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Matters related to the implementation of the Convention: effectiveness evaluation

Third global monitoring report

Note by the Secretariat

As is mentioned in the note by the Secretariat on the global monitoring plan for effectiveness evaluation (UNEP/POPS/COP.11/20), the annex to the present note sets out the third global monitoring report prepared by the global coordination group for the global monitoring plan. The executive summary of the report, including the conclusions and recommendations of the global coordination group, is reproduced in the six official languages of the United Nations in document UNEP/POPS/COP.11/20/Add.1. The present note, including its annex, has not been formally edited.

* UNEP/POPS/COP.11/1.

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Annex

Global Monitoring Plan

for Persistent Organic Pollutants

under the Stockholm Convention Article 16 on Effectiveness Evaluation

Third Global Monitoring Report

March 2023

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Acronyms and abbreviations

ACP	Arctic contamination potential
AMAP	Arctic Monitoring and Assessment Programme
CHMS	Canadian Health Measures Survey
c-OctaBDE	Hexabromodiphenyl ether and heptabromodiphenyl ether
c-PentaBDE	Tetrabromodiphenyl ether and pentabromodiphenyl ether
CTD	Characteristic travel distance
DecaBDE	Decabromodiphenyl ether
DDT	1,1,1-Trichloro-2,2-bis (4-chlorophenyl)ethane; dichlorodiphenyltrichloroethane
dl-PCB	Dioxin-like PCB
EE	Eastern Europe
EMEP	European Monitoring and Evaluation Programme
EQS	Environmental quality standard
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GAPS	Global Atmospheric Passive Sampling Network
GCG	Global Coordination Group for the Global Monitoring Plan
GC/ECD	Gas chromatography electron capture detector
GC/MS	Gas chromatography mass spectrometry
GEF	Global Environment Facility
GLB	Great Lakes Basin Monitoring and Surveillance Program
GMP	Global Monitoring Plan
GRULAC	Group of Latin America and the Caribbean
HBB	Hexabromobiphenyl
HBCD	Hexabromocyclododecane
HCB	Hexachlorobenzene
HCBD	Hexachlorobutadiene
HCH	Hexachlorocyclohexane
HELCOM	Helsinki Commission/The Baltic Marine Environment Protection Commission
HYSPLIT	Hybrid Single-Particle Lagrangian Integrated Trajectory
IADN	Integrated Atmospheric Deposition Network
ICES	International Council for the Exploration of the Sea
LAPAN	Latin Passive Air Monitoring Network
LC/MS	Liquid chromatography/mass spectrometry
LOD	Limit of detection
LOQ	Limit of quantification
LRET	Long-range environmental transport
MCCPs	Medium-chain chlorinated paraffins
MDL	Method detection limit
MEDPOL	Mediterranean Pollution Monitoring and Research Programme
MONARPOP	Monitoring Network in the Alpine Region for Persistent and other Organic Pollutants
MONET	Monitoring Network for Persistent Organic Pollutants
MSFD	Marine Strategy Framework Directive
NAPS	National Air Pollution Surveillance

NCP	Northern Contaminants Programme
ND	Not detected
NHANES	National Health and Nutrition Examination Survey
NILU	Norwegian Institute for Air Research
NIP	National implementation plan
NOAA	National Oceanic and Atmospheric Administration
OCPs	Organochlorine pesticides
OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic
PAXMAN	Passive Air XAD Monitoring and Archiving Network
PCA	Pentachloroanisole
PeCB	Pentachlorobenzene
PBDEs	Polybromodiphenyl ethers
PCB	Polychlorinated biphenyls
PCDD	Polychlorinated dibenzo-*p*-dioxins
PCDF	Polychlorinated dibenzofurans
PCNs	Polychlorinated naphthalenes
PCP	Pentachlorophenol
PFAA	Perfluoroalkyl acids
PFAS	Per- and polyfluoroalkyl substances
PFHxS	Perfluorohexane sulfonic acid
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonic acid
PFOSF	Perfluorooctane sulfonyl fluoride
POPRC	Persistent Organic Pollutants Review Committee
POPs	Persistent organic pollutants
POPsEA	POPs Monitoring Project in East Asian countries
PUF	Polyurethane foam
QA/QC	Quality assurance and quality control
RECETOX	Research Centre for Environmental Chemistry and Ecotoxicology
ROGs	Regional Organization Groups for the Global Monitoring Plan
SAICM	Strategic Approach to International Chemicals Management
SCAR ImPACT	Scientific Committee on Antarctic Research programme in Input pathways of Persistent Organic Pollutants to Antarctica
SCCPs	Short-chain chlorinated paraffins
TEQ	Toxicity equivalents
TOP	Total oxidizable precursor
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
WEOG	Western European and Others Group
WFD	Water Framework Directive
WHO	World Health Organization
WMO	World Meteorological Organization
XAD	Styrene/divinylbenzene-co-polymer resin

Glossary of terms

Core Matrices	These are the matrices identified by the Conference of the Parties to the Stockholm Convention at its second meeting as core for the first evaluation: A=ambient air; M=(human) mother's milk and/or B=human blood.
CTD	The characteristic travel distance, defined as the "half-distance" for a substance present in a mobile phase.
DDD, DDE	Metabolites of DDT.
I L-1	Instrumentation level capable of analyzing PCDD/PCDF and dl-PCB at ultra-trace concentrations must be a high-resolution mass spectrometer in combination with a capillary column.
I L-2	Instrumentation level capable of analyzing all POPs (capillary column and a mass-selective detector).
I L-3	Instrumentation level capable of analyzing all POPs without PCDD/PCDF and dioxin like PCB (capillary column and an electron capture detector).
I L-4	Instrumentation level not capable to do congener-specific PCB analysis (no capillary column, no electron capture detector or mass selective detector).
Initial POPs	Those persistent organic pollutants that were listed in Annex A, B and/or C to the Stockholm Convention when it was adopted on 22 May 2001. There are 12 initial POPs: aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, hexachlorobenzene, mirex, polychlorinated biphenyls (PCB), polychlorinated dibenzo-*p*-dioxins (PCDD), polychlorinated dibenzofurans (PCDF), toxaphene.
Intercomparisons	Participation in national and international intercalibration activities such as ring-tests, laboratory performance testing schemes, etc.
LOD	Limit of detection. The lowest concentration at which a compound can be detected; it is defined as that corresponding to a signal three times the noise.
<LOD	Result below the of limit detection.
LOQ	Limit of quantification. The lowest concentration that can quantitatively be determined is three times higher than LOD.
<LOQ	Result below limit of quantification. Compounds found at levels between LOD and LOQ can be reported as present, or possibly as being present at an estimated concentration, but in the latter case the result has to be clearly marked as being below LOQ.
MDL	Method detection limit. The MDL considers the whole method including sampling, sample treatment and instrumental analysis. It is determined by the background amounts on field blanks.
New POPs	Those persistent organic pollutants that were listed in Annex A, B and/or C to the Stockholm Convention by the Conference of the Parties to the Stockholm Convention. The first nine new POPs were listed at the fourth meeting of the Conference of the Parties in 2009. Since then, new POPs have been listed at every meeting of the Conference of the Parties. Also referred to as "newly listed POPs". As of March 2023, there are 19 new POPs: alpha hexachlorocyclohexane, beta hexachlorocyclohexane, chlordecone, "decabromodiphenyl ether (BDE-209) present in commercial decabromodiphenyl ether", dicofol, hexabromobiphenyl, hexabromocyclododecane, "hexabromodiphenyl ether and heptabromodiphenyl ether", hexachlorobutadiene, lindane, pentachlorobenzene, "pentachlorophenol and its salts and esters", "perfluorohexane sulfonic acid (PFHxS), its salts and PFHxS-related compounds", "perfluorooctane sulfonic acid (PFOS), its salts and perfluorooctane sulfonyl fluoride (PFOSF)", "perfluorooctanoic acid (PFOA), its salts and PFOA-related compounds", "polychlorinated naphthalenes, including dichlorinated naphthalenes, trichlorinated naphthalenes, tetrachlorinated naphthalenes, pentachlorinated naphthalenes, hexachlorinated naphthalenes, heptachlorinated naphthalenes, octachlorinated naphthalene", short-chain chlorinated paraffins, "technical endosulfan and its related isomers", "tetrabromodiphenyl ether and pentabromodiphenyl ether".
First phase	Activities to support the effectiveness evaluation conducted by the Conference of the Parties at its fourth meeting, information collected between 2000 and 2008.
Second phase	Activities to support the effectiveness evaluation conducted by the Conference of the Parties at its seventh meeting, information collected between 2009 and 2014.
Third phase	Activities to support the effectiveness evaluation conducted by the Conference of the Parties at its eleventh meeting, information collected between 2015 and 2020.

Executive summary

I. Introduction

1. The third global monitoring plan (GMP) report synthesizes information from the first, second, and third phase of the GMP and presents the current findings on concentrations of persistent organic pollutants (POPs) at the global scale.

2. The third phase of the GMP focused on the following three key areas: (i) incorporating all newly listed POPs in ongoing monitoring activities to cover the full scope of the chemicals listed under the Convention as of 2019; (ii) enhancing harmonized data handling through the GMP Data Warehouse to support the collection, processing, storing and presentation of monitoring data in regions with limited capacity; (iii) enhancing the comparability within and across monitoring programmes to evaluate changes in concentrations of POPs over time and their regional and global transport.

Key message:

The ability of the Stockholm Convention to determine on-the-ground effectiveness of actions to reduce global burden of POPs critically relies on continuation of international and national monitoring programmes.

II. Results of the global monitoring

A. Data availability

3. The availability of information on the changes in POPs concentrations over time is improving but remains limited for newer analytes in most regions. In regions such as Asia-Pacific, Eastern Europe (EE) and Western Europe and Others Group (WEOG), long-term monitoring programmes cover part of the region with some notable spatial gaps within the region. Continuity in data generation and increasing spatial coverage in certain geographical areas are important areas of focus.

B. Data consistency and comparability

4. Enhancing the comparability of data within and across monitoring programmes to evaluate the changes in POPs levels over time and to understand the regional and global transport of POPs was one of the focal areas of the third phase of the GMP. Quality assurance and quality control (QA/QC) including inter-laboratory exercises and intercalibration studies have been and continue to be essential for ensuring data consistency and comparability. The interlaboratory assessments coordinated by the United Nations Environment Programme (UNEP) have been a large contributing exercise. In addition, new inter-calibration studies have been conducted. For example, an international intercomparison exercise for polyurethane foam disks samplers including 15 laboratories was carried out in 2016 and 2017. The results highlighted the advantage of using a central laboratory for monitoring programmes.

5. For some media, particularly water and other media, as well as air to a lesser degree, differences in sampling approaches (e.g., passive vs. active; gas-phase, particle-phase or total concentrations), sites and strategies (e.g., time-integrated sampling or intermittent sampling) and sampling matrix (e.g., use of filtered vs. non-filtered water samples) continue to mean that comparison of data may be complex. Water data appears to be rarely taken from “background” sites and in many cases are near to or within urban catchments. Together with year-to-year differences in sampling sites and wide differences in detection limits among studies, this greatly limits the ability to make meaningful comparisons across countries or between years.

C. Data handling

6. The five regional organization groups for the GMP are tasked to identify and report the best available POPs monitoring data on core media (air and human tissues) and other media, as available, considering three types of information: primary GMP data (the results of measurements of POPs concentrations in core matrices collected for the GMP or other monitoring programmes that are compatible with the goals of the GMP); GMP metadata (information or data that describe the primary GMP data, for example information on the methodologies employed); and supplementary data (other data or information that may be accepted, for example data from published sources).

7. Providing enhanced support to the regional organization groups for harmonized data handling for the compilation, processing, storing and presentation of their data in the regional reports has been a large focus of the third phase of the GMP. The GMP Data Warehouse has been further developed to

add a new data visualization tool and support data handling to assist the regional organization groups and the global coordination group in preparing the regional and global monitoring reports.

D. Monitoring results

Key messages from monitoring results:

There are sufficient data to determine trends for many of the listed POPs but not all. In general, concentrations are declining and are starting to level off where regulatory action was taken decades ago. It is noted, however, that in some cases, such as hexachlorobenzene, there are slight increases, likely due to releases from secondary sources and the effects of climate change.

