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JRC TECHNICAL REPORT

An EU analysis of the ecological disaster in the Oder River of 2022

Lessons learned and research-based recommendations to avoid future ecological damage in EU rivers, a joint analysis from DG ENV, JRC and the EEA

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Preface

The summer of 2022 was a wake-up call for many. Among the many worrying pictures of severe drought impact across Europe, citizens were also confronted with the shocking images of hundreds of thousands of fish that died in the river Oder, within the space of just a few weeks in July and August 2022. This was one of the largest ecological disasters in recent European river history. The Member States most involved, Poland and Germany, removed the dead fish, published reports analysing the events and, to the extent possible, the causes. They also committed to do whatever is required to ensure the Oder ecosystem is restored.

The EU institutions offered their support and expertise from the outset including in terms of possible funding for restoration.

Fragile river ecosystems, already subject to many pollution pressures (e.g. excessive nutrients and wastewater discharges), can reach an ecological tipping point – in this case facilitating the blooming of a harmful algae that produced toxins causing widespread damage across a large part of the river ecosystem. This was facilitated by very high releases of polluting salts, drought, high water temperatures and low flow. The Oder's ecological disaster and the fish die off are yet another sad proof that the European Zero Pollution Ambition for 2050, pledged as part of the Green Deal, is simply a necessity.

At European level, we have a responsibility to reduce the risks of repeating such an event, in the Oder or in any other river in Europe that is similarly fragile or at risk of becoming so due to climate change. Moreover, the event underlined again the necessity that all rivers and other surface waters meet the objectives of EU water legislation, which will increase their resilience against these risks.

Building on the German and Polish analysis, the European Commission (Joint Research Centre and Directorate General Environment) and the European Environment Agency have drafted this report, containing an analysis of the event, its causes and consequences, and a range of recommendations at all levels. Considering that our climate is changing and rendering aquatic ecosystems even more vulnerable, it is both important and urgent to do all that is needed to prevent an event like in the Oder from happening again. It is only through better knowledge, faster warning systems, closer transboundary cooperation and a much improved implementation of water policies that the EU will be better equipped to face such events with a minimal impact on its vital ecosystems such as rivers.

Signed by		
Florika Fink-Hooijer Director General, DG Environment, European Commission	**Stephen Quest** Director General, Joint Research Centre, European Commission	**Hans Bruyninckx** Executive Director of the European Environment Agency

Summary

During August 2022 massive fish kills were noted on the Oder river and eventually resulted in the death of approximately 360 tonnes of fish and had an ecological impact along 500 km of the river. It is almost certain that their deaths were caused by a substantial toxic algal bloom that happened at this time. The causal species was identified as *Prymnesium parvum*, a species adapted to brackish salinities. A key factor that enabled the proliferation of this species was the high salinity of the Oder river during this time, probably due, at least partly to discharges of industrial wastewater with a high salt content e.g. from mining activities. Other contributing factors were the drought and the resulting low water levels reducing dilution and flow and also hydromorphological modifications to the river. High nutrient concentrations, especially phosphorus and nitrogen were also key in promoting the algal blooms.

In the future, this could be avoided by improving online monitoring coupled with mandatory communication of pollution events across international river basin districts. It may also be necessary to review and implement dynamic control of all licenced discharges and review the role of hydromorphological modifications in slowing the flow allowing time for blooms to develop. In addition, a complete investigation of discharges in the catchment should be carried out to explain the increase in salt load that played a key role in bloom development. The presence and spread of this invasive and toxic algal species will most likely continue. Therefore, management strategies to prevent its proliferation must now be prioritised in this catchment but also in all other susceptible European river basin districts. A preliminary risk assessment of rivers using data available in the European Environment Agency (EEA) Waterbase database can be found in Annex 1.

1. Introduction

During August 2022 massive fish kills were noted on the Oder river that eventually resulted in the death of approximately 360 tonnes of fish. Severe ecological impact extended along 500 km of the river. The river Oder is one of Europe's 20 large rivers[1] and represents a significant tourism and recreational resource to the 16 million residents of its catchment and beyond. It also serves as a focus for nature preservation with numerous Natura 2000 sites located along its length.

Initially, there was complete uncertainty about the cause of the fish kill. This uncertainty and the size of the fish kill being massive (100s of tonnes) and occurring along hundreds of kilometres of a major European river led to widespread concern for both ecological and human health, with people being advised not to come into contact with the river. The Oder disaster received considerable public, press and political attention in the two most concerned countries and at European level.

At the time of writing of this report, it is clear that this ecological disaster was not only a natural phenomenon but was caused by a multitude of factors, many of which are of human origin. The massive algal blooms of the toxic brackish-water algae *Prymnesium parvum* that ultimately pushed the Oder ecosystem over its ecological 'tipping point', would not have been possible under natural conditions.

With global warming intensifying the frequency, duration and severity of future dry periods the likelihood of prolonged periods of low water flows is increasing and amplifies the risks and consequences of similar ecological disasters in other EU rivers, especially where rivers have been heavily modified to facilitate shipping and industrial activity.

Although political and public discussions are partly still ongoing, the ecological disaster in the Oder river clearly demonstrates that the situation of the continuing water pollution in all European rivers (the situation is not limited to cross-border river basins only), combined with increasingly low water levels and high temperatures needs to be addressed urgently.

The Water Framework Directive (WFD) and the Industrial Emissions Directive (IED) are two of the main European instruments to address water quality and emissions from industrial installations. The ongoing review of these two instruments will further improve the situation by better assessing new risks, pressures and impacts on water bodies and will help preventing the reoccurrence of such disasters. To the extent possible, knowledge gained from the Oder disaster has already been incorporated in the ongoing review of these instruments, e.g. by introducing a mandatory 'warning clause' in the case of significant pollution incidents.

[1] WISE Large rivers and large lakes — European Environment Agency (europa.eu)

2. Description of incident

The Oder River basin has a drainage area of 118,938 km^2, most of which is in Poland. It originates in the Czech Republic, flows through western Poland, forms the border between Poland and Germany, then drains north to the Szczecin Lagoon near Szczecin. (Figure 1). The population of the basin is close to 16 million inhabitants (2015) and 50.4% of the basin is agricultural cropland (JRC Oder Fact sheet[2]).

In early August 2022, the media started reporting about large amounts of dead fish found along the river Oder (or Odra in Polish and Czech). A German-Polish joint task force was formed to investigate what led to the mass kill of fish and aquatic organisms like freshwater bivalves and other molluscs alongside the mortality of birds, ducks, beavers and other wildlife.[3,4]

A subsequent formal investigation by the Polish authorities indicated that the first fish deaths in the summer period were observed on July 14, 2022 on the Gliwice Canal (Figure 2) but it is unclear if this was directly related to the subsequent fish kills.[6] Most of the fish kills were observed from the end of July 2022 to September 12, 2022 by which time a total of around 360 tons of dead fish were observed.[5] West Pomeranian was one of the regions that recorded the largest fish kills, mostly occurring over a 12 day period in mid-August (top left green box in Figure 2; Figure 3b). The disaster also directly and indirectly impacted nature protection areas /protected habitats and their protected species alongside the Oder River e.g. 'Stettiner Haff', the Natura 2000 area "Dolna Odra /Unteres Odertal", and many others. An illustration of the various areas protected under the EU Birds and Habitats Directives is included in Figure 3a.

[2] https://water.jrc.ec.europa.eu/pdf/oder-fs.pdf

[3] See https://www.bbc.co.uk/news/world-europe-62536918

[4] https://www.bbc.com/news/world-europe-62688036

[5] On the Polish side alone 249 tonnes of dead fish were reported, in total around 360 tonnes of dead fish were reported in Germany and Poland combined.

Figure 1 The Oder river basin.

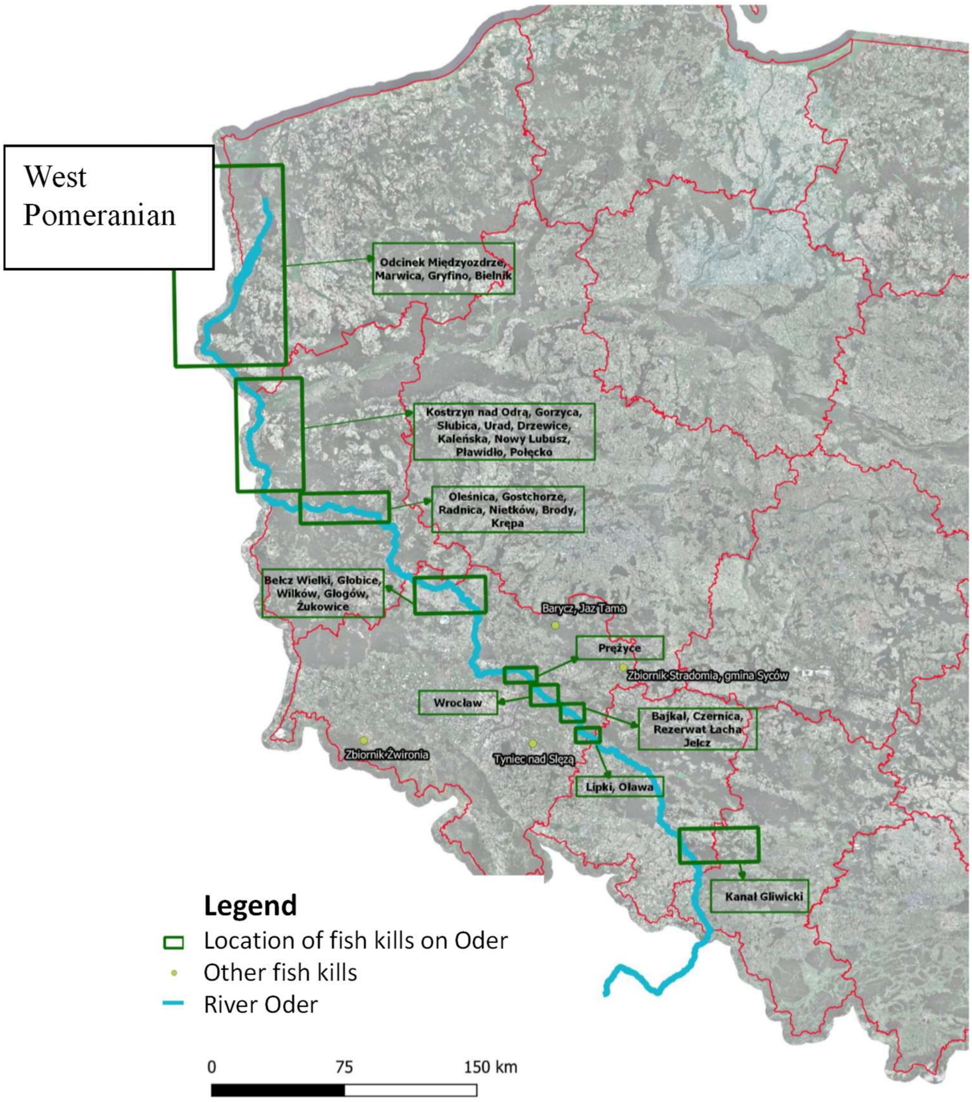

Figure 2 Map of locations where fish kills were observed from official Polish report (September 2022).[6]

[6] https://ios.edu.pl/wp-content/uploads/2022/09/Wstepny-raport-zespolu-ds.-sytuacji-na-rzece-Odrze-2.pdf

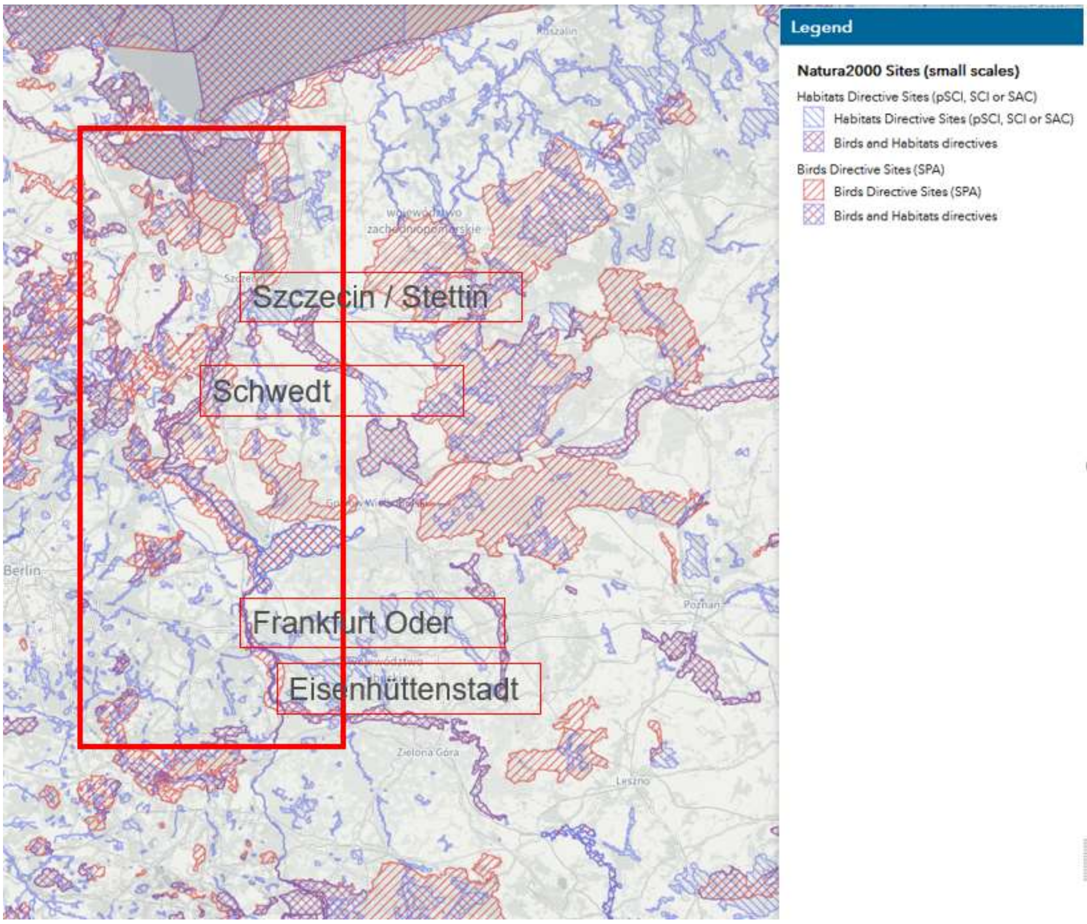

Figure 3a: Illustrative map of Natura 2000 sites (sub-divided into sites protected under the Birds and Habitats Directives) along the Oder river between Eisenhüttenstadt and Szczecin: Source: https://natura2000.eea.europa.eu/ (September 2022).

