% of the N_{TOT} reduction potential is lost, because of retention and 42% of the respective P_{TOT} reduction potential (Tables 16 and 17). Thus, N_{TOT} load into the Baltic Sea would decrease by 10,500 t and the respective P_{TOT} load by 1210 t, if all MWWTPs would follow HELCOM Recommendation 28E/5. Russia, Finland and Sweden comprise together 88% of the N_{TOT} reduction potential, whereas Poland and Russia 86 % of the P_{TOT} reduction potential.

Table 16. N_{TOT} reduction potential in MWWTPs at sea (taking into account retention in inland surface waters). BAP = Baltic Proper, WEB = Western Baltic, KAT = Kattegat, SOU = Sound, GUF = Gulf of Finland, GUR = Gulf of Riga, ARC = Archipelago Sea, BOB = Bothnian Bay, BOS = Bothnian Sea.

COUNTRY	BAP	WEB	KAT	SOU	GUF	GUR	ARC	BOB	BOS	Sum	
	t	t	t	t	t	t	t	t	t		%
DE[1)]	26	78								**103**	**1,0**
DK		3	2	0						**6**	**0,1**
EE					2					**2**	**0,0**
FI					908		89	1526	811	**3334**	**31,8**
LT	84					0				**84**	**0,8**
LV	7				4	148				**158**	**1,5**
PL	951									**951**	**9,1**
RU[2)]					3575					**3575**	**34,1**
SE	83		49	104				653	1387	**2277**	**21,7**
Sum	**1150**	**81**	**51**	**105**	**4489**	**148**	**89**	**2179**	**2199**	**10490**	**100**

[1)] The German data are not well suited for this kind of analysis because the compared data are based on different minimum sizes of MWWTP (Germany reports currently only indirect discharges from MWWTPs > 2000 PE; the German model for the source apportionment considers already MWWTPs >50 PE). Due to the above described discrepancies in the used data for the calculations, the reduction potential of the German MWWTPs were the same at source and at sea.
[2)] Due to aggregation of the data on point sources reported to PLC-7 project, the input reduction potential for point sources in Russia might be overestimated.

Table 17. P_{TOT} reduction potential in MWWTPs at sea (taking into account retention in inland surface waters). BAP = Baltic Proper, WEB = Western Baltic, KAT = Kattegat, SOU = Sound, GUF = Gulf of Finland, GUR = Gulf of Riga, ARC = Archipelago Sea, BOB = Bothnian Bay, BOS = Bothnian Sea.

COUNTRY	BAP	WEB	KAT	SOU	GUF	GUR	ARC	BOB	BOS	Sum	
	t	t	t	t	t	t	t	t	t		%
DE[1)]	11	2,6								**14**	**1,1**
DK	1,0	21	13	29						**63**	**5,2**
EE					0,0	0,0				**0**	**0,0**
FI					2,1		0,2	2,2	2,3	**7**	**0,6**
LT	26					2,1				**28**	**2,4**
LV	4,1				1,2	50				**55**	**4,5**
PL	550									**550**	**45,4**
RU[2)]	0,6				494					**495**	**40,8**
SE	0,1								0	**0**	**0,0**
Sum	**593**	**23**	**13**	**29**	**497**	**52**	**0**	**2**	**2**	**1212**	**100**

[1)] The German data are not well suited for this kind of analysis because the compared data are based on different minimum sizes of MWWTP (Germany reports currently only indirect discharges from MWWTPs > 2000 PE; the German model for the source apportionment considers already MWWTPs >50 PE). Due to the above described discrepancies in the used data for the calculations, the reduction potential of the German MWWTPs were the same at source and at sea.
[2)] Due to aggregation of the data on point sources reported to PLC-7 project, the input reduction potential for point sources in Russia might be overestimated.