The patterns for chemicals listed since 2009 are complex and variable across chemicals, media and areas. For example, certain chemicals showed mostly declining or no change in trends, while others showed increasing trends followed by decreasing trends, or consistent decreasing trends depending on the location. Analysis linking to localized actions could assist in understanding such variability. There are insufficient data to detect trends for many of the newly listed POPs.

It is important that data and samples be maintained in a coordinated and sustainable way, such as through environmental specimen banks, and that monitoring programmes operate efficiently and collaboratively to address challenges.

1. Measurements in air

8. New air monitoring activities, including high-volume sampling programmes and a large number of passive sampling stations implemented during the last reporting period have now accumulated enough data to provide temporal trend information on POPs. It is noted, however, that reporting of POPs in air is still limited in some regions.

9. Most of the POPs that were listed under the Convention before 2009 and several that were listed after 2009 have shown continued declining trends or the trends have levelled off at most monitoring stations worldwide with some exceptions. Slight increases have been noted for hexachlorobenzene, likely associated with secondary sources and effects of climate change. Most of the polychlorinated biphenyls (PCB) data sets in core media showed decreasing trend, while increasing trend was observed in some areas. Hexachlorobutadiene (HCBD) on the other hand appeared to be increasing in some parts of Asia-Pacific.

10. In most regions, some of the listed polybromodiphenyl ethers (PBDEs) showed declining trends, while other listed PBDEs did not, with the exception of Latin America and the Caribbean (GRULAC), where trends for PBDEs were unclear and potentially increasing. Perfluorooctane sulfonic acid (PFOS) and perfluorooctanoic acid (PFOA) were variable depending on the location and the region, with declines reported in Asia-Pacific and WEOG.

11. Air measurements of water soluble and ionizable POPs such as PFOS and PFOA are limited and could be supplemented by including monitoring data for those chemicals in precipitation.

12. There were limited data in some regions for decabromodiphenyl ether, hexabromobiphenyl, hexabromocyclododecane (HBCD) and toxaphene, and insufficient data to conclude on trends for dicofol, chlordecone, pentachlorophenol/pentachloroanisole (PCP/PCA), polychlorinated naphthalenes (PCNs) and short-chain chlorinated paraffins (SCCPs) in all regions.

2. Measurements in human tissues

13. For the majority of POPs, including some of the newly listed organochlorine compounds, the levels in human milk and/or blood have generally fallen over the last 20 years with higher levels seen only in sporadic cases. The levels of several initial POPs such as chlordane, dieldrin, DDT, hexachlorobenzene and toxaphene are decreasing over time in human milk and/or blood. PCP seems to be on a downward trend, although time-series data are scarce. The levels of PCB and polychlorinated dibenzo-*p*-dioxins/polychlorinated dibenzofurans (PCDD/PCDF) in human milk have fallen steadily from their earlier high levels. Some of the newly listed POPs showed an increase over time followed by a decrease, including for hexabromocyclododecane (HBCD), PBDEs, PFOS and PFOA.

14. There are some initial biomonitoring data on SCCPs available under the UNEP/WHO Human Milk Survey. More monitoring data for SCCPs is necessary as the production and use of those chemicals are known to be high volume and information on human exposure is limited.

15. No monitoring data could be found for chlordecone and HCBD in human milk or blood. No clear trend over time could be observed for heptachlor, hexachlorocyclohexanes, mirex and

pentachlorobenzene. Due to insufficient data, no clear trend could be determined for endosulfan, polybromobiphenyls including hexabromobiphenyl and PCNs.

3. Measurements in water

16. Data were available from ongoing monitoring programmes in Asia-Pacific and EE, as well as from the UNEP/GEF GMP II project in 22 countries in 2017–2019. Otherwise, data were taken mainly from the scientific literature. No specific studies of temporal trends of each chemical in water were found. Therefore, median concentrations for combined data from specific regions with the periods 2000–2009, 2010–2014 and 2015–2019 were compared. A challenge with these comparisons was that variation could be introduced due to differences in sampling locations and effects of seasonality.

17. In general, significant declines of PFOS were found in inland waters of several countries or regions including the Elbe and Rhine in Europe, lakes in Japan, and the North American Great Lakes. In oceans, PFOS concentrations declined significantly in the North Atlantic Sea and in the Mediterranean Sea, but not in the North Sea. Significant declines were observed in the Bohai Sea, the Yellow Sea and the South China Sea.

18. Median PFOA concentrations showed fewer declines compared to PFOS, although large differences from the mid-2000s to 2019 were seen at most sites in the Danube, as well as in the Elbe and the Rhine.

19. Median PFOS concentrations exceeded the European Union environmental quality standard (EQS) for inland surface waters of 0.65 ng/L in 21 of the 45 country sites for samples from 2015–2019 and earlier time periods. Median concentrations of PFOA did not exceed a proposed EQS of 100 ng/L in any of the 45 country sites, although some individual results exceeded this level.

20. Assessment of temporal trends at most locations was challenging due to year-to-year differences in sampling sites and to wide differences in detection limits among studies.

4. Measurements in other media

21. A significant body of data on POPs in non-core-media such as snow, ice, sediment, soil and biota are available for some parts of the world such as the Great Lakes, the Arctic, the Baltic, and Japan.

22. The changes over time, where available, indicate that for the POPs listed before 2009 (e.g., DDT, hexachlorobenzene, PCB, PCDD/PCDF), significant decreases have been observed over the past three decades. Levels of some of those initial POPs may still be at levels of concern in some species and regions (e.g., PCB in polar bears and whales). Chemicals such as HBCD, HCBD, PBDEs, PCNs, PFOS and SCCPs are slowing in their increase and in some cases decreasing since they were listed.

23. Given the wide spread of media and methodologies, more standardized data reporting would improve comparability.

24. Environmental specimen banks including biological samples and analytical extracts from sampling media have been shown to be cost effective for the establishment of temporal trends and could be used for future listed POPs.

5. Long-range environmental transport

25. The analysis of airflow back trajectories and monitoring data on initial POPs and newly listed POPs in Africa suggested that elevated air concentrations measured at some sites of the Monitoring Network for POPs (MONET) were primarily due to sustained local emissions. At the same time, low concentrations observed at the sites in Mt. Kenya represented the continental background levels, largely affected by long-range environmental transport (LRET) of POPs from distant sources.

26. In Asia-Pacific, decreasing trends of DDT and increasing trends of HCBD were observed at monitoring sites of the East Asian Monitoring Programme which supported the view that these changes were affected by LRET rather than local emissions.

27. Potential sources and LRET pathways of POPs in GRULAC were analyzed using the Hybrid Single-Particle Lagrangian Integrated Trajectory-National Oceanic and Atmospheric Administration (HYSPLIT-NOAA) model in 2018 at three sites in Barbados, Jamaica and Uruguay. Back trajectories indicated potential effect of marine emissions and emissions from small vessels on the site in Barbados, effect of emissions from nearby sources of the Dominican Republic, Haiti, Puerto Rico and the Caribbean islands on the site in Jamaica, and effect of LRET from the sources in Argentina, Brazil, Chile and Paraguay on the site in Uruguay.

28. LRET of POPs in the EE region was assessed by the application of multi-compartment modelling for hexachlorobenzene, PCB and PCDD/PCDF. Predicted levels of pollution and emissions of all studied POPs have decreased significantly between 1990 and 2018 (hexachlorobenzene by 90%, PCB by up to 80%, PCDD/PCDF by 40–75%). Model simulations indicated changes in the spatial distributions in the region and changes in the significance of imports from lower latitudes.

III. Evaluation of the global monitoring plan and recommendations for the next phase

Cross-cutting conclusions across all media:

The levels of many POPs, even those that have been regulated and managed, remain of concern. Existing monitoring programmes as well as ad hoc monitoring programmes such as those for water need to continue in order to determine trends. Large scale repeated monitoring programmes and sharing of metadata would allow comparison of data and enhance the ability to assess LRET.

Coordination with other programmes (e.g., ad hoc surveillance work on indoor air and urban and industrial emissions; monitoring and research programmes aiming to understand current exposure levels and emissions to the broader environment including urban areas and waste sectors) as well as development of environmental fate and exposure models would enable more comprehensive understanding of exposure and effectiveness of actions to protect human health and the environment.

Opportunities exist to link with climate science and biodiversity to better understand and interpret monitoring data in a broader context.

A. Arrangements

1. Further updating of the guidance and implementation plan

29. The third phase of the GMP was conducted in accordance with the amended GMP for POPs,[1] the amended implementation plan for the GMP for POPs[2] and the updated guidance on the GMP.[3] Along with the outcomes of the effectiveness evaluation report,[4] the areas for possible revision and addition have been identified and recommended for updating in the fourth round.

2. Data comparability and quality assurance and quality control

30. Recommended areas of future work to improve data comparability and quality assurance and quality control include the following:

(a) Encourage Parties to continue to participate in interlaboratory assessment activities organized by UNEP and to further explore and participate in such activities organized by other organizations, for example the International Atomic Energy Agency (IAEA), where applicable;

(b) Make further efforts to have databases easily searchable, openly accessible (e.g., data downloadable) and to integrate and make link with other databases;

(c) Further develop simple visualization tools such as those implemented under the GMP Data Warehouse;

(d) Enhance the ability to archive large data files in view of the advancement of high-resolution and non-target analytical methods, including for example in collaboration with NORMAN digital sample freezing platform which focuses on water data archiving. These approaches generate large data files that require sufficient and secure storage and provide an opportunity for retrospective analysis targeting newly listed POPs and related chemicals including precursors and transformation products.

[1] UNEP/POPS/COP.6/INF/31/Add.1.

[2] UNEP/POPS/COP.6/INF/31/Add.2.

[3] UNEP/POPS/COP.9/INF/36; UNEP/POPS/COP.10/INF/42.

[4] UNEP/POPS/COP.11/INF/36.

B. Challenges to implementation

1. Need for further capacity enhancement on a regional basis

31. For most regions, monitoring activities have been put in place and have produced data for the development of the third regional monitoring reports.[5] The GEF projects conducted to date have been extremely useful in enabling developing regions to participate in the GMP and the effectiveness evaluation under the Convention. Nevertheless, all regions have experienced limitations in the availability of data, including limited spatial coverage, limited temporal trend data and limited analytical capacity. For some regions, there are multiple limitations. Tackling such limitations will remain a key focus for the fourth round.

32. Data to date demonstrated that ongoing and sustained strategic monitoring programmes maximize utility of data and enable conclusions to be drawn. Increases in the number of such monitoring programmes will be a valuable future contribution.

2. Efficiencies of monitoring programmes

33. Enhanced coordination would be essential in order to be able to respond to the growing demand for information on POPs.

34. In order to manage pressures for analysing more newly listed POPs, monitoring programmes may need to adjust their protocols and resources to better align with new priorities. Possible strategies include reduced frequency of analysis of initial POPs such as organochlorine pesticides and PCB, optimized analytical methods and partnerships among laboratories to address specialized analytical needs.

35. It is not necessary for every laboratory to be an expert for analysis of all classes of POPs. Many monitoring programmes are incorporating the latest advancements in the field of science such as high-resolution and non-targeted analysis and associated data archiving for future reference. Future reporting may be able to draw on data generated through such advancements.

3. Sample archiving and specimen banks

36. Investing resources to ensure the integrity and sustainability of specimen banks could provide a highly cost-effective tool for understanding the effectiveness of regulatory and policy interventions as they enable retrospective analysis on current and future POPs, as well as for screening studies on candidate POPs.

4. Data archiving and accessibility

37. Databases and compilations such as the GMP reports play an important role in identifying, documenting and making accessible reliable and comparable data sets of POPs. These data are needed for assessing environmental levels and trends of POPs and for combining with emission estimates and models in integrated assessments of sources, fate and transport of POPs.

5. Challenges with POPs listed after 2009

38. Certain high molecular weight POPs including polar/ionizable chemicals (e.g., PFOS) exist in air primarily on the particle-phase. To improve understanding of regional and global transport of particle-associated POPs, it is necessary to improve performance of fate models to interpret temporal trend information from monitoring data, obtain more information on gas-particle partitioning properties of POPs and conduct studies on transport and fate of particle-associated POPs.

6. Chemical mixtures

39. Human health and the environment are impacted by exposure to chemical mixtures which includes known and unknown POP-like chemicals and their transformation products. Research in this area is advancing rapidly thanks to increased accessibility to high-resolution analytical equipment (e.g., GC/MS/MS, LC/MS/MS).