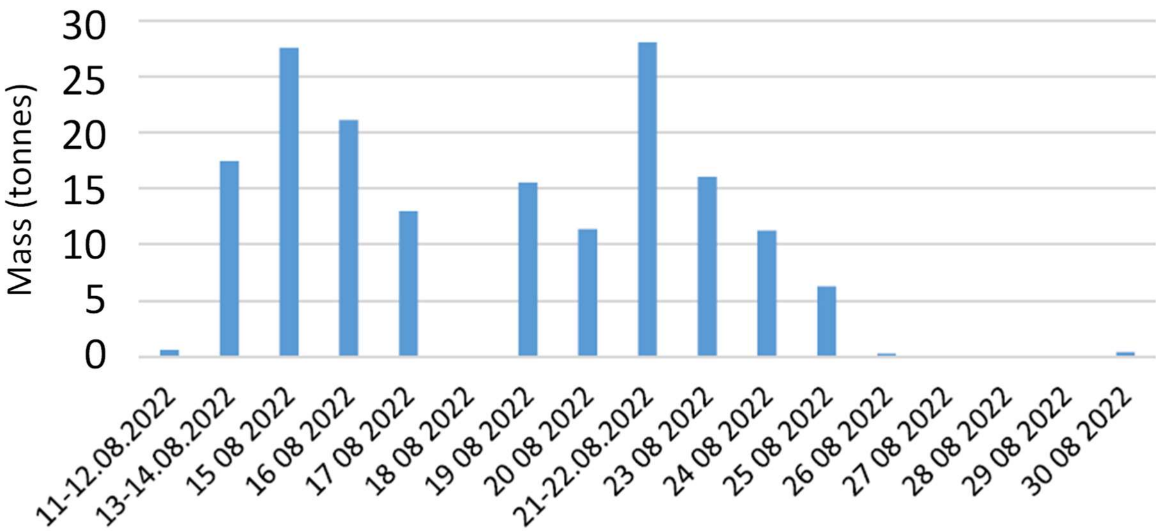

Figure 3b Distribution of fish deaths in West Pomeranian from the official Polish report.[7]

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[7] https://ios.edu.pl/wp-content/uploads/2022/09/Wstepny-raport-zespolu-ds.-sytuacji-na-rzece-Odrze-2.pdf

3. Publicly available information and scientific interpretation

For this report public information that became available while the disaster unfolded was analysed. The information was derived from the reports from national authorities and supplemented and enriched with information from various independent sources. A preliminary risk analysis is presented in an appendix to this report to provide an overview of European rivers that may be at risk.

The initial start of the disaster was characterised by a lack of understanding of the causes of the fish kill and an absence of formal communication, mainly between national competent authorities but to a lesser extent also to the public, despite this being an international river basin district. The late and incomplete communication and information exchange between national authorities is known to have hampered an early response and efforts to limit the amount of ecological damage, as well as the initiation of possible mitigating measures. The need to ensure enactment of existing communication plans in order to minimise damage was subsequently highlighted[8]. The following sections consider the publicly available information that became available as the incident progressed.

4. In situ monitoring

High frequency, near real time *in situ* monitoring at Frankfurt (Oder)[9] provided an excellent source of information describing the evolution of the event based on key parameters such as conductivity (Figure 4) (an indicator of solute concentration), chlorophyll-a (Figure 5) and nitrate (Figure 6).[10,] An increase in conductivity can be noted from the 1st of August with an accelerated increase on the 4th of August 2022. The observed increase of conductivity, close to double previous values is characteristic of a discharge from an upstream industrial or municipal source[11]. The exact original source of the pollution remains unclear although it is clear that the underlying contributing factors are anthropogenic. At this station a rapid increase in chlorophyll-a from around 20 µg l^{-1} was noted between the 7th and 8th of August of approximately 140 µg l^{-1} representing a very large phytoplankton bloom. This was accompanied by a decline in nitrate, most likely due to uptake by the algae. Generally, an increase of this magnitude over such a short time-period of two days is not possible by in-situ algal growth; therefore, the increase is likely to largely represent a downstream movement of a bloom.

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[8] https://www.bmuv.de/en/download/status-report-on-fish-die-off-in-the-oder-river

[9] https://lfu.brandenburg.de/lfu/de/aufgaben/wasser/fliessgewaesser-und-seen/gewaesserueberwachung/wasserguetemessnetz/frankfurt-oder/

[10] https://lfu.brandenburg.de/lfu/de/aufgaben/wasser/fliessgewaesser-und-seen/gewaesserueberwachung/wasserguetemessnetz/frankfurt-oder/

[11] Salinity levels of rivers are usually classified as; a) Low salinity impact class (<700 µS cm^{-1}): b) Moderate salinity impact class (700–1500 µS cm^{-1}) and: c) High salinity impact class (>1500 µS cm^{-1}). The threshold level for water suitable for irrigation is (<700 µS cm^{-1}). Source: https://www.nature.com/articles/s41467-021-24281-8

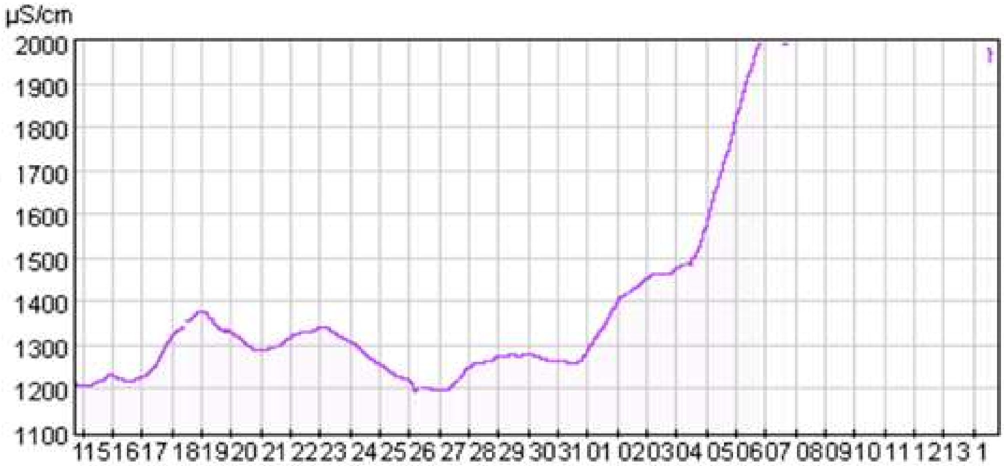

Figure 4 Conductivity at Frankfurt (Oder) during July and August 2022.[10]

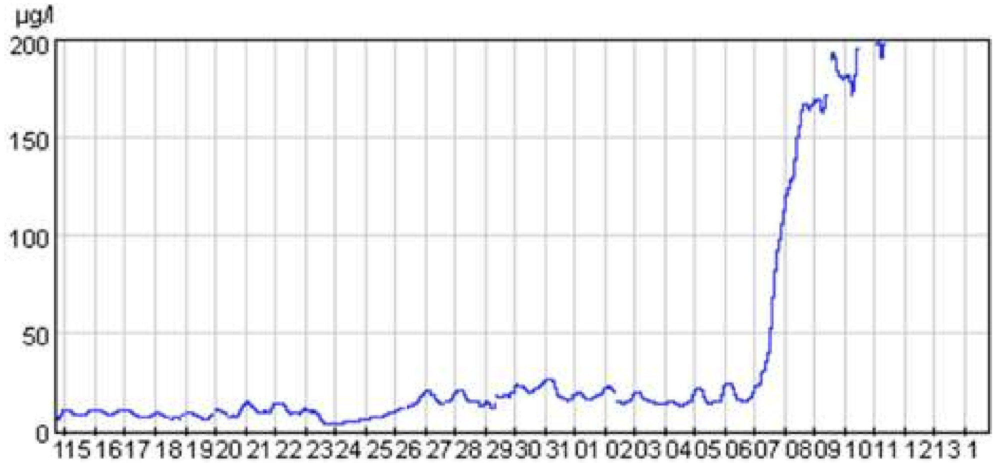

Figure 5 Chlorophyll-a at Frankfurt (Oder) during July and August 2022. [10]

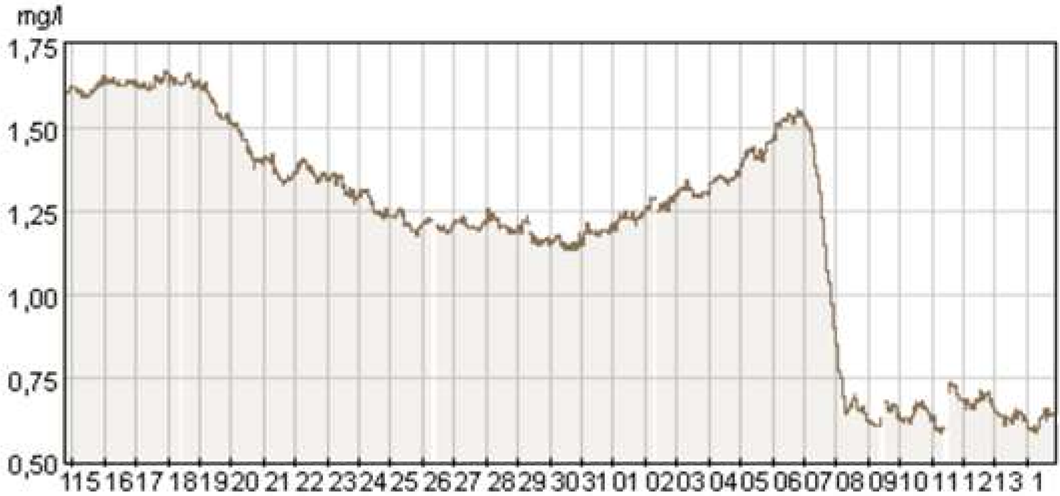

Figure 6 Nitrate concentration at Frankfurt (Oder) during July and August 2022. [10]

5. Satellite observations

While *in situ* monitoring at high frequency is extremely useful in tracing the event progression, the spatial resolution is obviously limited. Remote sensing, using the work published online by Brockmann Consult shows the progression of the algal bloom in space and time for the Oder river (Figure 7).[12] Higher concentrations of chlorophyll-a are evident in the lower and upper reaches of the river in early July. In early August, high concentrations exceeding 150 µg l^{-1} are found in the upper and middle reaches, which progressively increase in extent until the middle of August, with notable increases downstream. At the peak in mid-August there were elevated concentrations for over 200 km of river length (Figure 7). The algal bloom dissipated towards the end of August. Additional Earth Observation information was gathered through the Copernicus Emergency Management Service report on the Oder as requested by Poland. It indicated, in addition, that concentrations of chlorophyll-a were elevated with respect to previous years.

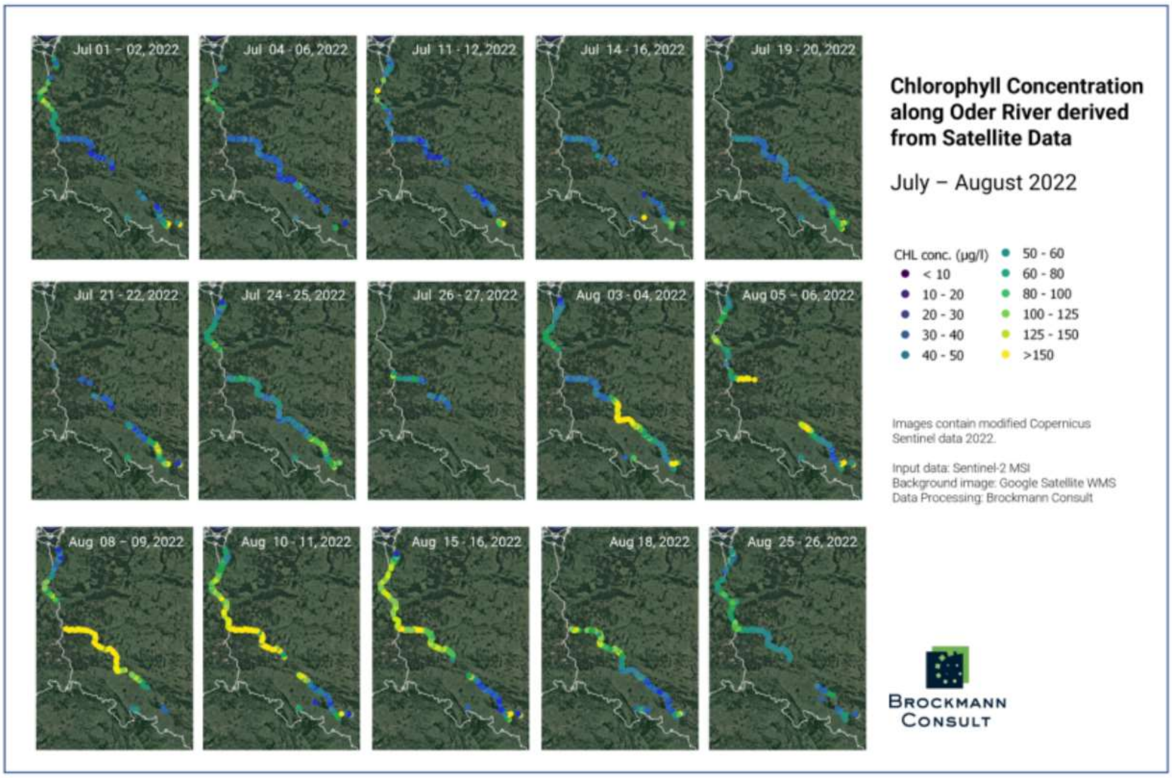

Figure 7 Chlorophyll-a concentration in the Oder River between July and August 2022 produced by Brockmann Consult.[12] Note high concentrations and long extent of bloom from early to mid-August. Data gaps are from unusable imagery (e.g. cloud cover). Graphic © Brockmann Consult

[12] https://www.igb-berlin.de/en/news/new-analysis-satellite-data-confirm-massive-algal-bloom-oder-river

6. Characterisation of the algal bloom

Subsequent investigations into the species composition of the algal bloom revealed that it was largely caused by a species more typical of brackish water *Prymnesium parvum*.[13] The University of Vienna researcher Dr Elisabeth Varga independently confirmed the presence of associated algal toxins prymnesins[13]. The detection and confirmation of toxins is analytically challenging with no established calibration standards currently available. These factors mean analysis is restricted to only specialised laboratories, limiting the speed and amount of sample processing. The high salinity of the Oder River during this period was a contributing factor that promoted the development of this species, which subsequently released toxins resulting in mass mortality of fish and other taxa.