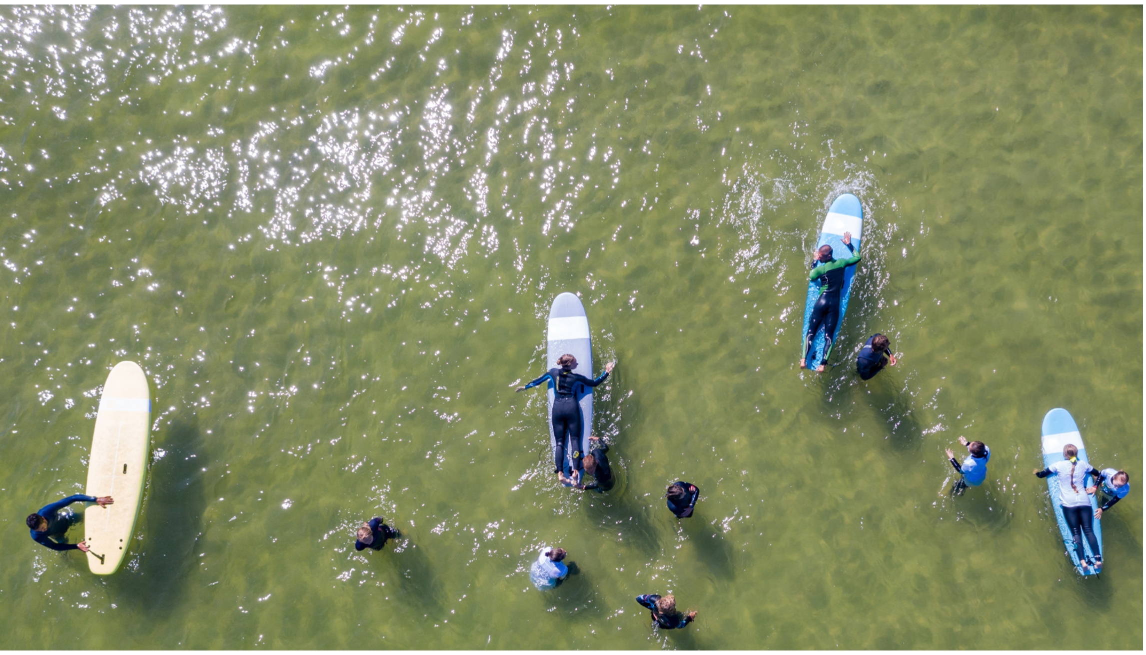
5.4. Conclusions and recommendations

Even if municipal wastewater treatment has improved substantially during the last decades there is still remarkable potential to reduce the nutrient load from this sector: N_{TOT} load into the Baltic Sea would decrease by 10,500 t and the respective P_{TOT} load by 1210 t, if all MWWTPs would follow HELCOM Recommendation 28E/5. This would correspond to nearly 10% of the BSAP reduction targets. Russia, Finland and Sweden comprise together 88% of the N_{TOT} reduction potential, whereas Poland and Russia 86 % of the P_{TOT} reduction potential.

The uncertainties in estimating reduction potential were partly connected to the comprehensiveness of national nutrient load reporting. During this study many countries updated/corrected their data and it was discovered that there is a need for further checking of possible shortcomings in data reporting.

Russia submitted only aggregated data disabling precise calculations of PE numbers and retention in inland waters. For other countries also only average catchment-wise retention values were applied. Better knowledge about the location of the plants and retention dynamics would give more reliable estimates of how much of the potential reductions would actually benefit the Baltic Sea. This would be especially important for Polish and Russian plants.

6. Recommendations



These are preliminary proposals to future work:

— Important to improve the quality/coverage of both point source data and diffuse source data in the PLC database. This may require corrections in the data and addition of missing data if available. Better knowledge of the origin of diffuse loads is needed for many Contracting Parties.
— Collection of relevant supporting parameters (e.g. a specific list of measures applied in each catchment, changes in connectivity, changes in local population density, changes in levels of activities such as aquaculture or industries, usage of fertilizers) into the PLC database or relevant associated system.
— Ensure data reported on measures and supporting parameters (i.e. to provide a causal framework) are of compatible scale, i.e. can be linked to ascertain causative effects (i.e. deterioration/improvement).
— A defined process would also be needed to evaluate each identified measure and its effectiveness, including aspects such as regional potential or local application. Such an evaluation would provide for regional recommendations on future measures.
— Based on the above an analysis of linkages between applied measures and observed changes on load could be carried out.

7. Effectiveness of measures and the PLC-8 project

During the PLC-6 and PLC-7 projects it became evident, that it was not possible to reliably estimate reasons behind the past changes in nutrient loads, with the exception of point source loads. Furthermore, it was not possible to evaluate projected future reductions in a harmonized way. However, since that time there has been a lot of progress in development of nutrient load models in many PLC countries, which has led to more accurate estimates of nutrient loads in the past and projected loads in future.

Therefore, now the intention in the forthcoming PLC-8 Effectiveness of measures (EOM) project is to include some examples from river catchments with decreasing nutrient inputs and to quantify reasons behind the decreases. An additional aim is to compile information on the planned measures and to evaluate what is their implementation status in 2023. Furthermore, the intention is to estimate what the expected reductions in nutrient loads by 2030 are. According to preliminary discussions in the PLC group at least Denmark, Finland, Germany and Sweden should be able to submit that kind of data.

Presently, there are still many open issues concerning what kind of EOM data countries are finally able to submit for the PLC-8 project (e.g. spatial scale, time period, accuracy of different mitigation measures, effect of climate change). To solve these questions a pilot project and a workshop dealing with EOM will be organized in 2022.

The preliminary draft of the content of the PLC-8 EOM report:

1. Changes in point source loads (1995 to 2021)
    b. Indirect and direct point source loads
    c. Inputs of nutrients from nine big municipal wastewater treatment plants
    d. Potential to reduce nutrient inputs from municipal wastewaters
5. Examples of river catchments with reduced nutrient inputs (1995 to 2021): quantify the effectiveness of the measures taken
6. Connectivity and inputs from scattered dwellings
7. Implementation status of the planned mitigation measures in 2023
8. Expected reductions in nutrient inputs by 2030

8. References

Stålnacke, P., Pengerud, A., Vassiljev, A., Smedberg, E., Mörth, C.-M., Hägg, H. E., Humborg, C. and Andersen, H.E. 2015. Nitrogen surface water retention in the Baltic Sea drainage basin. Hydrol. Earth Syst. Sci., 19, 981–996.