40. Future reporting under the GMP would benefit from information on the levels of all listed POPs and potential candidate POPs in the same samples, where available, as this enhances understanding of co-occurrences, thus co-exposure and environmental loads. Similarly, reporting of the concentrations of precursors of listed per- and polyfluoroalkyl substances (PFAS), for example through “total” methods, could enhance understanding of environmental loads.

[5] UNEP/POPS/COP.10/INF/41, http://chm.pops.int/tabid/525.

C. Media-specific recommendations for the next phase

1. Air

41. Recommendations on the air monitoring are as follows:

(a) Continue passive air sampling and capacity-building in a sustainable manner to enhance information on temporal trends and to improve spatial coverage;

(b) Develop a strategy for POPs monitoring using passive and active air sampling in order to better address data gaps in some regions in the long-term and growing needs of the Convention. The strategy should be developed through regional commitment and expertise, as well as through consultation with established programmes;

(c) Ensure the continuity of newly established sampling programmes and activities to generate long-term measurement data in order to assess the changes in POPs levels over time. Continue air monitoring using active and passive samplers according to QA/QC protocols to ensure data consistency;

(d) Continue air monitoring of newly listed POPs. Enhance collaboration with expert laboratories that have existing and recognized analytical methodologies to assist in the measurement of newly listed POPs found in air that lack analytical methods. Further develop GMP guidance to address those challenges;

(e) Regional experts should define monitoring priorities based on available resources and information on POPs concentrations in air and emissions, taking into account the GMP guidance;

(f) Maintain and update databases to ensure data quality, consistency, data continuity and ease of access. Improve compatibility among databases to facilitate data exchange and compilation;

(g) Improve waste management practices, management of contaminated sites, elimination of obsolete stockpiles and public education in order to further reduce intentional emissions of POPs from commercial use present in stockpiles and waste streams and unintentional emissions via open burning.

42. Furthermore, it is suggested to include in the work of the next phase of the GMP to develop a monitoring strategy such that the long-term temporal trends of POPs can still be assessed with a reduced sampling or analytical schedule.

43. Archived air samples or extracts can be used for retrospective analysis of POPs to rebuild temporal trends when funding and resources become available in the future. An example of this is the Australian Monitoring Programme, Passive Air (XAD) Monitoring and Archiving Network (PAXMAN), which has archived passive air samples over the period 2010–2020. The Government of Australia commissioned analysis of a subset of those samples for POPs, including chlorinated paraffins, HBCD, PBDEs, PCB and PCNs in samples spanning the period 2010–2020.

44. Those new developments have implications beyond the scope of the GMP but are important for understanding hazards and risks associated with POPs which may inform regulation of chemicals and the effectiveness evaluation of the Convention. Monitoring programmes and studies on POPs should consider urban sources of POPs and employ high-resolution analysis (non-target and suspect screening) to investigate chemical mixtures in air, including transformation products of POPs. Advances in in-silico approaches and assays for assessing toxicity should be explored as a complementary means for tracking the toxicity of the entire air mixture of POPs and related POP-like chemicals in air.

45. Future GMP should consider bridging this data gap with available long-term precipitation data and historical records found in ice cores which solely reflects atmospheric deposition over time.

46. Beyond the current scope of the GMP, but relevant to future work on effectiveness of the Convention towards the protection of human health and the environment from POPs, includes the development of strategies for linking the information on POPs concentration in air with toxicity. In vitro methods such as transcriptomics and bioassays to assess various toxicity end-points are now available with the required sensitivity to be applied to air sample extracts.

2. Human tissues

47. Recommendations on the human tissues monitoring are as follows:

(a) The global, regional and national monitoring programmes should continue to evaluate temporal trends of both POPs and other environmental pollutants in blood and/or milk. This would allow following the effectiveness of the Convention and to evaluate whether regulations and other actions taken in order to reduce the exposure to POPs were purposive and efficient;

(b) Continue the UNEP/WHO Human Milk Survey with a timing synchronized with the cycle of the effectiveness evaluation of the Convention to enable the GMP to use the latest available data. Participation from more countries in this survey would increase its representativeness;

(c) Continue and expand monitoring of newly listed POPs to provide the information necessary to assess the changes over time. In order to be able to follow up on those chemicals over time, it is important to start monitoring them now. In addition to the initial POPs that are already regulated, it is important to monitor possible substitutions;

(d) Encourage archiving of human samples as a cost-effective means for conducting retrospective analysis of newly listed POPs to generate baseline information and temporal trends of newly listed POPs as they are added to the Convention.

3. Water

48. Recommendations on the water monitoring are as follows:

(a) Continue water monitoring at established sites. As noted in the third regional monitoring report for Africa,[6] this would be critical to allow the establishment of concentration trends in future assessments;

(b) Future GMP assessments of PFAS in water should consider using the successful study design of the UNEP/GEF GMP II project (Baabish et al. 2021). The multiple sampling times at the same site and use of the same analytical laboratory yielded an excellent set of results;

(c) Repeat the UNEP/GEF GMP project prior to the next global assessment, ideally in a larger number of sites, but at a minimum at the same sites as those used in 2017–2019;

(d) Carefully design future sampling programmes as PFAS levels in river water may be influenced by wastewater and surface runoff in urban areas. Multiple sampling points preferably at sites that are well characterized in terms of flow and proximity to sources are needed;

(e) Conduct a global campaign for inland freshwater and coastal seawater sampling prior to each GMP assessment involving all regions. This would provide a more robust set of data than the current mix of national data and published scientific articles;

(f) Set lower detection limits in future assessments of temporal trends at all locations, especially in open oceans, coastal seas and lake waters. Detection limits in the range of 1–5 pg/L for perfluorohexane sulfonic acid (PFHxS), PFOS, and PFOA have been demonstrated by several monitoring programmes and should be universally adopted;

(g) Make efforts for more widespread measurements of precursors of PFHxS, PFOS and PFOA in waters by “total” methods (e.g., total oxidizable precursor, total extractable organic fluorine) or by targeting specific known precursors;

(h) Conduct an integrated analysis of data including other media such as air, sediments and biota with global models. This would improve understanding of the fate of PFAS in the environment and estimation of future trends of PFAS particularly in top predators and humans in remote areas, thus supporting the implementation and effectiveness evaluation of the Convention.

4. Other media

49. Recommendations on the monitoring of other media are as follows:

(a) Facilitate cooperation and enhance capacity to maintain long-term monitoring plans and programmes and environmental specimen banks integrating multiple media and to ensure robust QA/QC and reporting in a coherent transparent service in order to improve the accuracy for estimating the changes over time;

(b) Report evidence of the success of past regulations in decreasing the exposure to POPs in order to consolidate the need for further work on chronically low levels of the initial POPs (e.g., hexachlorobenzene, PCB) and the growing threat of partially regulated POPs (e.g., HCBD, PBDEs, PFOS, PFOA, SCCP) and other chemicals with POP characteristics sometimes used as alternatives;

(c) Make best efforts to integrate POPs monitoring work and its resulting data of abiotic media and macroscopic organisms, with climate data and molecular biology/toxicology in curated and accessible repositories;

[6] UNEP/POPS/COP.10/INF/41, http://chm.pops.int/tabid/525.

(d) Make best efforts to establish and maintain conditions that facilitate common understanding and cooperation between local agents and scientists to develop effective strategies in public health and environmental policies on POPs.

5. Long-range environmental transport

50. The followings are needed to better understand the LRET of POPs:

(a) The monitoring data in Africa revealed POPs contamination of ambient air at remote sites suggesting potential contribution of LRET. Additional meteorological data, information on climatological conditions and modelling tools are needed to establish the contribution of LRET on the distribution of POPs in the region;

(b) The existing data for several sites in Africa were collected over a short period of time. Additional monitoring data are needed to verify the modelling predictions with the monitoring results;

(c) Regional capacity for application and interpretation of LRET modelling results is needed to support policy makers to incorporate the modelling predictions in their national and regional POPs management interventions;

(d) Measurements of HCBD in air are available in a limited sites in East Asia. Additional monitoring data on long-term variations of HCBD concentrations in other locations are needed to reveal the sources and the scale of this increase;

(e) More detailed assessment of LRET in Asia-Pacific, including back trajectory analysis, modelling studies and compilation of information on emission sources is needed to analyze the trend data and to clarify their LRET and possible sources;

(f) Currently in the Asia-Pacific regions, monitoring data are available only in East Asia and the Pacific Islands. There is a strong need to establish environmental monitoring in the south, west and central Asia, so as to expand the monitoring network to cover all Asia-Pacific;

(g) The first analysis of back trajectories in the sites in the GRULAC region indicated the necessity for temporally disaggregated data to establish seasonality in order to relate and understand the observed concentrations and possible sources that contributed to those concentrations. Such information would allow evaluating those possible sources and defining local or regional reduction and mitigation actions;

(h) More systematic studies should be designed and implemented to address LRET of POPs in GRULAC. Passive air monitoring and active sampling along with modelling could be used to analyze the transport of POPs between sources and receptor areas. POPs modelling capabilities and training should be stimulated in the region;

(i) The satellite images of the fires reported in 2018 in the GRULAC region indicated possible generation of some POPs. It is highly recommended to review those contributions in detail to identify the types of burning that took place in the region (agricultural, waste or vegetation);

(j) Although not currently in the scope of the GMP, uncertainties in emission inventories of POPs can be reduced in a targeted way within an integrated assessment approach by applying models to estimate ranges of plausible emissions that are necessary to account for observed POPs levels (“top-down” approach). More effective methods to identify and characterize emissions of POPs are needed to assess the impact of transport of goods and waste, in particular e-waste, all over the world;

(k) Improved modelling capabilities within the integrated assessment approach will enable the vast corpus of environmental monitoring data that has been established over the past decades to be leveraged to achieve a more quantitative and predictive understanding of the levels and trends of POPs and POP candidates in the environment;

(l) Shorter-term effects of climate change and climate variability that vary by regions or by chemicals should be taken into account when interpreting POPs levels in environmental media;

(m) It is important to understand how climate change induced changes in the ecosystems affect the temporal trends of POPs in other media including biota through, e.g., changes in diet, in order to separate the effects of changes in ecosystems on temporal trends of POPs from the effects of global regulation and bans on the POPs through listing under the Convention;

(n) Research studies are needed as existing models are often not adequate for assessing new compounds that behave differently in the environment (e.g., polar/ionizable POPs). For instance, studies of partitioning to particles and particle-associated transport and fate are needed for high molecular weight POPs and polar/ionizable chemicals that exist in air primarily on the particle-phase;

(o) Monitoring programmes need to be flexible and adaptable to deal with the challenges presented by newly listed POPs;

(p) Enhancing modelling capabilities, especially by improving emission inventories and estimates of POP degradability, and by improving understanding of air-surface exchange, will help to reduce uncertainties about the extent of LRET of POPs and POP candidates. This is of great importance to interpret trends and ascertain the effectiveness of actions that have been undertaken, and to forecast impacts of current action or inaction;

(q) Improved integration between monitoring programmes and modelers may help to identify gaps in information and optimize future study designs and ongoing monitoring efforts.

6. Recommendations beyond the scope of the GMP for the effectiveness evaluation

51. Recommendations on the future work for evaluating the effectiveness of the Convention towards the protection of human health and the environment from POPs include the following:

(a) Link the GMP work with data from monitoring and research programmes aiming to understand current exposure levels and emissions to the broader environment including urban areas and waste sectors, given that newly listed POPs can be found in household and commercial products. Declines in environmental background concentrations are likely to be slower if listed POPs have exemptions to allow continued use or presence in recycled materials;

(b) Strengthen cooperation to integrate GMP and other data with numerical models to estimate spatial and temporal trends of POP emissions and to link with human and environmental burdens. This could enhance understanding of the effectiveness of actions to protect human health and the environment;

(c) Enhance cooperation with other monitoring efforts under the Basel Convention, the Rotterdam Convention, the Minamata Convention, the United Nations Framework Convention on Climate Change and the Convention on Biological Diversity. The information reviewed to provide baselines and to determine current trends in the WEOG region was predominantly drawn from a relatively small number of existing international programmes, which can in turn depend on contributing national programmes or ad hoc programmes. The ability to compare POPs levels over time makes the long-term viability of international and national programmes of critical importance.