Prymnesium parvum has a global distribution and blooms resulting in fish mortality have been recorded since the early 1900s in brackish water. It is also common for harmful blooms to reoccur in subsequent years. For example, in Europe, recurrent blooms have been noted in Germany, the UK, Norway, and Sweden, although not with as far-reaching catastrophic consequences in river systems.[14,] Fish kills typically occur via toxin release at very high concentrations of algal cells, which require high nutrients (nitrogen and phosphorus) to develop.[15]

A datasheet on *Prymnesium parvum* that covers taxonomy, overview, distribution, dispersal, diagnosis, biology & ecology, environmental requirements, natural enemies, impacts, uses, prevention/control and further information can be accessed online https://www.cabidigitallibrary.org/doi/10.1079/cabicompendium.121720. The datasheet also includes information on documented global occurrence of *P. parvum* blooms.

A comprehensive review on the relevant biology important in the ecology and identification of this organism, its occurrence, nutritional requirements, factors governing its toxicity, and methods used to control toxic blooms with which it is associated can be found elsewhere (S. Watson, 2001, https://tpwd.texas.gov/publications/pwdpubs/media/pwd_rp_t3200_1158.pdf).

One of the incidents of recent expansion with this alien species was documented in Pennsylvania (Environ. Sci. Technol. 2009, 43, 24, 9046–9047 https://pubs.acs.org/doi/10.1021/es903354w).

Yin et al. (2021) documented in a Nature publication a protocol to assess optimal growth condition for the species. (https://doi.org/10.1038/s41598-021-92214-y). Their work showed that *P. parvum* can reach a maximum growth rate when the water temperature, pH and salinity is 18.11 °C, 8.39, and 1.23‰, respectively. Moreover, maximum growth rate of *P. parvum* was reached when the concentration of nitrogen, phosphorous, silicon and iron reach 3.41, 1.05, 0.69 and 0.53 mg l^{-1}, respectively. The order of the effects of the environmental factors impacting the biomass density of *P. parvum* was pH > salinity > water temperature, while the order of the effects of nutrients impacting the biomass density of *P. parvum* was nitrogen > phosphorous > iron > silicon.

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[13] https://www.igb-berlin.de/en/news/suspicion-confirmed-algal-toxin-produced-brackish-water-species-detected-oder-water

[14] Edvardsen, B., & Paasche, E. (1998). Bloom dynamics and physiology of Prymnesium and Chrysochromulina. NATO ASI SERIES G ECOLOGICAL SCIENCES, 41, 193-208.

[15] Edvardsen, B., & Imai, I. (2006). The ecology of harmful flagellates within Prymnesiophyceae and Raphidophyceae. In Ecology of harmful algae (pp. 67-79). Springer, Berlin, Heidelberg.

7. Investigative monitoring by the Polish authorities

In response to the crisis, the Polish authorities launched a monitoring campaign that intensified as the magnitude of the disaster became apparent, with daily samples being taken along the entire length of the river. Basic chemistry data was eventually made available at temporal and spatial resolution to cover the Oder river incident at the following Polish government website https://www.gov.pl/web/odra/badania-odry. Accessibility was difficult with data available per site per date rather than as a download to facilitate analysis. Data were collated and an initial examination was carried out within the JRC. Electrical conductivity is a convenient indicator of solute concentrations and a useful tracer of salt concentrations in the catchment. Conductivity values ranged from a maximum of 7290 µS[16] cm^{-1} in the Gliwice canal (18th August) to a minimum of 417 µS cm^{-1} at Chałupki (22th August) which is located at the border with the Czech Republic, 60 km upstream from where the Gliwice canal discharges into the main Oder river (Figure 8).

As well as the conductivity being high in the Gliwice canal, indicating some discharges there, it was also high towards the sea as would be expected from the naturally high salt concentrations (Figure 8). This illustrates one of the difficulties in using conductivity to track pollution, as rivers will have high conductivity often many km upstream from the sea. One way around this is to look at concentrations of ions (Na^+, Mg^{2+}, Ca^{2+}, SO_4^{2-} , Cl^- etc.) in the water that exceed values expected from a seawater source alone. Using chloride (Cl^-) as a reference ion, we can therefore calculate 'non-marine' concentrations. Sulfate (SO_4^{2-}) was also measured and this is a known useful indicator of mine drainage contamination.[17] Converting the sulfate concentrations to meq (milli-equivalents) we can calculate the non-marine concentrations allowing us to focus on sulfate from other origins. In Figure 9 (A & B) any data with non-marine sulfate above 3 meq l^{-1} are plotted in red. In Figure 9 A, we can see a distinct group with high non-marine sulfate and chloride. If we look at Figure 9 B which plots the coordinates, we can see that all the positions that had a non-marine sulfate above 3 meq l^{-1} are located upstream of the main Oder river on the Gliwice canal (PLRW60000117169) (Figure 9 B, Figure 10). This most likely indicates a source of anthropogenic emissions of effluents with elevated salt loads in this part of the catchment area.

[16] Water with conductivity ranges between 2500-10,000 µS/cm is no longer suitable for irrigation, nor can it be used to produce drinking water https://mrccc.org.au/wp-content/uploads/2013/10/Water-Quality-Salinity-Standards.pdf

[17] Gray, N.F. Field assessment of acid mine drainage contamination in surface and ground water. Geo 27, 358–361 (1996). https://doi.org/10.1007/BF00766705

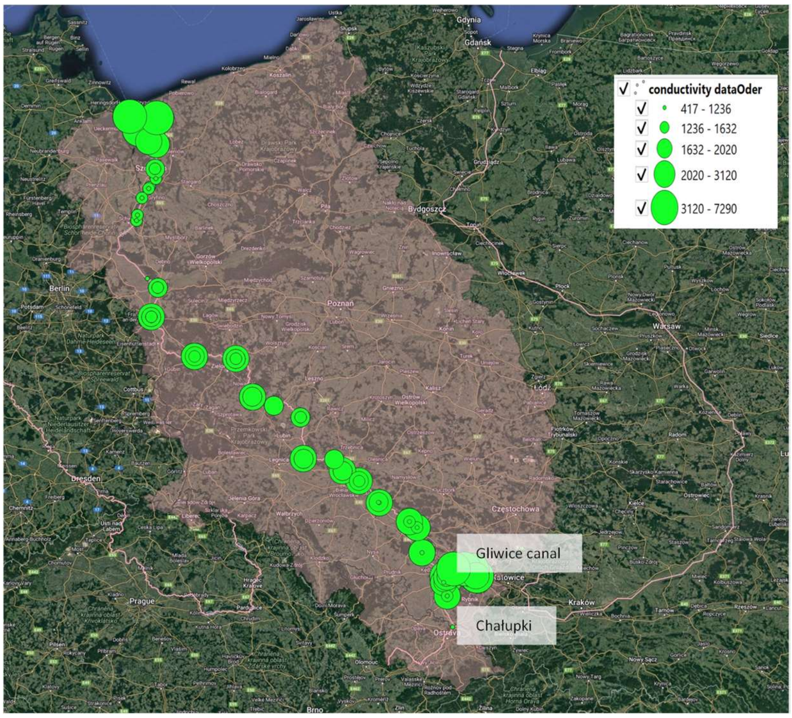

Figure 8 Distribution of conductivity measured in situ by Polish authorities between 2022/07/28 to 2022/08/24. Base map Google.

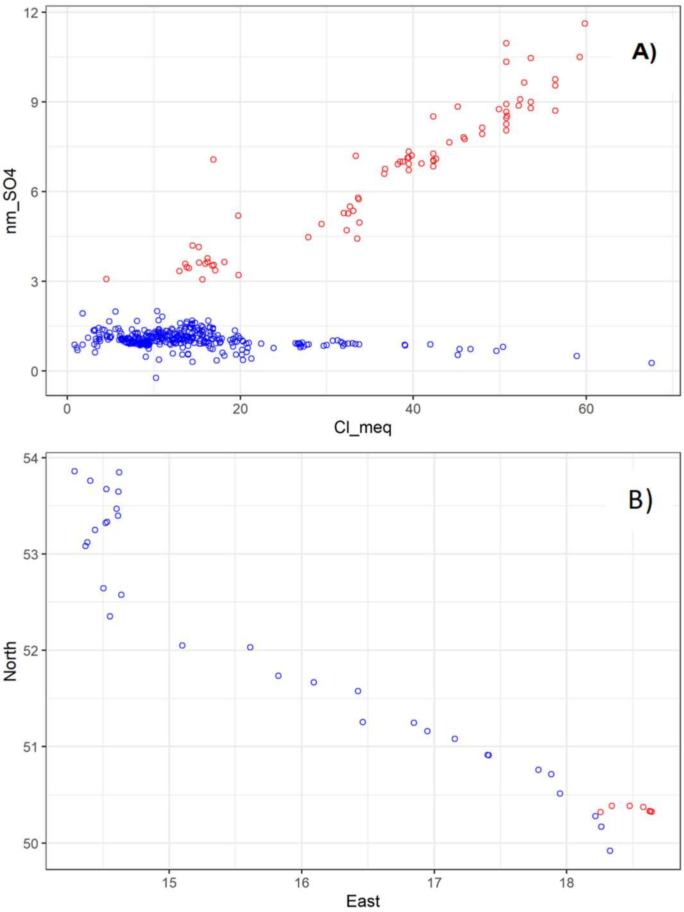

Figure 9 A) plot of non-marine sulfate against chloride concentration in meq l^{-1}. B) coordinates of sample locations along the Oder river. Red indicates non-marine sulfate concentration above 3 meq l^{-1}. Data are from July 28th – August 24th.

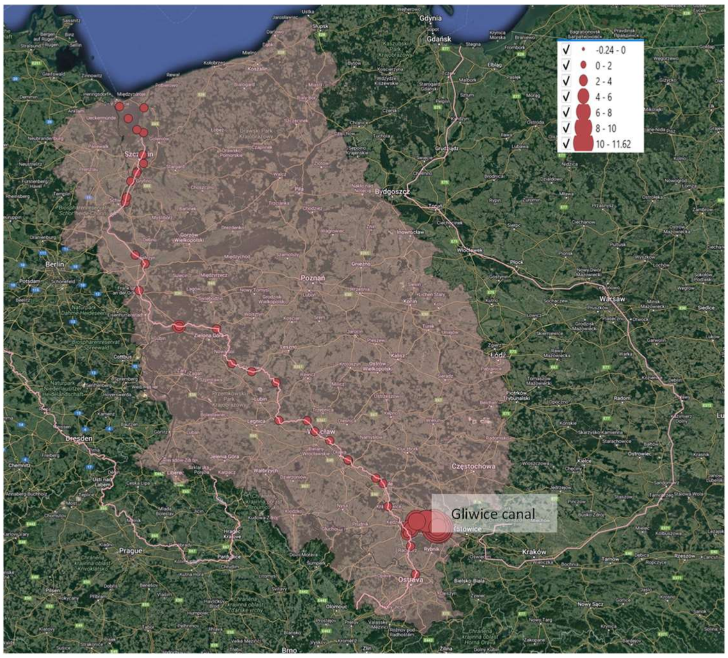

Figure 10 Location and concentration of non-marine sulfate in meq l^{-1} measured by Polish authorities between 2022/07/28 to 2022/08/24. Base map Google.

8. European Environment Agency (EEA) data

The European Environment Agency (EEA) holds a substantial amount of information on the European environment.[18] The European Pollutant Release and Transfer Register (E-PRTR) provides easily accessible key environmental data from industrial facilities in Europe. Depending on reporting thresholds, each industrial facility provides information on the quantities of pollutants released.[19] Examining the register for Polish sites in the Oder catchment for the years 2018-2020 revealed 34 facilities with chloride discharges. Using this, we can see that the Gliwice Canal has several emissions sources with high chloride according to the E-PRTR database - see Figure 11 which contrasts non-marine sulfate (red) with emissions of chloride (yellow). However, while this database is useful, it does not serve the purpose of monitoring as it typically contains information from larger well-managed facilities reported in an aggregated manner and only at annual frequency. Therefore, it lacks detail on emission points, and cannot replace national data gathered by local investigative teams.

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[18] https://www.eea.europa.eu/

[19] https://www.eea.europa.eu/data-and-maps/data/industrial-reporting-under-the-industrial-6

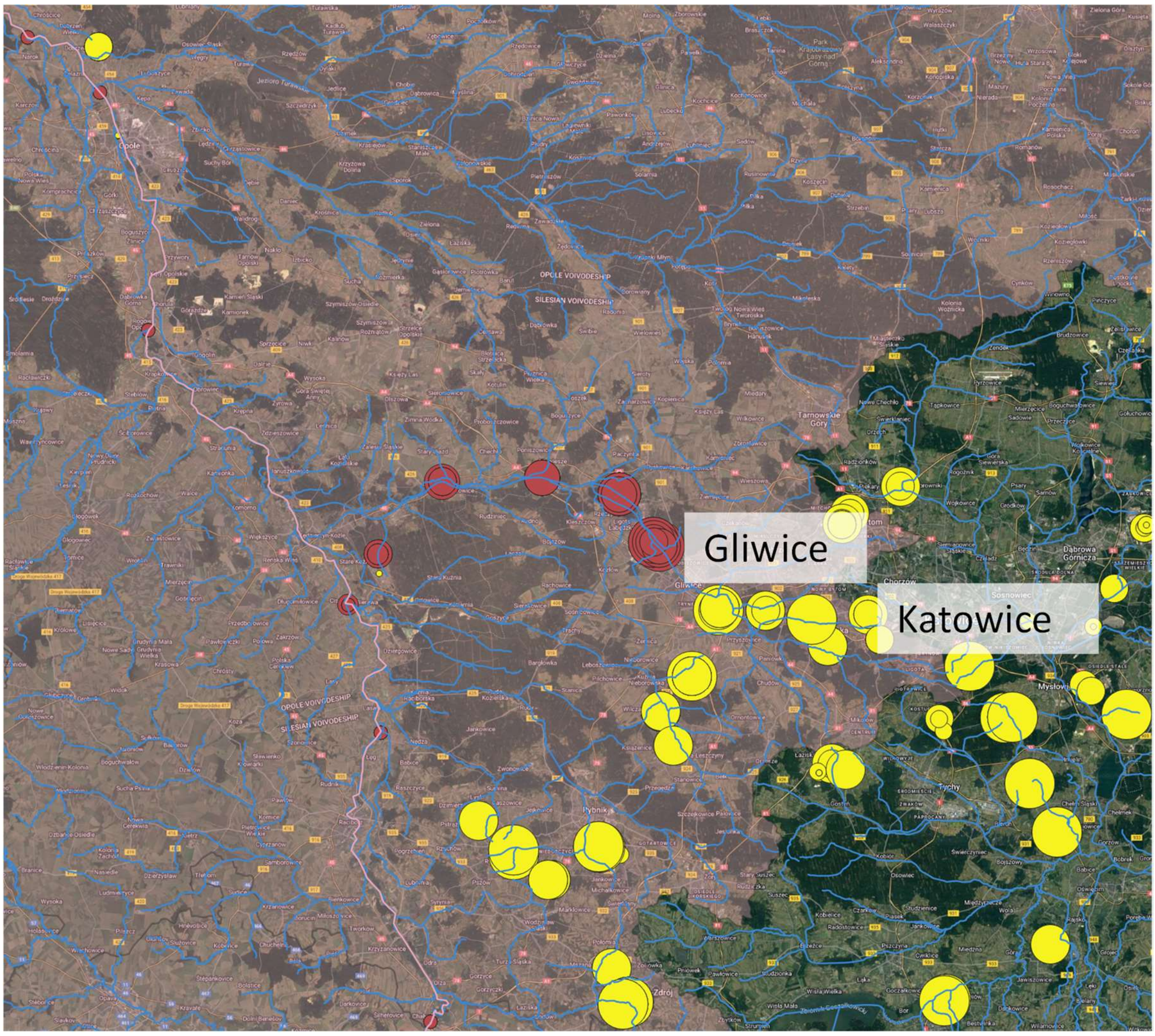

Figure 11 Map contrasting non-marine sulfate (red) with emissions of Chloride (yellow) for the area around Gliwice canal. Larger points are indicative of larger values. Oder catchment shaded pink. Base map Google.

The EEA also hosts 'Waterbase' a water quality database which contains a substantial amount of information on catchment water quality supplied by member countries.[20] Examining the data for conductivity indicates that the upper part of the catchment has recorded high values for conductivity in the past (Figure 12)[21].

[20] https://www.eea.europa.eu/data-and-maps/data/waterbase-water-quality-icm-2

[21] Salinity levels of rivers are usually classified as; a) Low salinity impact class (<700 μS cm^{-1}): b) Moderate salinity impact class (700–1500 μS cm^{-1}) and: c) High salinity impact class (>1500 μS cm^{-1}). The threshold level for water suitable for irrigation is (<700 μS cm^{-1}). Source: https://www.nature.com/articles/s41467-021-24281-8

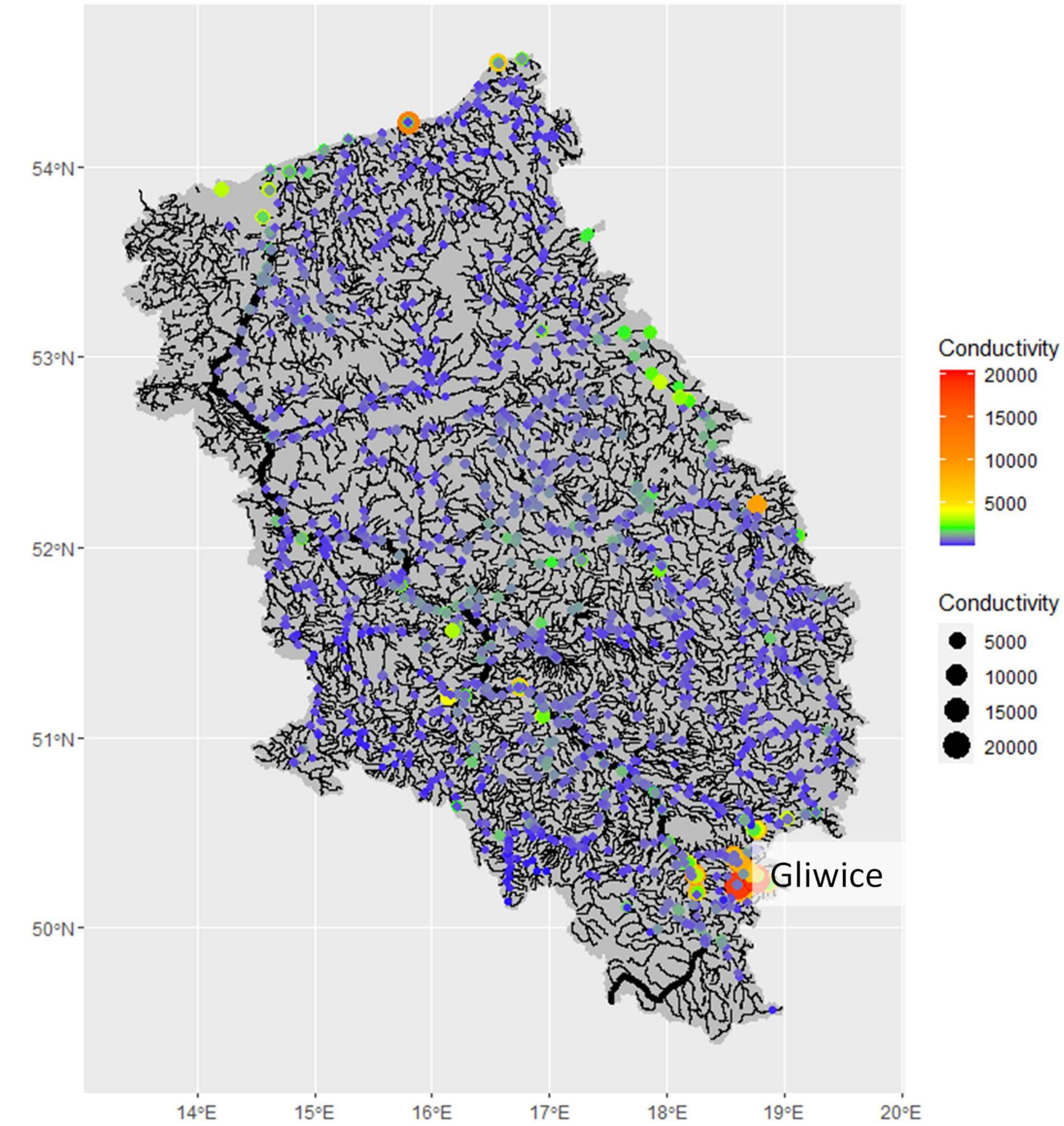

Figure 12 Map of the Oder catchment showing tributaries and main channel (in black) with conductivity (µS cm^{-1}) records from the EEA database (2013-2020). Note high values in the upper catchment.

As part of reporting for the 2nd River Basin Management Plans (RBMPs) the 'significant pressures' and 'significant impact type' was reported by member states. The significant pressures are those where the pressure contributes to an impact that may result in failing to achieve Environmental Objectives. This information is publically available on EEA dashboards (Workbook: WISE_SOW_PressuresImpacts (europa.eu)) and indicates that the main identified pressures are: unknown, diffuse, hydromorphology and point sources (Figure 13). Whereas, the 'significant impact type' is where the ecological status or potential of the surface water body is less than good and therefore at least one significant impact type or the option 'Unknown impact type' must be reported (Workbook: WISE_SOW_PressuresImpacts (europa.eu)).[22] The most common known significant impact types reported were: 'Altered habitats as a result of hydrological and morphololgical alterations', nutrient pollution and chemical pollution.[23] (Figure 14). Other known impact types were organic pollution, saline or other intrusion and acidification.

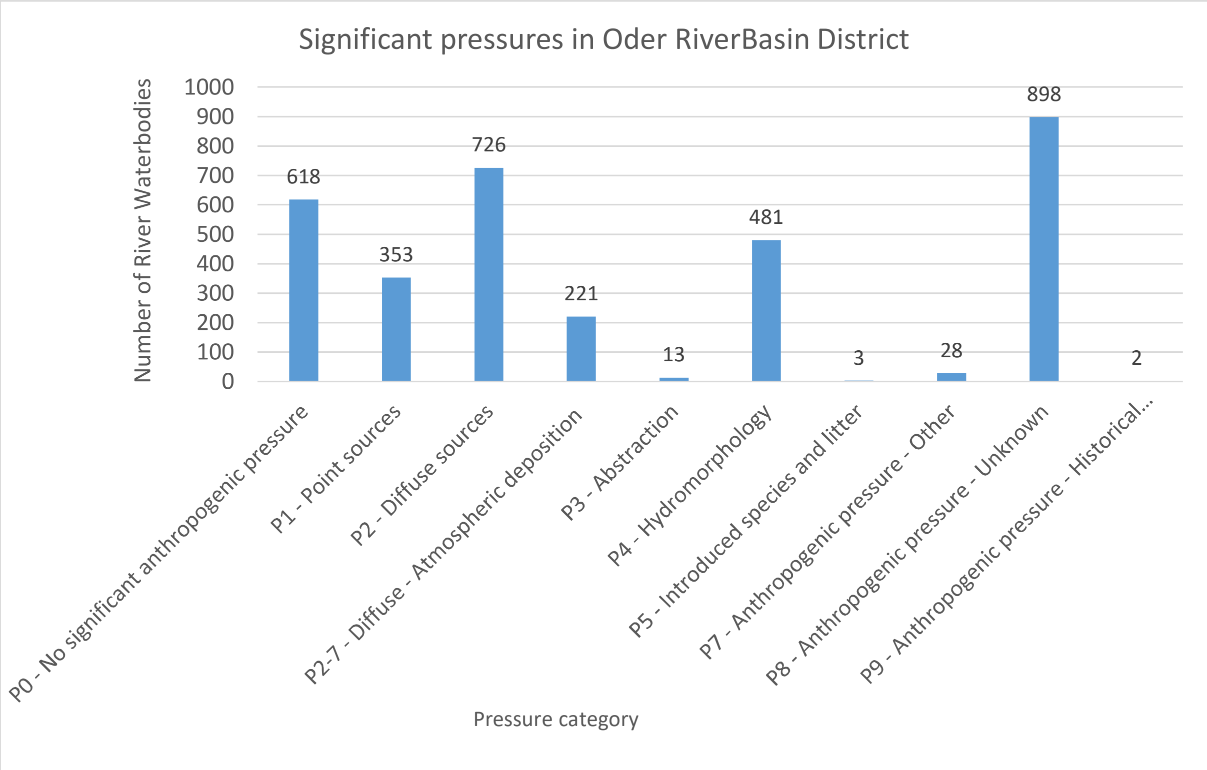

Figure 13 Significant pressures identified in the 2nd river basin management plan (Poland and Germany) for the Oder river catchment waterbodies. The Oder River RBD has a total of 2187 river waterbodies of which approximately 80% are in Poland. Each waterbody can have more than one significant pressure or impact.

[22] https://cdr.eionet.europa.eu/help/WFD/WFD_521_2016/Guidance/WFD_ReportingGuidance.pdf

[23] https://www.eea.europa.eu/data-and-maps/data/wise-wfd-4

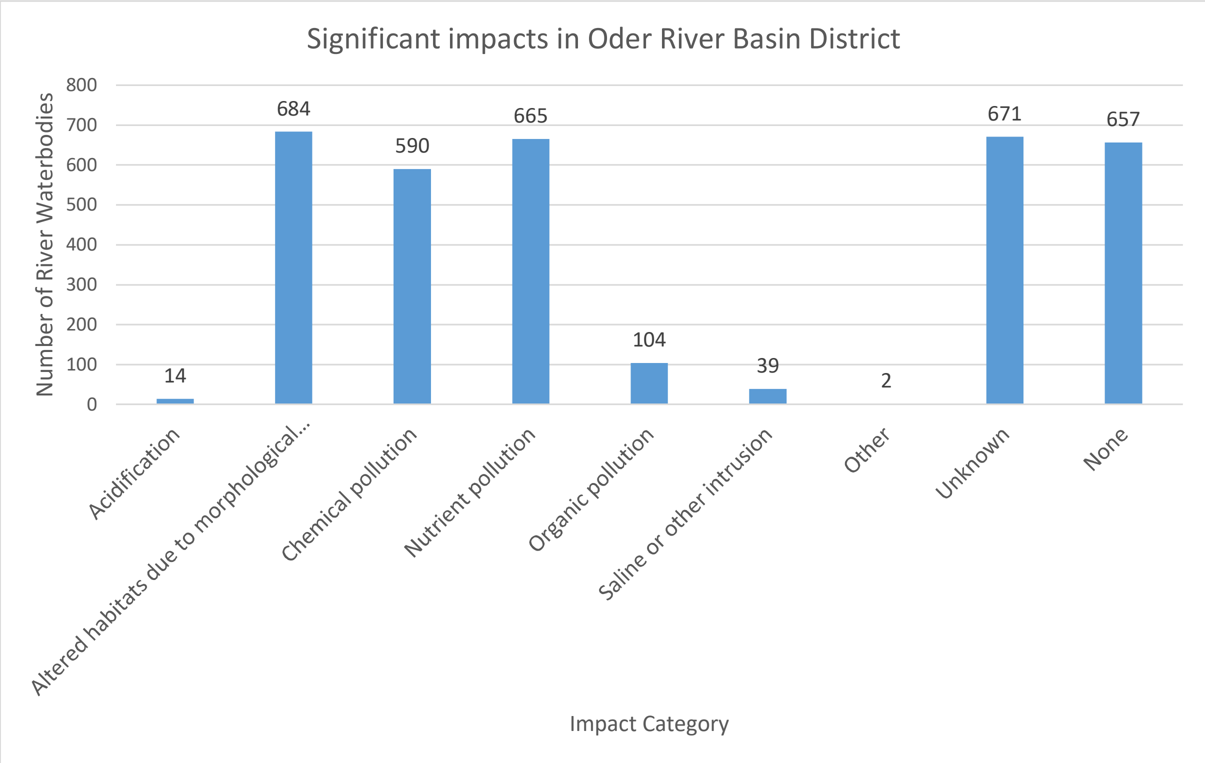

Figure 14 Known significant impact types identified in the 2nd river basin management plan (Poland and Germany) for the Oder river catchment waterbodies. The Oder River RBD has a total of 2187 river waterbodies of which approximately 80% are in Poland. Each waterbody can have more than one significant pressure or impact.