Concluding message:

Sixteen years after the Stockholm Convention came into force, the GMP has shown that primary sources of the initial POPs have been substantially reduced and current low levels can be attributed to effectiveness of policies and regulations. Baseline concentrations of many but not all POPs listed after 2009 are becoming available through monitoring programmes for core and other media. Additional data in the future will enable the evaluation of trends to inform effectiveness of management actions. The Convention and its GMP have raised awareness, triggered action and provided a framework for collaboration and integration at the national, regional and global levels.

I. Introduction

Persistent organic pollutants (POPs) are a group of chemicals that have toxic properties, resist degradation in the environment, bioaccumulate through food chains and are transported long distances through moving air masses, water currents and migratory species, within and across international boundaries. The objective of the Stockholm Convention is to protect human health and the environment from POPs, with the ultimate goal of eliminating them, where feasible. An important way to evaluate the effectiveness of the Convention in reducing and eliminating release of POPs is to measure the concentration of the POPs listed under the Convention in relevant matrices.

As of March 2023, the Convention lists 31 POPs, including groups of substances, as summarized in **Table 1** below. In this report, the 12 POPs listed under the Convention adopted on 22 May 2001 are referred to as "initial POPs", whereas those listed by the Conference of the Parties at its subsequent meetings are referred to as "new POPs" or "newly listed POPs".

Table 1. Persistent organic pollutants listed under the Stockholm Convention as of March 2023.

#	Chemical name	Abbreviation	Annex	Year of listing	Primary use
1	1,1,1-Trichloro-2,2-bis (4-chlorophenyl)ethane	DDT	B	2001	Pesticide
2	Aldrin	–	A	2001	Pesticide
3	Alpha hexachlorocyclohexane	Alpha-HCH	A	2009 (COP-4)	Pesticide
4	Beta hexachlorocyclohexane	Beta-HCH	A	2009 (COP-4)	Pesticide
5	Chlordane	–	A	2001	Pesticide
6	Chlordecone	–	A	2009 (COP-4)	Pesticide
7	Decabromodiphenyl ether (BDE-209) present in commercial decabromodiphenyl ether	DecaBDE	A	2017 (COP-8)	Industrial
8	Dicofol	–	A	2019 (COP-9)	Pesticide
9	Dieldrin	–	A	2001	Pesticide
10	Endrin	–	A	2001	Pesticide
11	Heptachlor	–	A	2001	Pesticide
12	Hexabromobiphenyl	HBB	A	2009 (COP-4)	Industrial
13	Hexabromocyclododecane	HBCD	A	2013 (COP-6)	Industrial
14	Hexabromodiphenyl ether and heptabromodiphenyl ether	c-OctaBDE	A	2009 (COP-4)	Industrial
15	Hexachlorobenzene	HCB	A, C	2001	Pesticide / Industrial / Unintentional production
16	Hexachlorobutadiene	HCBD	A, C	2015 (COP-7) 2017 (COP-8)	Industrial / Unintentional production
17	Lindane	Gamma-HCH	A	2009 (COP-4)	Pesticide
18	Mirex	–	A	2004	Pesticide
19	Pentachlorobenzene	PeCB	A, C	2009 (COP-4)	Pesticide / Industrial / Unintentional production
20	Pentachlorophenol and its salts and esters	PCP	A	2015 (COP-5)	Industrial
21	Perfluorohexane sulfonic acid (PFHxS), its salts and PFHxS-related compounds*	PFHxS	A	2022 (COP-10)	Industrial
22	Perfluorooctane sulfonic acid (PFOS), its salts and perfluorooctane sulfonyl fluoride (PFOSF)	PFOS	B	2009 (COP-4) 2019 (COP-9)	Industrial

#	Chemical name	Abbreviation	Annex	Year of listing	Primary use
23	Perfluorooctanoic acid (PFOA), its salts and PFOA-related compounds	PFOA	A	2019 (COP-9)	Industrial
24	Polychlorinated biphenyls	PCB	A, C	2001	Industrial
25	Polychlorinated dibenzo-*p*-dioxins	PCDD	C	2001	Unintentional production
26	Polychlorinated dibenzofurans	PCDF	C	2001	Unintentional production
27	Polychlorinated naphthalenes, including dichlorinated naphthalenes, trichlorinated naphthalenes, tetrachlorinated naphthalenes, pentachlorinated naphthalenes, hexachlorinated naphthalenes, heptachlorinated naphthalenes, octachlorinated naphthalene	PCNs	A, C	2015 (COP-5)	Industrial / Unintentional production
28	Short-chain chlorinated paraffins	SCCPs	A	2017 (COP-8)	Industrial
29	Technical endosulfan and its related isomers	Endosulfan	A	2011 (COP-5)	Pesticide
30	Tetrabromodiphenyl ether and pentabromodiphenyl ether	c-PentaBDE	A	2009 (COP-4)	Industrial
31	Toxaphene	–	A	2001	Pesticide

Note: *PFHxS, its salts and PFHxS-related compounds are not yet fully monitored under the GMP.

According to Article 16 of the Convention, the Conference of the Parties periodically evaluates whether the Convention is effective in achieving the objective of protecting human health and the environment from POPs. The evaluation is conducted on the basis of available scientific, environmental, technical and economic information, including comparable monitoring data on the presence of POPs in the environment and humans, national reports submitted pursuant to Article 15 and non-compliance information provided pursuant to the procedures established under Article 17.

The global monitoring plan (GMP) for POPs, which has been put in place under the Convention, is a key component of the effectiveness evaluation. It provides a harmonized framework to identify changes in concentrations of POPs over time, as well as information on their regional and global environmental transport.

While the first[7] and second global monitoring reports[8] provided baseline information and first indications as to the changes in concentrations of the chemicals listed under the Convention as of 2013, this third monitoring report covers the full scope of the chemicals listed in the Convention as of 2019 and provides an enhanced ability to determine trends in concentrations over time.

The following documents provided an important basis for the implementation of the third phase of the GMP: amended GMP for POPs;[9] amended implementation plan for the GMP;[10] updated guidance on the GMP.[11]

The global coordination group (GCG) for GMP[12] oversaw and guided the implementation of the third phase of the GMP, with particular emphasis on:

(a) Addressing the sampling and analysis of the newly listed POPs;

(b) Harmonizing data collection, storage and handling;

(c) Addressing the needs for ensuring sustainability of ongoing monitoring activities and for further capacity strengthening to fill the existing data gaps;

[7] UNEP/POPS/COP.4/33.

[8] UNEP/POPS/COP.8/INF/38.

[9] UNEP/POPS/COP.6/INF/31/Add.1.

[10] UNEP/POPS/COP.6/INF/31/Add.2.

[11] UNEP/POPS/COP.10/INF/42.

[12] http://chm.pops.int/tabid/179.

(d) Improving data comparability within and across monitoring programmes.

The long-term viability of existing monitoring programmes (environmental monitoring and human biomonitoring) continues to be essential in ensuring that changes in concentrations over time can be identified. The national air monitoring activities that contributed data in the first and second phase of the GMP continued during the third phase. The contribution of data from the global and regional air monitoring programmes was also a fundamental input to the third phase and is expected to remain so in the long term. Collaboration with strategic partners ensured cost-effective generation of data and use of harmonized protocols for POPs monitoring.

The implementation of the second phase of the UNEP/WHO Human Milk Survey was another important pillar of the GMP, providing useful long-term results showing how human exposure to POPs changed over time as measures were implemented to enforce the Convention.

II. Results of the global monitoring plan

1. Data availability

1.1 Main findings

Data availability and coverage has significantly increased at the global scale compared to the first two phases of the GMP. All UN regions have benefited from increased generation of harmonized monitoring data of POPs levels in the core media. The third regional monitoring reports[13] provided detailed information on regional and subregional data. The UNEP/GEF GMP projects supported data generation and capacity enhancement in developing regions and provided a useful platform to increase the level of monitoring activities. The need for continued capacity assistance remains critically important.

Many long-term monitoring programmes have enlarged the scope of their activities to cover newly listed POPs. **Table** 2 provides an overview of the contributing monitoring programmes in each UN region. Currently, 30 of the 31 POPs listed under the Stockholm Convention (see **Table 1**) are monitored under the GMP.

Through the existing air monitoring network and newly initiated programmes, the ongoing human exposure studies, and water monitoring activities, a better spatial coverage of POPs concentrations in the environment and in human populations has been achieved.

Table 2. Monitoring programmes contributing data to the GMP.
(Source: Third regional monitoring reports under the global monitoring plan.[14])

Region	Air	Human tissues	Water	Other media
Africa	Global Atmospheric Passive Sampling (GAPS) network MONET-Africa UNEP/GEF GMP I and II projects	UNEP/WHO Human Milk Survey	MONET-Africa pilot project UNEP/GEF pilot project and GMP II project	Limited monitoring dealing with the contamination of water, soil, sediments and foodstuffs by POP pesticides UNEP/GEF GMP projects
Asia-Pacific	POPs Monitoring Project in East Asian Countries (POPsEA) China national POPs monitoring programme Japan national monitoring programme MONET-Fiji UNEP/GEF GMP I and II projects GAPS network	China monitoring programme on human milk Japan POPs monitoring programme on human milk Japan monitoring programme on human blood UNEP/WHO Human Milk Survey	United Nations University (UNU-IAS)/Shimadzu project (2018) National water monitoring programmes: China, Japan UNEP/GEF GMP II project	Japan national monitoring programmes on water, ground water, bottom sediments, soil, biota, foodstuffs UNEP/GEF GMP II project (national samples)
EE	APOPSBAL Arctic Monitoring and Assessment Programme (AMAP) GAPS network European Monitoring and Evaluation Programme (EMEP) MONET-Europe MONET-EE	UNEP/WHO Human Milk Survey	Joint Danube Survey (2009, 2013 and 2019) Aqua MONET-Europe NORMAN Association	National programmes on e.g., soil, sediments and biota are available in the region but rather variable, episodic
GRULAC	GAPS network Latin Passive Air Monitoring Network (LAPAN) UNEP/GEF GMP I and II projects	UNEP/WHO Human Milk Survey	UNEP/GEF GMP II project	UNEP/GEF GMP II project (national samples)

[13] UNEP/POPS/COP.10/INF/41, http://chm.pops.int/tabid/525.

[14] UNEP/POPS/COP.10/INF/41, http://chm.pops.int/tabid/525.

Region	Air	Human tissues	Water	Other media
WEOG	AMAP Australia's Casey Station Australian Monitoring Program: National Passive Air Sampling and Archiving Program EMEP GAPS network Great Lakes Basin Monitoring and Surveillance Program (GLB) Integrated Atmospheric Deposition Network (IADN) MONET-Europe Monitoring Network in the Alpine Region for Persistent and other Organic Pollutants (MONARPOP) National Air Pollution Surveillance (NAPS) Northern Contaminants Programme (NCP) Norwegian Troll Station Spanish Monitoring Program on POPs Swedish National Monitoring programme for Air Toxic Organic Micro Pollutants (TOMPs) program UK-Norway SPMD Transect	AMAP Australian Human Biomonitoring Spain Biomonitorización de Contaminantes en la Población Española (BIOAMBIENT.ES) USA National Health and Nutrition Examination Survey (NHANES) Canadian Health Measures Survey (CHMS) German Environmental Survey Swedish national monitoring program UNEP/WHO Human Milk Survey Peer reviewed literature	AMAP International Council for the Exploration of the Sea (ICES) database Peer reviewed literature National programmes in Canada, Finland, and Australia Helsinki Commission/The Baltic Marine Environment Protection Commission (HELCOM) NORMAN EMPODAT database Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) Mediterranean Pollution Monitoring and Research Programme (MEDPOL) Australian Pilot Monitoring Programme ICES database	AMAP Australian Pilot Monitoring Programme Great Lakes HELCOM OSPAR MEDPOL NCP

The first and second global monitoring reports revealed that most air data on POPs was contributed by a relatively small but growing number of monitoring programmes and that the continuation of these programmes was essential (see (Source: Guidance on the global monitoring plan, UNEP/POPS/COP.10/INF/42.)**Figure** 1).

The reports also revealed that data on POPs levels in air was lacking in some regions and should be addressed through capacity strengthening efforts and the establishment of sustainable and coordinated air monitoring programmes. Certain sub-regions such as Central, South and West Asia, and Antarctica have limited availability of information, either in terms of analytes or matrices covered.

Similarly, long-term biomonitoring programmes (UNEP/WHO global human milk survey, AMAP human maternal blood plasma monitoring programme in the Arctic, national programmes) continued their activities and further enlarged their geographical and/or analytical scope with standardized protocols for specimen collection and analysis (see **Figure 2**).