9. Historical data

In order to see if there has been an increase in salinity over the long term, we obtained data from the website of the International Commission for the Protection of the Odra River against Pollution.[24,25] The trend in conductivity in the Oder river at a downstream site - Hoenwutzen (DE) between 2005 – 2020 was examined. The site had a significant increase over time from levels <800 µS cm^{-1} to 1000 µS cm^{-1} (slope increase 12.79 per year) (Figure 15). Conductivity peaks also tended to be higher in recent years. However, the algal blooms were found to occur in summer in the Oder in 2022 and therefore altered conductivity levels during this period may be more relevant. Examining the trend seasonally, significant trends were observed in spring and summer (Figure 16). For comparison, a recent study in Nature found 65% of big rivers worldwide investigated had conductivity values below the low salinity impact threshold of 700 µS cm^{-1}. Therefore, when comparing the Oder levels of recent years with those commonly found in for example the Danube and Rhine, it needs to be noted that the average Oder conductivity levels of around 1000 µS cm^{-1} are higher than those in other EU rivers.[26] However, levels in the Elbe River for example have also been high being

[24] http://www.mkoo.pl/index.php?mid=1&lang=EN

[25] http://geoportal.mkoo.pl/IKSO/client/gisclient/index.html?applicationId=5223

[26] Salinity levels of rivers are usually classified as; a) Low salinity impact class (<700 µS cm^{-1}): b) Moderate salinity impact class (700–1500 µS cm^{-1}) and: c) High salinity impact class (>1500 µS cm^{-1}). The threshold level for water suitable for irrigation is (<700 µS cm^{-1}). Source: https://www.nature.com/articles/s41467-021-24281-8

reported above 1500 µS cm⁻¹ already in 2011.[27] However, more recently, values for the Elbe river during the period of 2013-2018, ranged from 280 µS cm⁻¹ (annual average)[28] to values of between 450 µS cm⁻¹ and 1700 µS cm⁻¹ (recorded in summer 2017)[29]. This illustration of salt concentrations in the Oder River being comparatively high in general is in line with Polish media reporting that the conductivity at the mouth of the Gliwice Canal exceeded 8,000 µS cm⁻¹ on 14 November 2022[30].

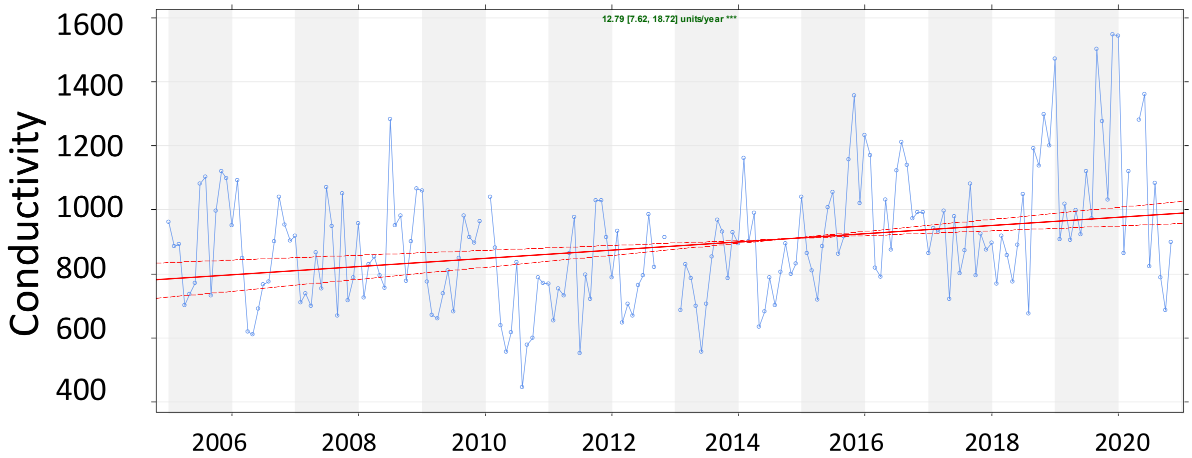

Figure 15 Trend in conductivity (µS cm⁻¹) in the Oder River at site Hoenwutzen (DE) 2005 – 2020.

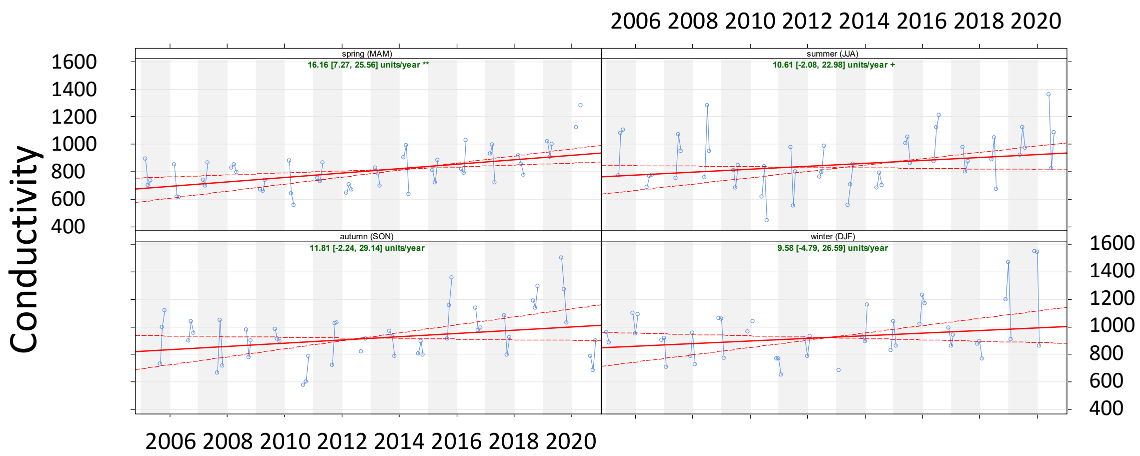

Figure 16 Seasonal trend in conductivity (µS cm⁻¹) in the Oder River at site Hoenwutzen (DE) 2005 – 2020.

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[27] Baborowski, M., Büttner, O. and Einax, J.W. (2011), Assessment of Water Quality in the Elbe River at Low Water Conditions Based on Factor Analysis. Clean Soil Air Water, 39: 437-443. https://doi.org/10.1002/clen.201000373

[28] https://www.ikse-mkol.org/fileadmin/media/user_upload/D/06_Publikationen/06_Messprogramme/2020_IKSE_Bericht_2013-2018.pdf

[29] https://www.mdpi.com/2073-4441/14/13/2078

[30] Water salinity breaks records - Puls Biznesu - pb.pl and Chciałam zobaczyć, jak wygląda Odra po katastrofie. Nie ma żadnego "po" - OKO.press

10. Travel time

The time it takes for water to travel downriver, from the top to the bottom of the catchment, has been modelled within the JRC by A. Annunziato as being of the order of 12 days.[31] This means that the period for communicating the occurrence of pollution events is short. The implementation of mandatory immediate notifications for downstream authorities and neighbouring countries would allow time for rapid action to remediate and lessen the effects of pollution events. In order to facilitate swifter notifications, responses and fast coordinated action in case of emergencies, the maximum water travel time from the beginning to the end of international rivers should be modelled and transparently be made known /communicated to competent authorities and the public for all transboundary river basins. That would greatly facilitate a rapid chain of reaction to all the downstream MS in case similar disasters would (re)occur in the future. At the same time this would also help to intensify internationally coordinated water management.

11. Nutrients loads

Nutrients, especially nitrogen and phosphorus are essential for forming, sustaining and setting upper limits to algal blooms.[32] As part of ongoing work in the JRC the modelled loads of nutrients were examined for the catchment (Figure 17). Higher loads were estimated in the upper section of the catchment. The Oder has long been regarded as nutrient enriched with sufficient nutrients to enable blooms to develop, meaning that hydrological factors are often more important in bloom occurrence.[33] That is, given sufficient nutrients and light, if the flow is slow or impeded the algae will have more time to grow and multiply and develop into blooms.

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[31] Analysis of travel time of Oder River, internal JRC analysis by A. Annunziato

[32] Carvalho, L., McDonald, C., de Hoyos, C., et al., 2013. Sustaining recreational quality of European lakes: minimizing the health risks from algal blooms through phosphorus control. J. Appl. Ecol. 50, 315–323.

[33] Siwek, Hanna, and J. Wybieralski. The content of nutrients and chlorophyll in the downstream part of the Odra river. Folia Universitatis Agriculturae Stetinensis 234, no. 93 (2004): 349–54.

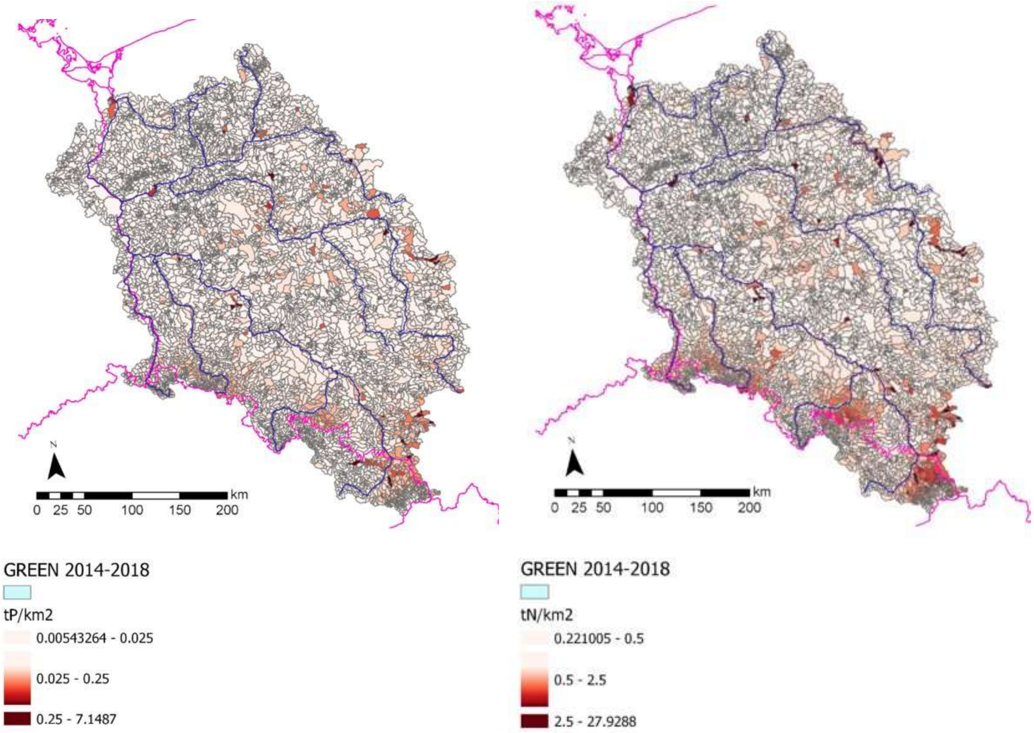

Figure 17 Nutrient specific loads in surface water (tP and tN /km2). Estimated using the GREEN model, annual average 2014-2018. Data source: Vigiak et al. Recent regional changes in nutrient fluxes of European surface waters. Science of the Total environment 858 (2023) 160063.

12. Member states reports

Following the disaster both Poland[6] and Germany[47] published separate national reports on investigations in late September. Independent research organisations from these countries also published reports. Some findings of these are listed in more detail in Annexes (2 to 4).

The direct cause of the ecological disaster in the Oder River was prymnesin toxins from *Prymnesium parvum* algae. This was estimated to lead to the death of around 360 tons of fish of various species, including those under protection, as well as molluscs. The entire length of the Oder River was classified as poor for the years preceding the incident based on biological and chemical condition. In the summer of 2022, conditions were optimal for a *Prymnesium* bloom. The high nutrients coupled with high sunlight, low water levels, hydromorphological modifications leading to slower flow and elevated salinity (favoured by *Prymnesium*), were the multicausal factors.

A key point is that the primary trigger for the observed *Prymnesium* bloom was the salt concentration. The sources of the salts, as well as the source habitats of *Prymnesium* in the catchment are unclear. The German national report estimated that in the period between August 5th, 2022 and August 15th, 2022, around 23,500 tonnes of additional sodium chloride were transported in Hohenwutzen in the Oder compared to August 4th 2022. The Polish national report identified 42 legal permits for the discharge of treated wastewater to the Oder River in which the composition of chlorides and sulphates are declared. At the time of report publication, Poland was still obtaining final data on the quality of discharged wastewater, both from legal and illegal sources, and their correlation with hydrological and environmental data.

Mass blooms of *Prymnesium parvum* in the waters of the Oder River and other rivers and reservoirs may repeat in subsequent years, as they have happened in other countries of the world. A DNA method has been developed, according to the German national report, so that *Prymnesium parvum* can be detected in environmental samples within one day.

13. Initial observation on the MS reports regarding salinity

Both national reports (PL[6], DE[47]), published in September 2022, concluded that the causes were multifactorial – promoted by warm temperatures, low rainfall, low water levels, reduced flow and the higher salinity, with the German report focusing on salinity providing the trigger for the disaster. Both reports refer to the doubling in salinity – occurring in less than a week at some sites. This is much more characteristic of a pollution incident than an unfortunate coincidence of climatic events. In both reports, the increased direct anthropogenic pressure receives less critical appraisal. The German report states that concentrations of dissolved salts have increased, particularly over the last 5 years. This does not seem to receive much attention in the Polish report, apart from conductivity being mentioned as being double last year's values. Perhaps a more detailed assessment of pressures and their evolution over the past decade would be useful. According to data from licensed facilities – the European Pollutant Release and Transfer Register (E-PRTR) hosted by the EEA there are examples of increased industrial discharges, including at least one example of a doubling in chloride discharge over the last 10 years. These should be more precisely considered in the partitioning of multifactorial contributions to the disaster. Germany's estimate that around 23,500 tonnes of sodium chloride were additionally transported during the event should be compared with permitted or identified discharges in the catchment. The river basin management plan for the Oder should be reviewed to learn why the pressures and impacts assessment did not fully identify this threat and take appropriate measures to avoid it. The water framework directive is the main EU policy avenue already in place to anticipate and manage pressure on aquatic systems.

14. Collated recommendations

The German and Polish national reports produced several recommendations in order to improve management and prevent a future reoccurrence of such a wide-scale pollution event. Here, these are collated together with those produced by experts from the European Commission and the EEA for this report.

1. **Improve knowledge and monitoring**
   a. For this situation, the high frequency, near real time automated monitoring station at Frankfurt (Oder) was critical for identifying and analysing the event. For an early response, continuous and precise (online) monitoring systems of water quality measurements are needed to inform the appropriate authorities and the public much more quickly. Such stations should also be placed further upstream in the catchment in order to improve and extend, the harmonised and automated measurement of physical, chemical and biological parameters, both spatially and temporally, by creating a larger network of such monitoring stations. The data of such monitoring networks should be made directly and publicly available.

b. Specifically for harmful algal bloom events, tests developed to detect the presence of the algae should be deployed to enable early intervention.
c. Satellite monitoring proved valuable for understanding the extent and rate of spreading of the event, and it can be useful to know who the relevant service providers are.
d. Data on the relevant parameters should be made available, as a download of the entire structured database in an analysis-ready format to enable faster understanding and response. In addition, websites delivering the data should be easily accessible, and stress tested for high demand situations.
e. Model and (publicly) communicate water travel times from the beginning to the end for all transboundary rivers in order to better facilitate a rapid reaction chain in case of disasters and intensify internationally coordinated water management.
f. Map the ecological impacts of the disaster with a special focus on protected habitats and species in Natura 2000 areas under the EU Birds and Habitats Directives as well as other nature protection areas.

2. Improve communication

a. The late and incomplete communication and information exchange between national authorities is known to have hampered an early response and efforts to limit the ecological damage, as well as the initiation of possible mitigation measures.

b. There is a need to improve cooperation and information flow in this international river basin district, and in light of this event, all International River Basin Districts should have a clear procedure for emergency communication and response in place.

c. Implementation of mandatory immediate notifications for downstream authorities and neighbouring countries would allow time for rapid action to remediate and lessen the effects of pollution events. This should also be accompanied by dissemination to catchment stakeholders. A provision enabling this should be incorporated into the Water Framework Directive and is included in the legal proposal of 26 October 2022 for stronger rules on surface and groundwater pollutants[34].

3. Improve (emergency) response and risk management

a. As the *Prymnesium* algae are now present in the Oder catchment, there is an increased risk of future blooms. Urgent preparations must be made to prevent further occurrence in the coming years, in the Oder basin but also in other basins that are potentially affected by similar phenomena. Maps of monitoring stations and river basins at risk are included in annex 1 of this report.
b. Following improvements to identify and monitor at high frequency saline discharges in the catchment, a system to allow reactive management cognisant of real time catchment wide discharged loads, river flow, travel time and resulting pollutant concentrations should be instigated.
c. This system should anticipate responses and forward plan the how, where and when to intervene to prevent bloom development for future events. If called upon the EU Emergency Response Coordination Centre (ERCC), which is at the heart of the EU Civil Protection Mechanism, could assist individual disaster-stricken countries,

[34] https://ec.europa.eu/commission/presscorner/detail/en/ip_22_6278 and https://environment.ec.europa.eu/publications/proposal-amending-water-directives_en

e.g. by coordinating the delivery of assistance, such as expertise, civil protection teams and specialised equipment.

d. Resources and capacity must be developed to identify harmful bloom forming algae and their toxins rapidly with high sample throughput. This currently represents a significant bottleneck.

e. Investment is required to adequately deliver improved responses.

4. Improve regulation

a. As concluded in the Polish report, there must be continuation of the ongoing inspections of entities conducting the discharge of polluted waters and the immediate elimination of illegal wastewater discharges. A total of 282 places where waste and toxic waste are discharged into the Oder without a permit have been reported.[35]

b. Adequate enforcement must be implemented together with a sufficient deterrent to protect against pollution.

c. Both countries recommended a review and verification of the existing permits for the discharge of wastewater and an introduction of an obligation to temporarily suspend or limit discharges in case of emergencies.

d. All industrial discharges and emissions, including emissions of salts, should be listed in a complete and up to date publicly accessible inventory of emissions as is required by article 5 (‘*Inventory of emissions, discharges and losses*’) of Directive 2008/105/EC on Environmental Quality Standards in the field of water policy (EQSD)[36]. This reporting should be better integrated with the E-PRTR.

e. Emission limit values in the permits of industrial installations should consider the water flow dynamics in the river. Such adaptation means that allowable pollutant loads can be modulated, according to the water levels and flows in the recipient waters.

f. This event has pointed to insufficient preparedness to respond to large-scale pollution incidents. River basin managers are encouraged to perform comprehensive risk assessment in the light of the more extreme climate.

5. Further investigations are still needed to establish the source of the incident

a. While the cause of the event is clearly multifactorial, the doubling of salinity in less than a week is unusual and needs further investigation. Such an investigation should include mapping of discharge points and permits as well as a historical analysis of pressures and how they have changed in past 10-20 years. For example, by mapping all possible discharge points, checking if they are covered by valid permits, and creating an inventory of the permitted maximum emission levels (in loads and concentration). In a next step, those should be put in relation to the monitored (low) water levels in order to assess the resilience of the aquatic ecosystem to emissions.

b. A mass balance between the additional load of salt (quantified in the German report) should be compared with reported emissions from identified discharges in the catchment.

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[35] https://www.euractiv.com/section/politics/short_news/polish-parliamentary-inspection-of-oder-river-reveals-illegal-wastewater-discharge/

[36] Article 5 on the inventory of emissions, is a further specification of the obligations to review of the environmental impact of human activity and monitor surface water status, groundwater status and protected areas under Articles 5 and 8 of the WFD

c. Further investigation is needed in trends in salinity both within the river and also from emissions in the context of water discharge over the last 10-20 years. This is in order to establish trends in (industrial) emissions and the variation in (historical) water discharge levels in the river itself.

6. **Environmental management**
    a. Hydromorphological changes should be reevaluated under climate change scenarios in the context of harmful bloom prevention.
    b. The Water Framework Directive (WFD), supported by the Industrial Emissions Directive (IED), are the appropriate pieces of EU legislation for managing water quality and industrial emissions[37]. Knowledge gained from this disaster should be incorporated in these instruments to assess new risks, pressures and impacts and develop appropriate programmes of measures in the river basin management plan to prevent future occurrence.
    c. Intensify work on developing and refining Europe-wide supporting standard thresholds for salinity and nutrients in freshwaters as part of the Working Group on Ecological Status (WG Ecostat) under the WFD Common Implementation Strategy (CIS).
    d. With reference to the above, all countries and the EU, should jointly develop and implement thresholds for salinity ensuring good ecological status.
    e. Countries should ensure that nutrient targets correspond to good ecological status (minimising the risks of algal blooms).

7. **Restoration**
    a. An inventory of the ecological damage, with a special focus on impacts on protected habitats and species and special protected (Natura 2000) areas under the EU Birds- and Habitats Directives, should be carried out to enable restoration targets to be set.
    b. A plan to restore the physical, chemical and biological integrity of the Oder River sufficient to re-establish its resilience and to prevent future disasters must be formulated and implemented[38]. Such plans should include a special focus on restoration measures related to a (barrier-free) reconnection of floodplains, oxbow lakes etc. This would diversify habitat types, spawning grounds, and increase the number of refuge areas. This will enhance the survival chances of fish and other aquatic organisms in the event of any future hazardous incidents.
    c. Given that hydrology is key to the development of blooms, this requires specific focus in the plan and in the context of climate change.
    d. Sufficient funding should be sought and put in place for restoration efforts.

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[37] Emissions from extractive activities are however not currently covered by the Industrial Emissions Directive. A proposal of the Commission COM (2022)156 to revise the Inudstrial Emissions Directive include the extension of the scope of the Directive to certain extractive activities.

[38] **Note**: possible funding opportunities aimed at the ecological restoration might be available at EU level, e.g. through funding instruments like EU Investment support (InvestEU), the Recovery and Resilience Facility (RRF), LIFE, and/or the EU fund for Strategic Investments (EFSI).

8. Research

a. Further need to understand how to avoid mass development of *Prymnesium parvum* with toxin formation as highlighted by Germany.

b. Work should be carried out to understand the social and environmental costs of the disaster.

c. A revised risk assessment of salinization of groundwaters should be carried out in the context of climate change and toxic algae. Do trends in salinization resulting from mining contamination and future water extraction for irrigation represent a risk to this and other European rivers?

d. Research should explore the effects of multiple stressors such as salinity, nutrients, hydromorphological alterations and climate change on ecological status.

List of figures

15. Annex 1 - Preliminary risk assessment of European rivers to blooms of *Prymnesium*

This chapter considers the risk of the dramatic damage to the ecosystem of the Oder river seen in the summer of 2022 being replicated in coming years in other systems.

While the understanding of the precise requirements that foster blooms of *Prymnesium* is not yet developed, a high conductivity has been noted as a key factor in previous publications. In the USA, a threshold of 1500 µS cm^{-1} conductivity has been used to identify and map sites.[39] This threshold of maximum conductivity (1500 µS cm^{-1}) was applied to the EEA Eionet Waterbase aggregated data[40] on European rivers, together with two other criteria: high nutrients (TP > 0.035 mg l^{-1} or NO_3-N >1.1 mg l^{-1}, i.e. 5 mg l^{-1} as NO_3) and non-marine SO_4 (above 3 meq l^{-1}). The non-marine SO_4 was based on experience from the Oder and allows rivers sites that will naturally have a high salinity close to their estuaries to be excluded from the risk analysis focusing on freshwater rivers. In addition, SO_4 has been shown to have a positive influence on *Prymnesium* growth.[41] Out of 110,049 yearly aggregated river station data records a total of 11,611 were monitored for the three criteria above of which 421 were estimated to be at risk (4%) (Figure 18). Further refinement of risk could be performed at local or MS level incorporating other key factors such as summer flow rate, catchment salt load, individual ion concentrations and most importantly the known presence or absence of the algae in the river basin district. The largest rivers, often with controlled slower flow and of high socioeconomic and ecological value could be a focus area for MS to further assess risk locally (Figure 19). Special attention could be focused on rivers in proximity to the Oder where the risks of the species spreading to nearby systems is greater.

Data on conductivity and ions is not present in the EEA Waterbase dataset for some countries (Figure 18). Some MS have more detailed local databases on river chemistry and this could be exploited nationally following a similar approach taken here. However, these parameters are often measured for groundwater and adding these, could help indicate where groundwaters, an important source for summer water flow in many rivers, could potentially represent a present or future risk within a catchment (Figure 20). Groundwater has previously been shown to be at risk from contamination from tailings pond sources within the Oder catchment for example.[42]

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[39] Hartman, K.J.; Wellman, D.I., Jr.; Kingsbury, J.W.; Cincotta, D.A.; Clayton, J.L.; Eliason, K.M.; Jernejcic, F.A.; Owens, N.V.; Smith, D.M. A Case Study of a *Prymnesium parvum* Harmful Algae Bloom in the Ohio River Drainage: Impact, Recovery and Potential for Future Invasions/Range Expansion. *Water* **2021**, *13*, 3233. https://doi.org/10.3390/w13223233

[40] https://www.eea.europa.eu/data-and-maps/data/waterbase-water-quality-icm-2

[41] Rashel RH, Patiño R (2019) Growth response of the ichthyotoxic haptophyte, Prymnesium parvum Carter, to changes in sulfate and fluoride concentrations. PLOS ONE 14(9): e0223266. https://doi.org/10.1371/journal.pone.0223266

[42] Duda, R., & Witczak, S. (2003). Modeling of the transport of contaminants from the Żelazny Most flotation tailings dam. Gospodarka Surowcami Mineralnymi, 19(4), 69-88.

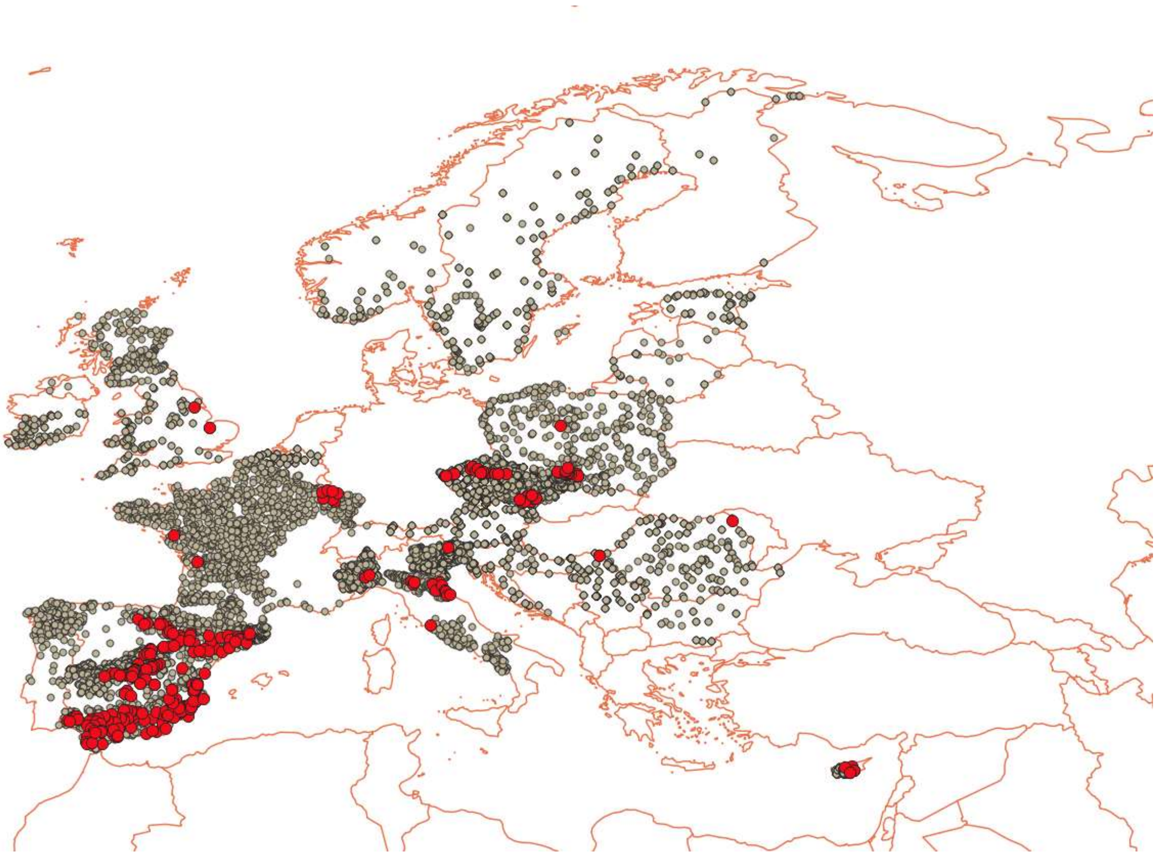

Figure 18 Map of Europe with stations reporting river chemistry for considered parameters (Waterbase). Stations potentially at risk are red (maximum conductivity per year > 1500 µS cm^{-1} and high nutrients (TP > 0.035 mg l^{-1} or NO_3-N >1.1 mg l^{-1}) and non-marine SO_4 above 3 meq l^{-1}. Only stations with data available for these parameters were included in the analysis. Note data gaps for some countries.