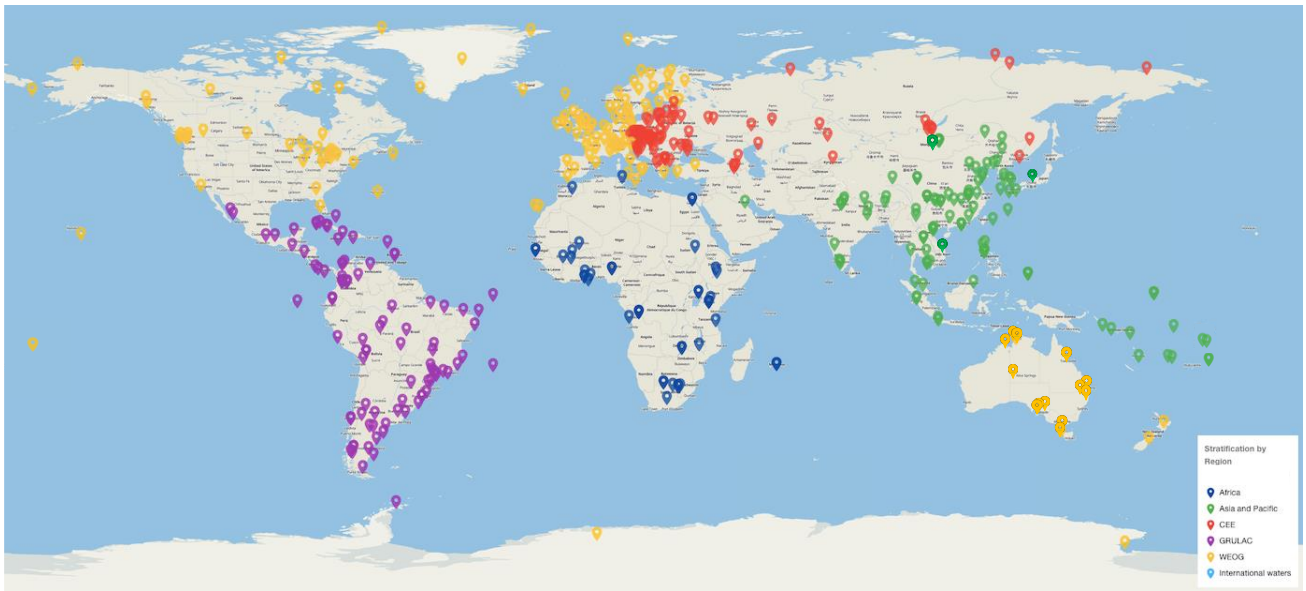


Figure 1. Sampling sites under existing active and passive air monitoring programmes for POPs that are contributing data to the third GMP report.
(Source: Guidance on the global monitoring plan, UNEP/POPS/COP.10/INF/42.)

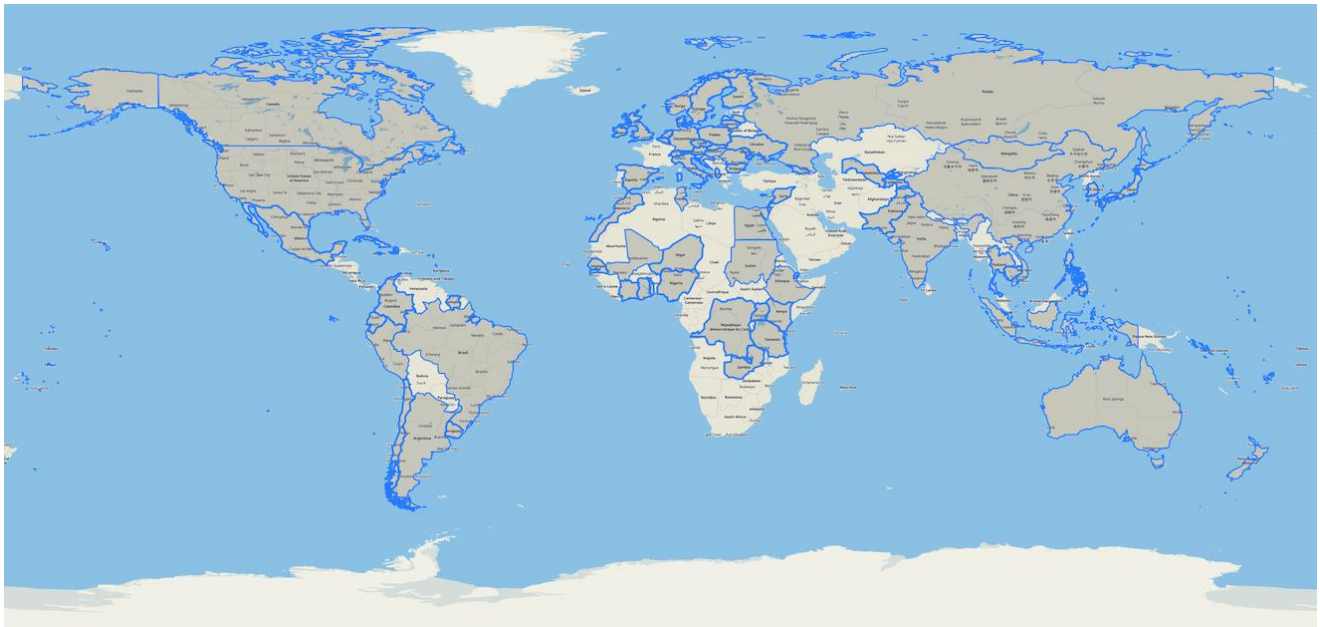


Figure 2. Geographical coverage of biomonitoring activities under the UNEP/WHO Human Milk Survey.

Information on the availability of baseline data and temporal trends of POPs in air, human tissues, water and other media in each UN region is summarized in **Table 3** below.

Table 3. Availability of baseline and temporal trends data of POPs in air, human tissues, water and other media by region.

Legend:

Adequate information is available	
Limited information is available	
No information is available	

Availability of baseline data

Chemical	Region	Air	Human tissues	Water and other media
Aldrin	Africa			
	AP			
	EE			
	GRULAC			
	WEOG		ND	
Chlordane	Africa			
	AP			
	EE			
	GRULAC			
	WEOG			
Chlordecone	Africa			
	AP			
	EE			
	GRULAC			
	WEOG			
Dicofol	Africa			
	AP			
	EE			
	GRULAC			
	WEOG		Not included	
DDT	Africa			
	AP			
	EE			
	GRULAC			
	WEOG			
Dieldrin	Africa			
	AP			
	EE			
	GRULAC			
	WEOG			
Endosulfan	Africa			
	AP			
	EE			
	GRULAC			
	WEOG			
Endrin	Africa			
	AP			

Availability of temporal trends data

Chemical	Region	Air	Human tissues	Water and other media
Aldrin	Africa			
	AP			
	EE			
	GRULAC			
	WEOG		ND	
Chlordanes	Africa			
	AP			
	EE			
	GRULAC			
	WEOG			
Chlordecone	Africa			
	AP			
	EE			
	GRULAC			
	WEOG			
Dicofol	Africa			
	AP			
	EE			
	GRULAC			
	WEOG		Not included	
DDT	Africa			
	AP			
	EE			
	GRULAC			
	WEOG			
Dieldrin	Africa			
	AP			
	EE			
	GRULAC			
	WEOG			
Endosulfan	Africa			
	AP			
	EE			
	GRULAC			
	WEOG			
Endrin	Africa			
	AP			

Availability of baseline data				
Chemical	**Region**	**Air**	**Human tissues**	**Water and other media**
	EE			
	GRULAC			
	WEOG		ND	
HBB	Africa			
	AP			
	EE			
	GRULAC			
	WEOG			
HBCD	Africa			
	AP			
	EE			
	GRULAC			
	WEOG			
HCB	Africa			
	AP			
	EE			
	GRULAC			
	WEOG			
HCBD	Africa			
	AP			
	EE			
	GRULAC			
	WEOG			
Alpha-HCH	Africa			
	AP			
	EE			
	GRULAC			
	WEOG			
Beta-HCH	Africa			
	AP			
	EE			
	GRULAC			
	WEOG			
Gamma-HCH (Lindane)	Africa			
	AP			
	EE			
	GRULAC			
	WEOG			
Heptachlor	Africa			
	AP			
	EE			
	GRULAC			
	WEOG			
Mirex	Africa			
	AP			

Availability of temporal trends data				
Chemical	**Region**	**Air**	**Human tissues**	**Water and other media**
	EE			
	GRULAC			
	WEOG		ND	
HBB	Africa			
	AP			
	EE			
	GRULAC			
	WEOG		USA only	
HBCD	Africa			
	AP			
	EE			
	GRULAC			
	WEOG			
HCB	Africa			
	AP			
	EE			
	GRULAC			
	WEOG			
HCBD	Africa			
	AP			
	EE			
	GRULAC			
	WEOG			
Alpha-HCH	Africa			
	AP			
	EE			
	GRULAC			
	WEOG		Trend not investigated	
Beta-HCH	Africa			
	AP			
	EE			
	GRULAC			
	WEOG			
Gamma-HCH (Lindane)	Africa			
	AP			
	EE			
	GRULAC			
	WEOG		Trend not investigated	
Heptachlor	Africa			
	AP			
	EE			
	GRULAC			
	WEOG			
Mirex	Africa			
	AP			

Availability of baseline data				
Chemical	**Region**	**Air**	**Human tissues**	**Water and other media**
	EE			
	GRULAC			
	WEOG			
PBDEs	Africa			
	AP			
	EE			
	GRULAC			
	WEOG			
DecaBDE	Africa			
	AP			
	EE			
	GRULAC			
	WEOG			
PCB	Africa			
	Asia-Pacific			
	EE			
	GRULAC			
	WEOG			
PCDD/PCDF	Africa			
	AP			
	EE			
	GRULAC			
	WEOG			
PCP/PCA	Africa			
	AP			
	EE			
	GRULAC			
	WEOG			
PCNs	Africa			
	AP			
	EE			
	GRULAC			
	WEOG		Sweden only	
PFOS	Africa			
	AP			
	EE			
	GRULAC			
	WEOG			
PFOA	Africa			
	AP			
	EE			
	GRULAC			
	WEOG			
PFHxS	Africa			

Availability of temporal trends data				
Chemical	**Region**	**Air**	**Human tissues**	**Water and other media**
	EE			
	GRULAC			
	WEOG			
PBDEs	Africa			
	AP			
	EE			
	GRULAC			
	WEOG			
DecaBDE	Africa			
	AP			
	EE			
	GRULAC			
	WEOG			
PCB	Africa			
	Asia-Pacific			
	EE			
	GRULAC			
	WEOG			
PCDD/PCDF	Africa			
	AP			
	EE			
	GRULAC			
	WEOG			
PCP	Africa			
	AP			
	EE			
	GRULAC			
	WEOG		Germany only	
PCNs	Africa			
	AP			
	EE			
	GRULAC			
	WEOG			
PFOS	Africa			
	AP			
	EE			
	GRULAC			
	WEOG			
PFOA	Africa			
	AP			
	EE			
	GRULAC			
	WEOG			
PFHxS	Africa			

Availability of baseline data				
Chemical	**Region**	**Air**	**Human tissues**	**Water and other media**
	AP			
	EE			
	GRULAC			
	WEOG			
PeCB	Africa			
	AP			
	EE			
	GRULAC			
	WEOG			
SCCPs	Africa			
	AP			
	EE			
	GRULAC			
	WEOG			
Toxaphene	Africa			
	AP			
	EE			
	GRULAC			
	WEOG			

Availability of temporal trends data				
Chemical	**Region**	**Air**	**Human tissues**	**Water and other media**
	AP			
	EE			
	GRULAC			
	WEOG			
PeCB	Africa			
	AP			
	EE			
	GRULAC			
	WEOG			
SCCPs	Africa			
	AP			
	EE			
	GRULAC			
	WEOG			
Toxaphene	Africa			
	AP			
	EE			
	GRULAC			
	WEOG			

Note: See **Table 1** for the abbreviations used for chemical names. AP: Asia-Pacific; EE: Eastern Europe; GRULAC: Latin America and the Caribbean Group; WEOG: Western Europe and Others Group; ND: Not detected.

1.2 Conclusions and recommendations

Conclusions	Recommendations
Although data availability and coverage has significantly increased at the global scale compared to the first two phases of the GMP, continuity in data generation for detection of trends in concentrations over time and, to various degrees, limited spatial coverage in certain sub-regions, remain important areas of work, particularly as the analytical scope of the GMP continues to increase by addition of new POPs.	Intensify and diversify efforts as required to address remaining gaps in data coverage and to monitor new POPs as they are added to the Convention.
Through sustained monitoring since the first phase of the GMP, information on temporal trends has become more available globally, in particular for the initial POPs. Long-term monitoring programmes have enlarged the scope of their activities to cover newly listed POPs in addition to the initial POPs. Activities for sampling of PFAS in water initiated as part of the second phase of the GMP continued to generate and delivered data.	Ensure sustainability of ongoing monitoring activities in the long-term in developed and developing countries to provide important information required to support the effectiveness evaluation under the Stockholm Convention.
While partnerships with advanced infrastructures and strategic partners performing monitoring activities have so far allowed us to compensate for the gaps in data coverage, national efforts are needed to re-establish POPs monitoring in core media as priority. Technical assistance will continue to be needed to increase expert capacities.	Encourage, and where appropriate, support continued participation of countries in relevant monitoring activities conducted at the national level, such as the human milk survey, in order to further strengthen the evidence and identification of trends.

2. Data consistency and comparability

2.1 Main findings

Enhanced comparability within and across monitoring programmes to enable the evaluation of changes in levels over time and understanding of the regional and global transport of POPs was an important priority area in the third GMP. QA/QC practices, along with inter-laboratory exercises and intercalibration studies, were essential for ensuring data comparability. Data consistency was also maintained by ensuring continuity of monitoring programmes and the activities established since the beginning of the GMP (see **1.1 Main findings**).

Efforts towards enhancing comparability within and across monitoring programmes, to evaluate changes in concentrations over time and the regional and global transport of POPs, continued in the third GMP through a number of new inter-calibration studies, including the global interlaboratory assessment on POPs coordinated by UNEP, which have become the largest exercise on POPs analysis with a wide spectrum of test matrices.

Figure 3 below illustrates the number of laboratories registered in the four rounds of the interlaboratory assessment. The first round was performed from 2010 to 2011 on the analysis of the 12 initial POPs listed under the Stockholm Convention. The second round conducted from 2013 to 2014 included the nine new POPs listed under the Convention in 2009. The third round completed its work in 2017 with 175 laboratories registered from all UN regions. The fourth round was concluded in 2019 with 147 laboratories registered. Overall, 179 laboratories submitted results in the four rounds of interlaboratory assessment. **Table 4** summarizes analytical performance obtained from those four rounds of interlaboratory assessments.

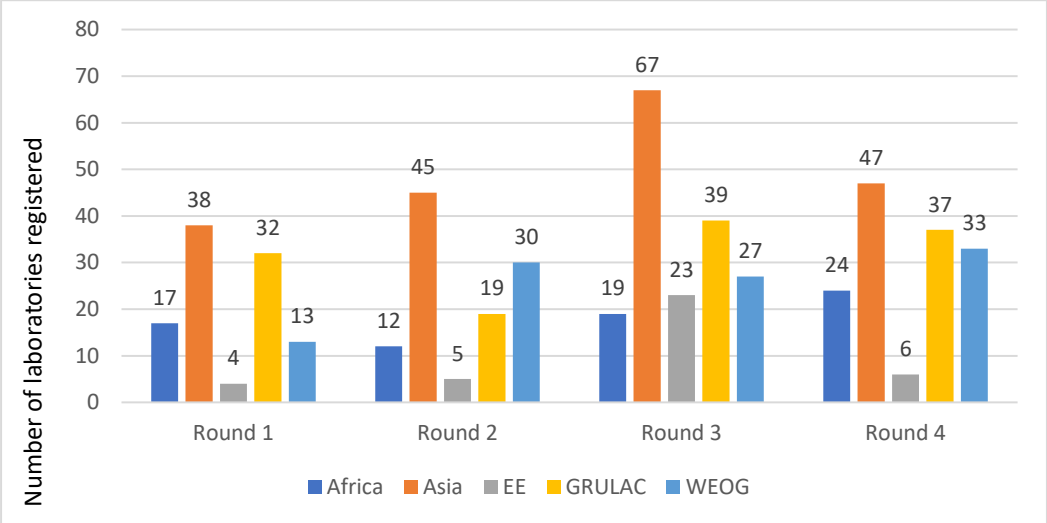


Figure 3. Number of laboratories registered in the four rounds of the UNEP global interlaboratory assessment on POPs.
(Source: Bi-ennial global interlaboratory assessment on persistent organic pollutants, UNEP 2021.)

Table 4. Z-score assessment of laboratory performance in the four rounds of the UNEP global interlaboratory assessment on POP.
(Source: Bi-ennial global interlaboratory assessment on persistent organic pollutants, UNEP 2021.)

z-scores	Round 1	Round 2	Round 3	Round 4	Total
Number of labs with results	65	104	133	117	179 (different labs)
S (satisfactory)	3,755	6,708	7,737	6,316	24,516 (61%)
Q (questionable)	550	1,057	1,207	1,159	3,867 (10%)
U (unsatisfactory)	1,020	2,237	3,570	3,399	9,823 (24%)
C (consistent)		153	128	356	581 (1%)
I (inconsistent)		336	613	641	1,474 (4%)
Total	**5,325**	**10,491**	**13,255**	**11,871**	**40,261**

Note: S=Satisfactory, <25% from assigned value; Q=Questionable, 25%–37.5% from assigned value; U=Unsatisfactory, >37.5% from assigned value.

The results emphasize the need for more attention to quality assurance (QA) and more extensive method validation. It is imperative that authorities, management and others provide the resources necessary for an adequate QA scheme in each laboratory. Regular, routine analyses instead of one-off projects would help to build up the required level of experience for this type of analysis. Long-term commitment to organize similar assessments on a regular basis (1–2 years) will be needed to obtain a reasonable-to-good comparability of POP laboratories world-wide.

Inter-programme comparability has been thoroughly assessed since the second phase of the GMP through a wide range of intercalibration exercises and co-location of samplers among programmes: for instance, data comparability from different sampling approaches (e.g., passive vs. active; gas-phase, particle-phase or total concentrations) and strategies (e.g., time-integrated sampling or intermittent sampling), sampling matrix (use of filtered vs. non-filtered water samples, use of human milk or blood for human exposure studies).[15]

Since the second phase of the GMP, a number of new inter-calibration studies have been conducted. For example, an international intercomparison exercise for PUF disks samplers, including 15 laboratories, was carried out in 2016–2017 led by the Norwegian Institute for Air Research (NILU), in collaboration with the Research Centre for Toxic Compounds in the Environment (RECETOX) and Environment and Climate Change Canada (ECCC) (Bohlin-Nizzetto et al. 2018; Melymuk et al. 2021). The study revealed a few discrepancies in results for POPs among research groups when participants performed their own analysis, with each group providing their own sampler housing, whereas the results were much more consistent and comparable when all the analysis was performed by a reference lab. The results highlight the advantages of using a central laboratory for regional and even global-scale programmes. Further information is available in the GMP guidance.

2.2 Conclusions and recommendations

Conclusions	Recommendations
Data consistency and comparability is critical in achieving the required resolution to determine trends in POPs levels over time and the regional and global transport of POPs.	Efforts towards ensuring comparability and consistency in monitoring data at the global and regional levels should continue.
By adopting suitable analytical methods, laboratories can prove their capabilities with successful participation in international comparison studies.	POPs analysis laboratories should implement robust and validated methods according to international scientific standards.
The GMP guidance[16] provides essential information supporting generation of harmonized, consistent and comparable monitoring data in all UN regions. The guidance is continuously updated to include the most recent technical and scientific information and to address monitoring needs for new chemicals (sampling and analysis), as they are listed in the Convention.	The GMP guidance should be used as the reference for framing monitoring activities contributing to the GMP.

[15] UNEP/POPS/COP.10/INF/42.

[16] UNEP/POPS/COP.10/INF/42.

3. Data handling

3.1 Main findings

3.1.1 Data handling by the regional organization groups

Since the establishment of the GMP in 2006, the regional organization groups (ROGs) are tasked to identify and report the best available POPs monitoring data on core media (air and human tissues) and other media as available, considering the following types of information:

(a) Primary GMP data:

Those are the results of measurements of POPs concentrations in samples of core matrices collected for the GMP, or for other programmes that are compatible with the goals of the GMP. They include measurements of POPs in specific samples and measurements of other covariables relating to those samples (e.g., biological covariates) that are necessary for interpreting the POPs data in a meaningful way, including the location and timing of sampling;

(b) GMP meta-data:

Those are other data or information that describe the primary GMP data in some way. This could include information on the methodologies employed (e.g., for sampling and analysis) and the laboratories responsible for a particular set of analyses, or the design and implementation of programmes that contribute to the GMP;

(c) Supplementary data:

Those are other data or information that may be accepted for use in the evaluation under the Stockholm Convention. This could include relevant information or data from published sources (e.g., the peer reviewed scientific literature, existing assessment), results of modelling activities that may assist the data interpretation and evaluation, or results of research activities that may be relevant to interpreting the primary GMP data in a valid and meaningful way (e.g., process studies, food-web studies).

These data can be accessible from databases or publications and are compiled by the ROG to be reported at each cycle in agreed formats.

Most of the regional data is hosted in the GMP Data Warehouse[17] described in the next section. Regionally available data are collected through the focal points of each Party in the region using the templates for collecting readily available data from the GMP Data Warehouse and evaluated by the ROG members based on the criteria established under the GMP such as analytical procedure and QA/QC protocol. Data processing is conducted by the GMP data management team to ensure consistency across the GMP phases. The compiled information submitted by the ROGs was also made available to other scientists to work with the data in statistical analysis and mathematical models.

In Asia-Pacific, some of the long-term monitoring programmes which started earlier than the adoption of the Convention generated data not compatible with the format of the GMP Data Warehouse. Those data were reported in the annex to the regional monitoring report[18] and were analyzed and summarized together with the data in the GMP Data Warehouse to support the effectiveness evaluation.

In the WEOG, most of the measurements of POPs that are available across the region originate from a small number of existing programmes. In many cases, those programmes have been operating for more than a decade and exercise well established data handling and QA/QC protocols for sample collection and analyses. Those methods are consistent with the standards outlined in the GMP guidance.[19] Scientists and researchers involved in the programmes are at the forefront of the field and employ what are the most appropriate data analysis methods based on up-to-date scientific expert opinion. The WEOG ROG has therefore relied on those programme experts for summarizing information on temporal trends of POPs in their respective monitoring programmes.

Many of the programmes in the WEOG region continue to deliver data to long-term databases such as EBAS.[20] These databases are integral for making the monitoring data available to modelers for assessing regional and global transport of POPs, making connections between emissions and environmental burdens, and for exploring climate change and climate variability effects on POPs.

[17] https://www.pops-gmp.org/.

[18] UNEP/POPS/COP.10/INF/41, http://chm.pops.int/tabid/525

[19] UNEP/POPS/COP.10/INF/42.

[20] http://ebas.nilu.no/.

3.1.2 GMP Data Warehouse

The GMP Data Warehouse has been made operational during the second phase of the GMP. During the third phase, harmonized data handling was enhanced to support the storage, processing, analysis and presentation of monitoring data. The GMP Data Warehouse was further developed to equip new data visualization tools to assist the ROGs and the GCG in preparing the regional and global monitoring reports. Four regions used GMP Data Warehouse for data handling and three ROGs used the GMP Data Warehouse services in generating their regional monitoring reports.

The objective of the GMP Data Warehouse is to ensure access to the most relevant and up-to-date information available for the purpose of the evaluation under the Stockholm Convention. All GMP data presented in the Data Warehouse are endorsed by the respective countries through the data collection process performed by the ROGs. The compilation and reporting work relies on a number of international monitoring programmes and data archives.

The electronic system of the GMP Data Warehouse is a modern multi-modular data repository for both primary and annually aggregated POPs data with a uniform visualization interface in five modules that serve the users the most. Data handling ensures joint presentation of new data collected in the third phase of the GMP (including new POPs, core matrices, and programmes) with earlier data without compromising information.