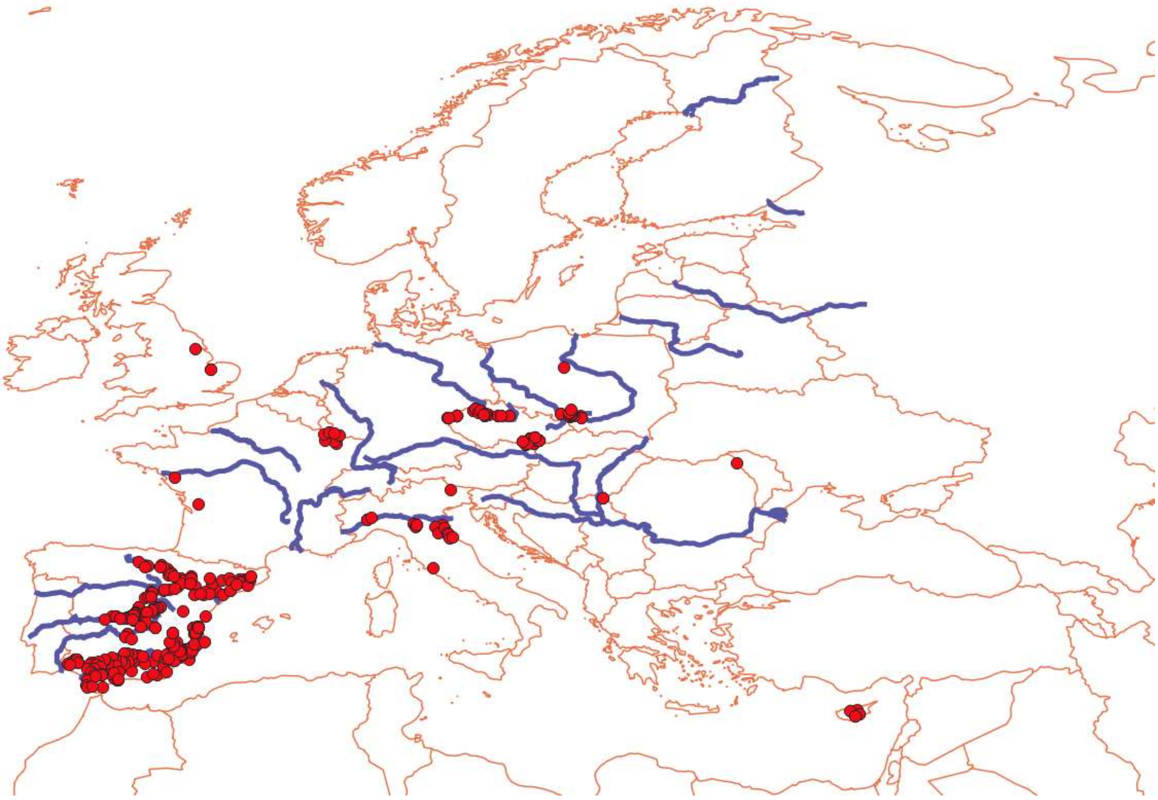

Figure 19 Map of Europe with stations potentially at risk (red) with large rivers overlain (source: EEA[43]).

[43] https://www.eea.europa.eu/data-and-maps/data/wise-large-rivers-and-large-lakes

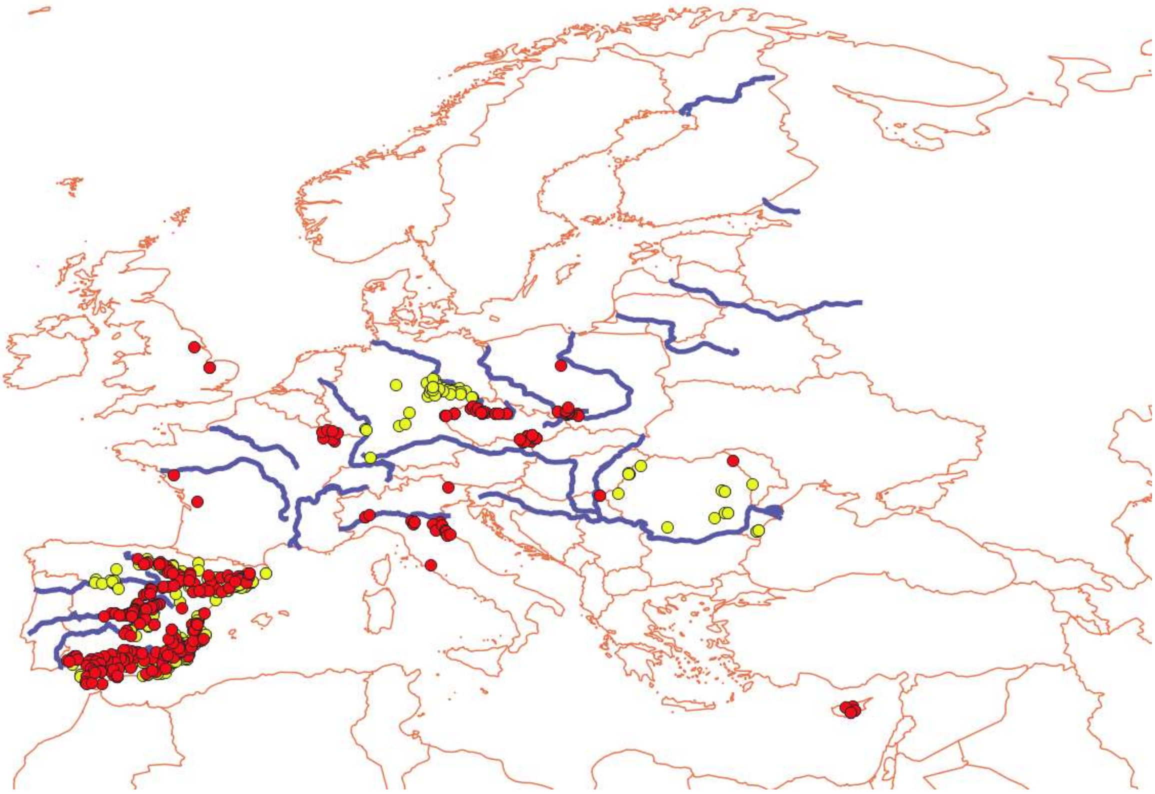

Figure 20 Map of Europe with river stations potentially at risk (red) with large rivers (source: EEA[44]) overlain. Groundwater bodies that had the same chemical risk criteria as rivers are in yellow.

[44] https://www.eea.europa.eu/data-and-maps/data/wise-large-rivers-and-large-lakes

16. Annex 2 - Additional information from position papers

Information, in addition to that presented above can be gathered from position papers that were produced by two MS scientific organisations.

16.1. The Leibniz Institute of Freshwater Ecology and Inland Fisheries (IGB) in Germany - policy document on the future of the Oder river.[45]

a. High nutrient loads in the water (caused by anthropogenic inputs), high water temperatures, partial damming of the river, and low water flow due to a prolonged period of drought additionally provided ideal conditions for the growth of the toxic algae.
b. Loss of connection to the floodplain has accentuated the influence of the drought.
c. Population collapses also result in the loss of important genetic diversity.
d. Subsequent fish kills were likely caused as a secondary effect of the bloom, either through night-time oxygen respiration or decay of the algal bloom.
e. The current dredging work reduces oxygen and introduces contaminants such as heavy metals.
f. Alteration of the residence time through dams increases the development time, allowing for the growth of algal blooms.
g. Emissions must be reduced, and international cooperation strengthened.

16.2. Polish Academy of Sciences statement on the Ecological disaster on the Oder river[46]

a. “long-term, very low water level, has made the river more sensitive to pollutants flowing into it. Global warming is rapidly increasing the likelihood of similar extreme dry episodes occurring in the future”
b. “wastewater discharges containing nutrients, especially nitrogen and phosphorus, are essential for the growth of phytoplankton and greatly accelerate the process;”
c. “discharges of saline industrial or mine waters, which could be the direct cause of the multiplication of the so-called golden algae (*Prymnesium parvum* or related flagellates), producing toxins that are deadly to fish and other fauna that breathe through the gills”
d. “a significant change in the hydrological conditions in the Oder due to its regulation, damming and use for the purposes of inland navigation resulting in a favorable extension of the water retention time in the river for algae multiplication”
e. “.. it cannot be said in any way that the ecological disaster on the Oder River was of a natural cause. One can even directly say that it is a model example of new, multifactorial threats related to climate change, discussed in the last IPCC Report”

[45] IGB_Policy_Brief_The_future_of_the_River_Oder_web.pdf (igb-berlin.de)

[46] https://klimat.pan.pl/katastrofa-na-odrze-geneza-terazniejszosc-zalecenia-na-przyszlosc/

17. Annex 3 - Additional information from formal report from Germany[47]

- "The expert group tested a large number of hypotheses. The most plausible hypothesis is a mass proliferation of *Prymnesium parvum* and the associated toxins caused by the high salt concentrations as the cause of the fish kill."
- Concluded the increase in conductivity, chlorophyll, oxygen and decrease in nitrate indicate the cause was an algal bloom subsequently identified as *Prymnesium parvum*. Additional measurements ruled out herbicides and over 1,200 known substances measured. Toxicity was also confirmed by *Daphnia* bioassay.
- Fish kills or blooms did not spread to the inner coastal waters in the estuary area of the Oder.
- High day-night fluctuations in the oxygen content of an average of 5 mg/l can also be clearly seen in August (Figure 21). At no time did the oxygen minima show a concentration that is harmful to fish.
- The prerequisites for an algal bloom were present in the Oder in summer: light and temperature conditions, increased nutrient concentrations, low water and low discharge as well as hydromorphological changes. The findings so far point to multicausal relationships. However, the primary trigger for the observed *Prymnesium* bloom is the salt concentration. The sources of the salts, other elements, and chemicals are unclear. Likewise, the primary habitats of *Prymnesium parvum* in the Oder are unknown.
- Overall, the river discharge in the Oder in the period under review was significantly lower than in previous years.
- Salt concentrations doubled from the start until mid-August before declining (Figure 22).
- In the period between August 5th, 2022 and August 15th, 2022, around 23,500 tonnes of sodium chloride were additionally transported in Hohenwutzen in the Oder compared to August 4th 2022.
- Elevated chloride concentrations, which exceed the value of 200 mg l^{-1}, have been occurring in the Middle Oder for many years. Long-term data from the Oder show a clear increase in the average annual mean values for chloride and sodium over the past 10 years, while other parameters remained unchanged.
- The measured values for total phosphorus were over 0.1 mg l^{-1}, as usual, so enough for a bloom.
- An acutely toxic effect of mercury on the fish fauna and other aquatic organisms could be ruled out during the study period.
- A maximum of phytoplankton abundances at the Frankfurt (Oder) sampling site on August 19, 2022 had 203 million cells per litre. Of these, 97 million cells per litre were accounted for by *Prymnesium parvum.*

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[47] https://www.umweltbundesamt.de/presse/pressemitteilungen/fischsterben-eingeleitetes-salz-fuehrte-zur

- A DNA method has been developed so that *Prymnesium parvum* can be detected in environmental samples within one day.
- Prymnesin B1 toxin was detected as were additional toxins derived from other algal species such as microcystin but the latter were at concentrations too low for toxicity.
- Climatic conditions to be expected in the future with intensive solar radiation, high temperatures, evaporation and low precipitation will continue to lead to increasing concentrations of substances dissolved in the water. Technical solutions for storage and volume management can only compensate in the short term.
- The need to ensure that similar toxic algal blooms do not occur on the river Werra, which has high salinity from potash mining, or the Elbe was acknowledged.[48]

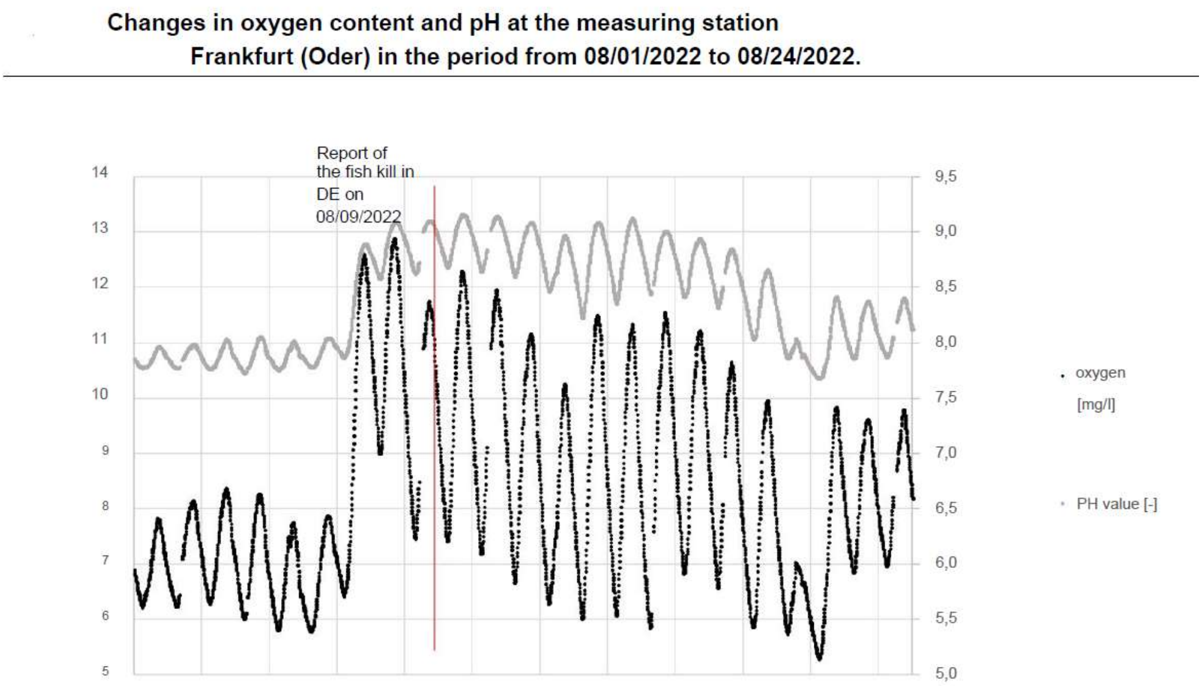

Figure 21 Changes in diurnal oxygen (black) – elevated with photosynthesis during the day and lower owing to respiration during the night. Also shown is pH in grey.[47]