The data validation by the ROGs through the GMP Data Warehouse supports comparability of the different samples, e.g., different sites, matrix, sampling methods, time span and sampling frequencies. Details on statistical considerations and their implementation are available in the GMP guidance.[21] Several figures used in this report are graphical outputs of the Data Warehouse.

Data that have undergone validation by the ROGs but have not been reported to the GMP Data Warehouse are available electronically in other databases or can be found in the regional monitoring reports.[22] These data include some long-term monitoring programmes that started earlier than the adoption of the Stockholm Convention and contain long-term trend information of the initial POPs as well as some of the newly listed POPs.

Once the validation and approval procedures are completed, the GMP Data Warehouse constitutes a publicly available repository and portal of global information on POPs levels that can serve as useful resource for experts, policy makers, modelers and researchers worldwide. The GMP Data Warehouse could be useful for subsequent dissemination of information on the POPs monitoring, raising awareness on monitoring activities and has a potential to be used by other fora such as biodiversity cluster.

3.2 Conclusions and recommendations

Conclusions	Recommendations
Clear data handling procedures are prerequisite for a successful continuity of the GMP and ability to draw on trends and broader exploitation of efforts done in GMP.	The GMP data handling should promote transparency of process, both with respect to the data themselves, and their treatment and analysis.
The GMP Data Warehouse[23] is an important tool for aggregating, archiving and visualizing the data from POPs monitoring programmes. The processes established are in line with the GMP guidance.	The GMP Data Warehouse should be further maintained to continuously support the ROGs and GCG in the generation of regional and global reports, as well as to increase the visibility of POPs monitoring activities.
The volume of good quality data on POPs in core media and trends over time has increased in all regions and is available from a number of data repositories and publications identified by the ROGs. However, given the limited information on trends of POPs in core media reported in the current report (see **Table 3**) coupled with the growing list of POPs, efforts should be made by ROGs to be more inclusive of other sources of peer-reviewed quality data (e.g., publications) for POPs in core-media that can inform the GMP and help to address these gaps. At the same time, the recognition of these data could support scientists and ongoing and useful activities.	The GMP guidance[24] and the criteria for including data to the GMP should be revised so that ROG members can tap into other sources of good and peer-reviewed data, as useful and peer-reviewed data sets for core media may be available from scientific experts in the field and could strengthen science-policy interface.

[21] UNEP/POPS/COP.10/INF/42.

[22] http://chm.pops.int/tabid/525.

[23] https://pops-gmp.org.

[24] UNEP/POPS/COP.10/INF/42.

4. Monitoring results

4.1 Ambient air

Key messages:

Most of the initial POPs were measured in air and showed declining trends. Presence of many of the initial POPs in air is believed to be linked with primary emissions from obsolete stockpiles and/or from combustion sources. Secondary emissions (re-volatilization from environmental reservoirs) could also be important for some of the POPs.

Regarding the new POPs detected in air, concentrations have either peaked or started to exhibit declining trends. However, many of the new POPs were not measured or detected in air due to analytical challenges.

Strategies for addressing the challenges associated with the increasing number of POPs include: establishing partnership with expert labs; optimizing sample collection and frequency of analysis of different POPs classes.

Global coverage of POPs monitoring in air continues to increase, largely attributed to adoption of passive air sampling methods. It is important to ensure sustainability of new air sampling programmes for successful future GMP.

Data on POPs in air is still limited in some areas such as Russia and sub-regions in Asia-Pacific.

Air measurement of water soluble and ionisable POPs such as PFOS and PFOA are limited and could be supplemented by including monitoring data for these chemicals in precipitation.

Although not currently in the scope of the GMP, topics such as urban sources of POPs, transformation products of POPs in air and consideration of the broader chemical mixture in air continue to gain importance. New analytical techniques such as non-target analysis, combined with *in silico* and toxicogenomic methods are important for revealing previously unknown hazards attributable to POPs, POP-like and POP-derived chemicals in air.

4.1.1 Introduction

Air was selected as a core medium for the GMP because it plays an important role in the transport of POPs and it is a medium that responds relatively quickly to changes in emissions reflecting control measures (i.e., the concentrations in air could quickly increase or decrease responding to changes in emissions). By making measurements in air at a global scale and over time, it is possible to obtain information on the long-range environmental transport (LRET) of POPs and monitoring data that reveal temporal trends.

The presence of POPs in air is complex and reflects numerous contributions that may have their own temporal behavior. These include changes in primary emissions (e.g., due to control strategies on POPs), changes in secondary emissions (e.g., re-volatilization from soil or water of previously emitted and deposited chemicals), and various other confounding factors such as meteorology, climate and other changes to the environment.

This chapter on ambient air provides a global overview based on information reported in the third regional monitoring reports[25] submitted to the tenth meeting of the Conference of the Parties in 2022. These regional reports reflected progress made over the 6 years after the second global monitoring report submitted to the eighth meeting of the Conference of the Parties in 2017.[26]

New air monitoring activities, including high-volume sampling programmes and a large number of passive sampling stations implemented during the previous phase have accumulated enough data to contribute to temporal trend information on POPs. Such an effort has significantly improved the spatial coverage of temporal trends.

4.1.2 Overview

The following summaries reflect the current status of: (i) availability of air monitoring data for POPs, (ii) progress in addressing data gaps, and (iii) availability and status of temporal trend data for POPs. In addition, the summaries cover specific issues and visual highlights for each region. Error! Reference source not found. shows air monitoring sites which contributed to the current report.

Global temporal trend of gamma-HCH (lindane) concentrations based on both high-volume and passive sampling-based air monitoring programmes is shown in **Figure 5**. The results of gamma-HCH reflect the level of data availability for a POP listed after 2009 that is abundant in air and has well established analytical methods.

[25] UNEP/POPS/COP.10/INF/41, http://chm.pops.int/tabid/525.

[26] UNEP/POPS/COP.8/INF/38.

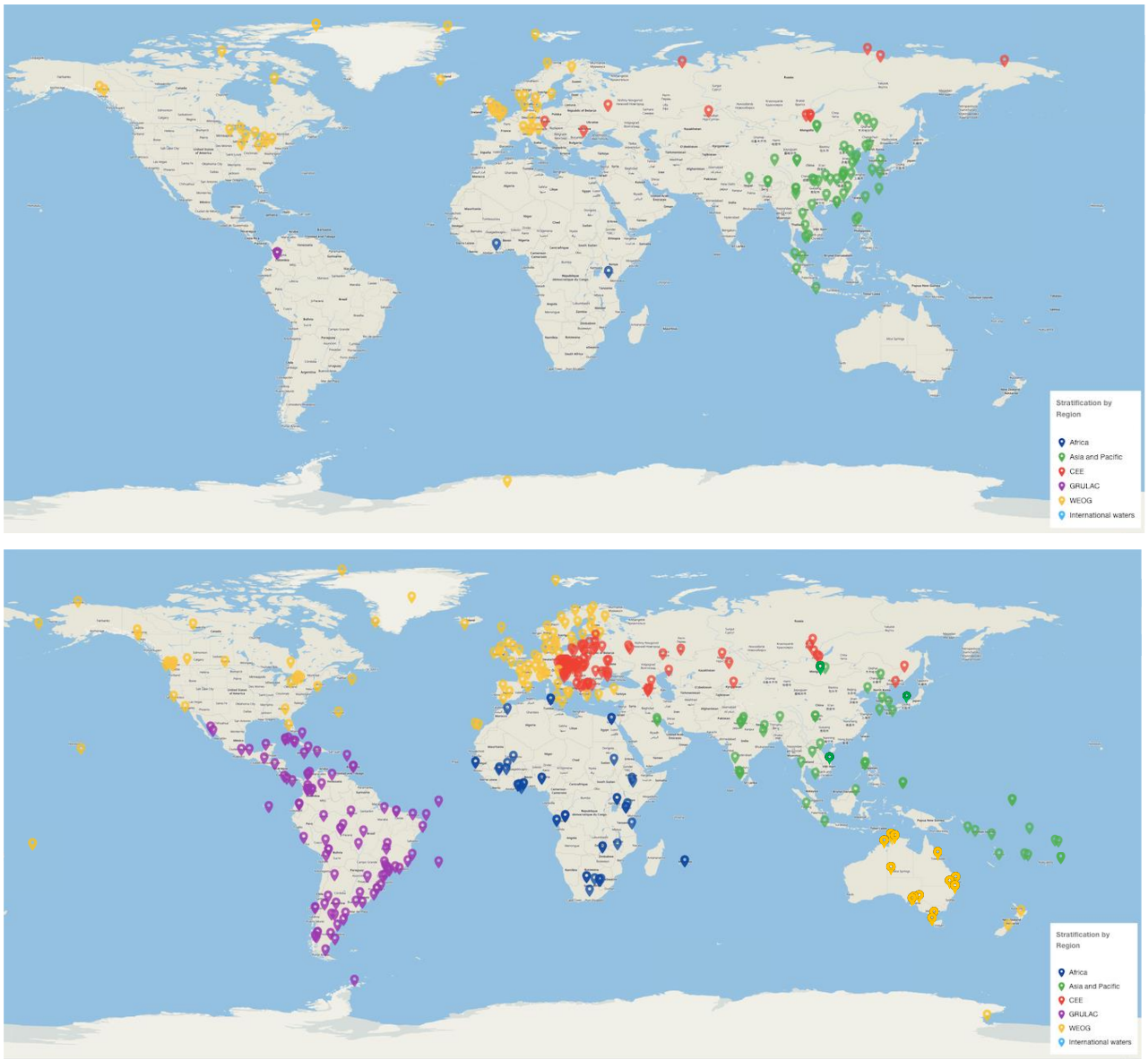


Figure 4. Air monitoring sites contributing data to the third GMP report.
(Upper panel: Air monitoring sites using active air sampling methods. Lower panel: Air monitoring sites using passive air sampling methods.)

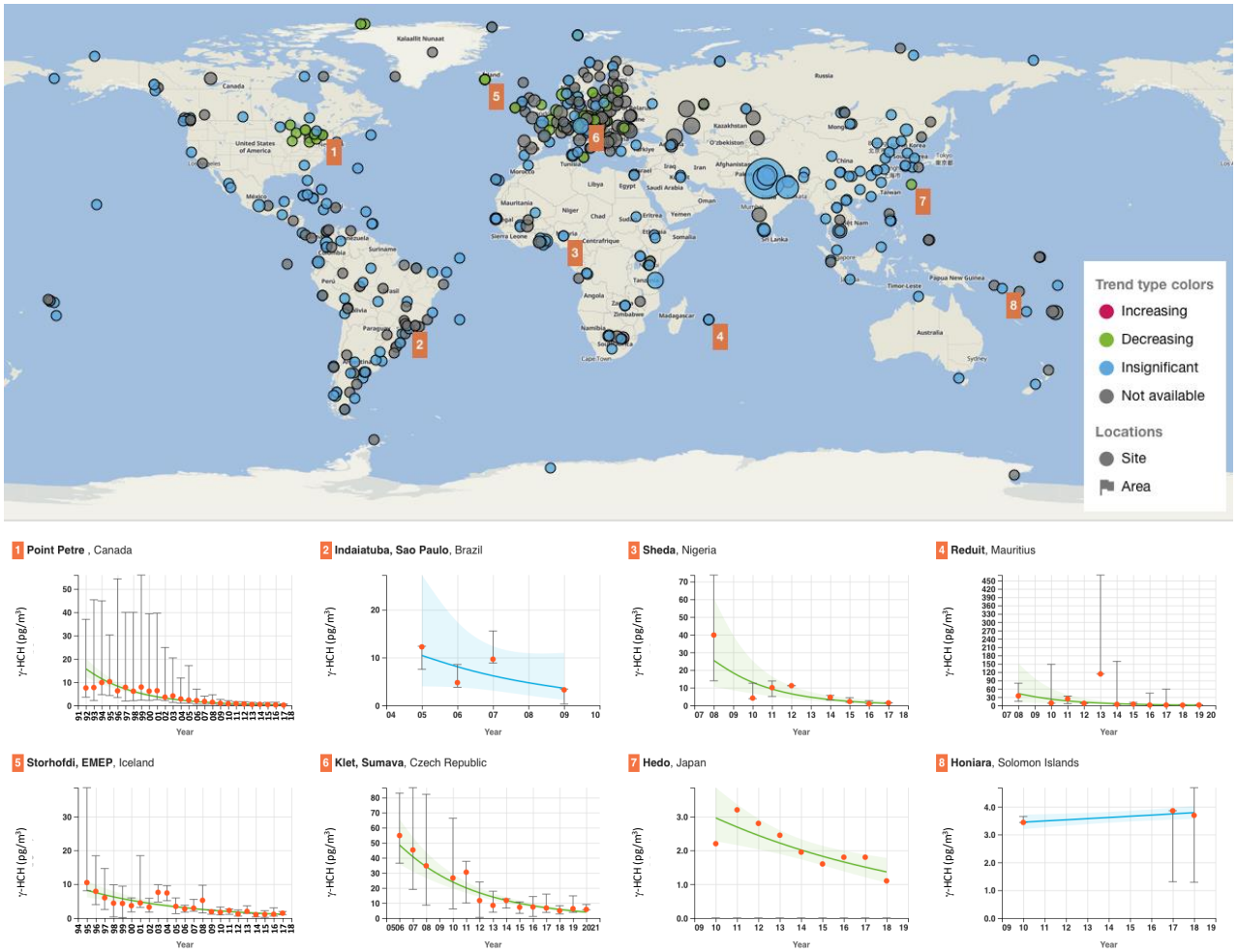


Figure 5. Global temporal trends of gamma-HCH (lindane) concentrations (pg/m^3) in air.
(Upper panel: All air monitoring sites reporting gamma-HCH air monitoring results. Colour of marker indicates the trends: ● increasing; ● decreasing; ● insignificant; ● not available. The diameter of the sampling site circle marker relates to the concentration level (mean) of gamma-HCH. Lower panel: Temporal trends of air concentrations measured at 8 sites correspond to the location flag numbers in the map in the upper panel.)