[48] https://www.bmuv.de/en/pressrelease/oder-fish-die-off-salt-discharges-caused-mass-proliferation-of-toxic-alga

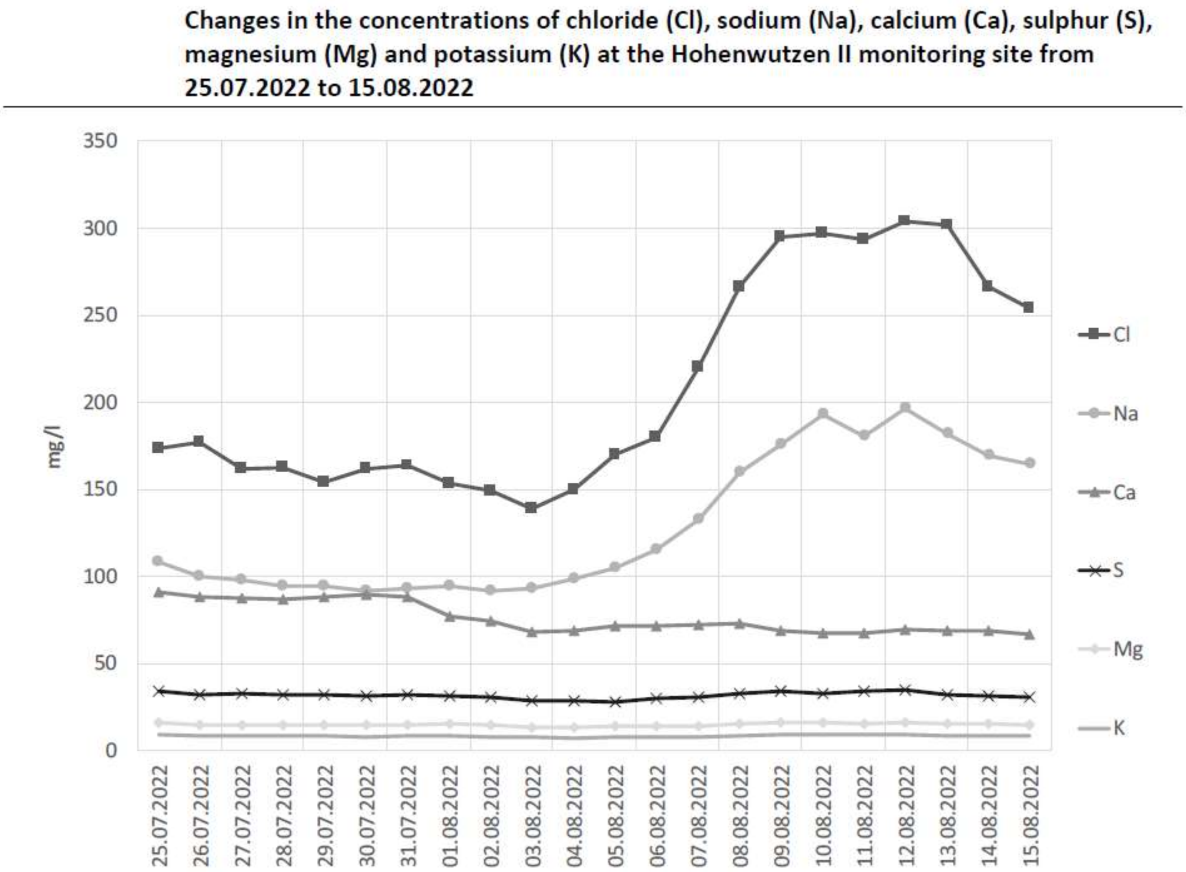

Figure 22 Concentrations of major ions during summer 2022. Note doubling of salt component (Na and Cl). [47]

18. Annex 4 - Additional information from formal report from Poland[6]

- Prymnesin toxins from *Prymnesium* were likely the immediate perpetrator of the ecological disaster in the Oder river.
- It should be emphasized here that in the years preceding the ecological catastrophe, the condition of the river along its entire length was poor, which was influenced by the bad or poor condition of biological elements, the condition of physicochemical elements and the chemical condition assessed along the river course.
- The environmental conditions in the Oder River in July and August 2022, i.e. high conductivity and concentration of chloride, sulphate and sodium ions, high temperature, low water level and slow water flow as well as high insolation, they were optimal for the development of *Prymnesium* and allowed these algae to develop and bloom (Figure 23).
- There are currently 42 legal permits for the discharge of treated wastewater to the Oder River in which the composition of chlorides and sulphates are declared.
- The report includes recommendations of specialists aimed at preventing or limiting the risk of such ecological disasters in the future in the Oder River and in other

waters in Poland with similar characteristics, exposed to the occurrence of this species. These are incorporated in the section on collated recommendations above.

- 249 tons of fish of various species, including those under protection, as well as molluscs, were documented as dying (the value would be around 360 including DE).
- A high deficit of precipitation reaching almost 20% in the first 6 months of the year and high anomalies of monthly sums of insolation compared to the reference period 1991-2020, which ranged between 20h and 60h (25%) above the norm.
- In the period from June 1 to August 20, 2022, the water levels of the Oder were generally near the lower limit of the average levels.
- During the periods when fish were dying, a significant increase in the conductivity of the Oder River water above 2000 $\mu S\ cm^{-1}$, was noticed. The wave of water, rich in salt, moved along the current of the Oder in a critical period. Compared to the average values at the benchmark point on the Oder River above Wrocław from previous years (1030 - 1287 $\mu S\ cm^{-1}$), these values were much higher, even compared to the comparatively dry year of 2015 (1287 $\mu S\ cm^{-1}$).
- Algal blooms in the water reservoirs connected with the Oder River, such as Baikal, Czernica, Łacha Jelcz, were confirmed in the period when fish died in these reservoirs. The most intensive blooms in these reservoirs took place from a few to several days after the bloom of the Oder River. Intensive blooms on selected dam reservoirs supplying the Oder River (Turawskie Lake, Otmuchowskie Lake, Zalew Mietkowski) were found, but the relatively small numbers of *Prymnesium parvum* in these reservoirs contradict the thesis about a possible significant discharge of algae from the reservoir.
- Laboratory tests of the waters of the Oder River, the Gliwice Canal and reservoirs directly adjacent and connected with the Oder River showed high concentrations of *Prymnesium parvum*, exceeding the level of 50-100 million cells per litre, at which, according to the literature, fish deaths may already be recorded.
- Genetic tests of the biological material collected from the Oder River showed that the biological material contained genes coding for enzymes catalyzing the production of primnesines.
- Laboratory tests of biological material extracted from water samples taken from the Oder River, the Gliwice Canal and the reservoirs connected with the Oder River showed the presence of primnesines.
- According to research, the risk of algae bloom increases with water conductivity above 1500 $\mu S\ cm^{-1}$.
- The literature does not indicate the possibility of suppressing blooms in the case of larger reservoirs and rivers similar in size to the Oder.
- The intensive bloom of *Prymnesium parvum* in the waters of the Oder was probably multifactorial.
- Satellite images showing the spatial-temporal course of changes in chlorophyll concentration along the Oder River in the period from July 19, 2022 to August 26, 2022, significantly substantiate the hypothesis of the location of the original source of *Prymnesium parvum* in the upper Oder river and the successive movement of the algal bloom downstream.

- In the analyzed period, the specific electrical conductivity of water at almost all tested points, in the case of most of the measurements made, significantly exceeded the normative values.
- It can be concluded that at the turn of July and August, the waters of the Oder had favourable conditions for the development of these algae and development of toxicity, i.e. significantly increased conductivity, chloride and sulphate content, increased water temperature, high insolation, significant fluctuations in water parameters over time. The hydromorphology of the Oder's waters is also important here, as it is a largely regulated river – with the presence of many water reservoirs, as well as slowing down the flow in front of weirs, canals, i.e. places favourable to blooms.
- Mass blooms of *Prymnesium parvum* in the waters of the Oder River and other rivers and reservoirs may repeat in subsequent years, as they have happened in other countries of the world.

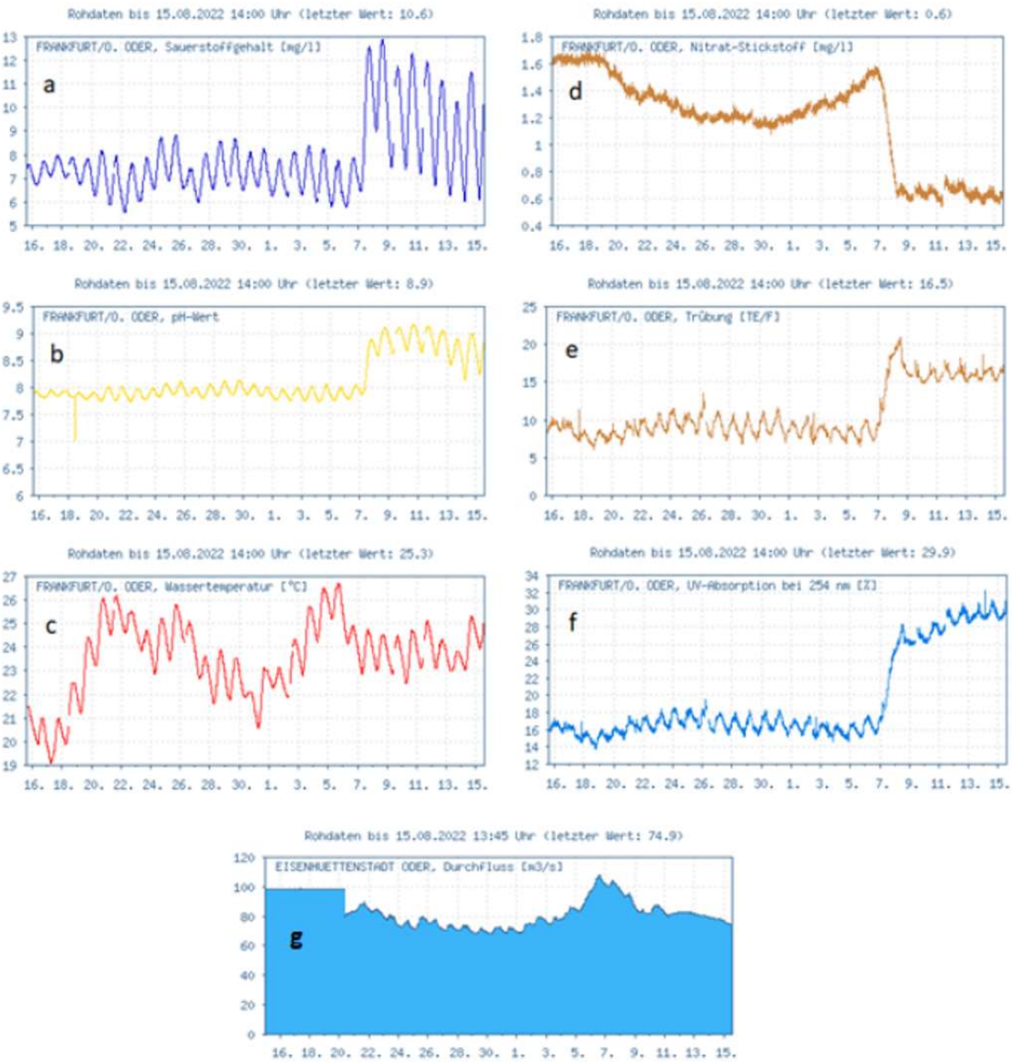

Figure 23 Time series of water parameters recorded at the measuring station in Frankfurt (Oder) (prepared on the basis of images downloaded from the website): (a) dissolved oxygen, (b) pH, (c) water temperature, (d) nitrate nitrogen, (e) turbidity, (f) UV absorption 254 nm, (g) flow rate. Rapid changes in parameters were principally attributed to upstream sources, rather than for example in situ algal growth at this station.[6, 10]

19. Annex 5 - List of abbreviations / acronyms

Term or abbreviations	Meaning or definition
Bloom	A substantial growth of algae, often visible as discolouration or scum
Conductivity	Measure of ability to conduct an electric current, which increases with salinity
Chlorophyll-a	Green photosynthetic pigment often used as a surrogate of algal biomass in water
CIS	Common Implementation Strategy (under the WFD)
DNA	Deoxyribonucleic acid
EEA	European Environment Agency
ENV	European Commission - Directorate-General for Environment
E-PRTR	European Pollutant Release and Transfer Register
EQSD	Environmental Quality Standards Directive
ERCC	EU Emergency Response Coordination Centre
GWD	Groundwater Directive
Hydromorphological	Relating to the physical characteristics and water content of waterbodies
IED	Industrial Emissions Directive
IGB	Leibniz-Institut für Gewässerökologie und Binnenfischerei
IPCC	Intergovernmental Panel on Climate Change
JRC	European Commission - Joint Research Centre
Meq (milliequivalents)	Equivalents refer to moles of charge
MS / MSs	Member State / Member States
Prymnesium parvum	A species of flagellated algae belonging to the haptophytes with the ability to produce toxins
Phytoplankton	Microscopic algae suspended in the water
Prymnesins	A class of toxins made by *Prymnesium parvum*
RBMPs	River Basin Management Plans
WFD	Water Framework Directive
WG	Working Group
WG Ecostat	Working Group Ecological Status

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