4.1.3 Information on air from regional monitoring reports

4.1.3.1 Africa

In Africa, air monitoring was primarily carried out using passive air sampling through the MONET-Africa, UNEP/GEF GMP projects and GAPS network; with two active air sampling sites in Kenya and Ghana operated under MONET-Africa. The African region consists of 6 sub-regions with 54 countries, in which air monitoring data were available from 19 countries.

Initial trends began to emerge for POPs levels in ambient air for sites that existed for over 10 years (see **Figure 6**). Pesticides (aldrin, endrin, oxychlordane, heptachlor, *p,p'*-DDD, endosulfan I, and gamma-HCH) showed at least 5% decline in air concentrations.

The high prevalence of pesticides in ambient air reinforces the need to strengthen management and control activities to reduce pesticide releases to the environment. Although these chemicals have been regulated in most countries, the management of contaminated sites and soils and treatment of obsolete stocks remain a top priority in the region. Countries are encouraged to adopt alternatives to regulated pesticides. Targeted research activities on alternative pesticides should be encouraged to reduce overreliance on POPs and minimize their releases.

PCB showed slower decline with only some congeners (PCB-28, 138, and 153) recording 2.08% decline in concentrations. Dioxin-like PCB (dl-PCB, including PCB-105, 118, and 156) started to decline by 1.44–4.17 %.

The presence of PCB in ambient air long after their ban could suggest releases from old transformers; evaporation from contaminated soils and combustion processes including incineration and open burning of wastes need to be controlled.

Few PCDD/PCDF showed emerging declining trends with percent reduction between 2.63–7.89%.

This suggests that there is a need to strengthen the regional capacity for adoption and integration of best available technique and best environmental practices in environmental management; management of municipal, industrial and medical wastes; and elimination of open burning of wastes and agricultural fields, in order to reduce releases of unintentional POPs such as PCDD/PCDF. Significant success in reduction of unintentionally released POPs depends on creating awareness among the general population to cease biomass burning and open burning of wastes.

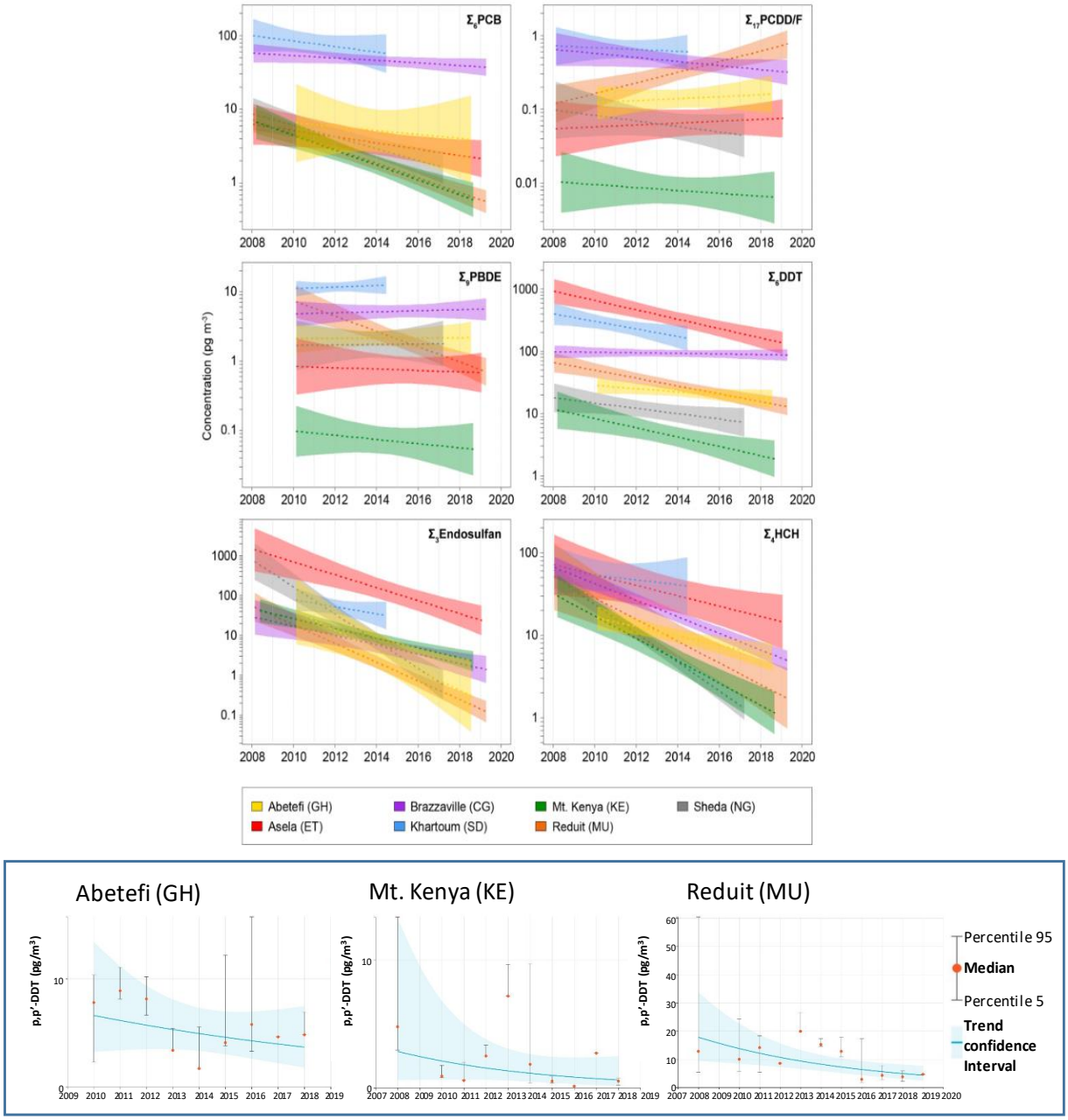


Figure 6. Temporal trends of DDT, endosulfan, HCH, PBDE, PCB, PCDD/PCDF concentrations (pg/m^3) in air in the African region.
(Upper panel: Temporal trends of DDT, endosulfan, HCH, PBDE, PCB, PCDD/PCDF concentrations in air measured at 7 sites in the African region. Adapted from White et al. 2021. Lower panel: Temporal trends of p,p'-DDT concentrations measured at 3 sites in the African region.)

For commercial chemicals, PBDEs recorded a percent decline between 0–3.45% for the congeners 28, 47, 99, 100, and 154, while no declining trends were established for BDE-17, 153 and 175/183. PFOS and PFOA did not show any significant trends in air concentrations.

The presence of PBDEs and PFAS in ambient air suggests active releases from the industrial activities, products and wastes. Countries should develop integrated waste management schemes to properly address the widespread sources of these chemicals and develop and implement national/regional plans for the environmentally sound management of wastes containing and/or consisting of PBDEs and PFOS.

4.1.3.2 Asia-Pacific

Air monitoring in Asia-Pacific was mainly conducted using active air sampling methods at background sites in POPs Monitoring Project in East Asian countries (POPsEA), and rural and urban sites in national monitoring in China and Japan. Passive air sampling methods were also used under the UNEP/GEF GMP II project in Asia-Pacific and GAPS network, including a few sites in the Asia-Pacific.

In the region, baseline concentrations and trend data were available in Japan, China and the Republic of Korea. Limited baseline and trend data were also available in East Asian countries under the POPsEA project, including Cambodia (2006, 2009, 2015), Indonesia (2005, 2006, 2012), Laos (2008, 2011, 2017), Malaysia (2008, 2010, 2017), Mongolia (2006, 2007, 2013), Philippines (2006, 2011), Thailand (2006, 2007, 2014) and Viet Nam (2005, 2006, 2009–2010 (13 times per month), 2012–2013 (4 times per 3 months)). Passive air sampling data under the UNEP/GEF GMP II project in the Asia-Pacific region would be useful as baseline data for future trend analysis in these sub-regions.

Background air monitoring data in the region showed generally decreasing trends of many POPs. Particularly evident was a continuous decrease of input of newly synthesized DDT in East Asia, which was also detected and reported in the second regional monitoring report.[27] The clear decreasing trends of DDT were observed in the two background monitoring sites, Hedo (Okinawa, Japan) (see **Figure 7**) and Gosan (Jeju, Republic of Korea), both of which conducted active sampling every month under the POPsEA project.

In addition to DDT, statistically significant decrease of other POPs, including oxychlordane and cis-heptachlor epoxide (Hedo and Gosan), HCHs (Hedo and Gosan), and BDE-47 and BDE-99 (Gosan) were observed. Furthermore, decreasing trends of PCDD/PCDF and dl-PCB as well as PCB were observed in national monitoring in China. Endosulfan levels also showed decreasing trends in Hong Kong Special Administrative Region (SAR) (China) and Fukue (second background site in Japan). Statistically significant decrease of some of chlordanes and heptachlors, including oxychlordane and cis-heptachlor epoxide, DDT, HCHs, tetraBDE, and PCB as well as PCDD/PCDF and dl-PCB were observed in the national monitoring in Japan. These monitoring data broadly supported the view that POPs emissions in the region was generally decreasing.

Both the initial POPs and the newly listed POPs were monitored in background sites (Hedo and Fukue), national monitoring programmes in China and Japan and in the UNEP/GEF GMP II project. The data on newly listed POPs would be useful as a basis for future trend analysis in the region. Continuation of background monitoring in the Asia-Pacific by both active and passive sampling, including Cambodia, Indonesia, Laos, Malaysia, Mongolia, Philippines, Thailand, Viet Nam, Fiji, Kiribati, Marshall Islands, Niue, Palau, Solomon Islands, Tuvalu and Vanuatu, would expand coverage of temporal trend data and provide a clearer view of temporal changes of POPs in the air in the region.

The national monitoring in Japan showed statistically significant decrease of PFOS in air as a whole. However, PFOS in air in Hedo (Japan) and in Hong Kong SAR (China) showed increasing tendency in recent years (not statistically significant). Hexachlorobutadiene (HCBD) levels in air in Hedo, Fukue, and national monitoring in Japan increased dramatically in recent years (see **Figure 8**). PeCB levels in Hedo and Gosan also showed a slight increasing tendency while the level in Fukue showed a decrease. PCB in Hedo and some isomers of chlordanes in Gosan showed statistically significant increase in recent years. Continuation of existing monitoring as well as expanding the network would clarify the meaning of these trends (whether they reflect LRET or local emissions) and provide a better understanding of the POPs emission and trends in the region.

Contrary to East Asia and the Pacific, data in South, West and Central Asia are limited or not available. Although the population in East Asia is around 1.6 billion, exceeding any of the other four regions, it covers less than a half of total population in Asia. It is indispensable to expand environmental monitoring activity to efficiently cover the remaining Asian sub-regions.

[27] UNEP/POPS/COP.10/INF/41, http://chm.pops.int/tabid/525.

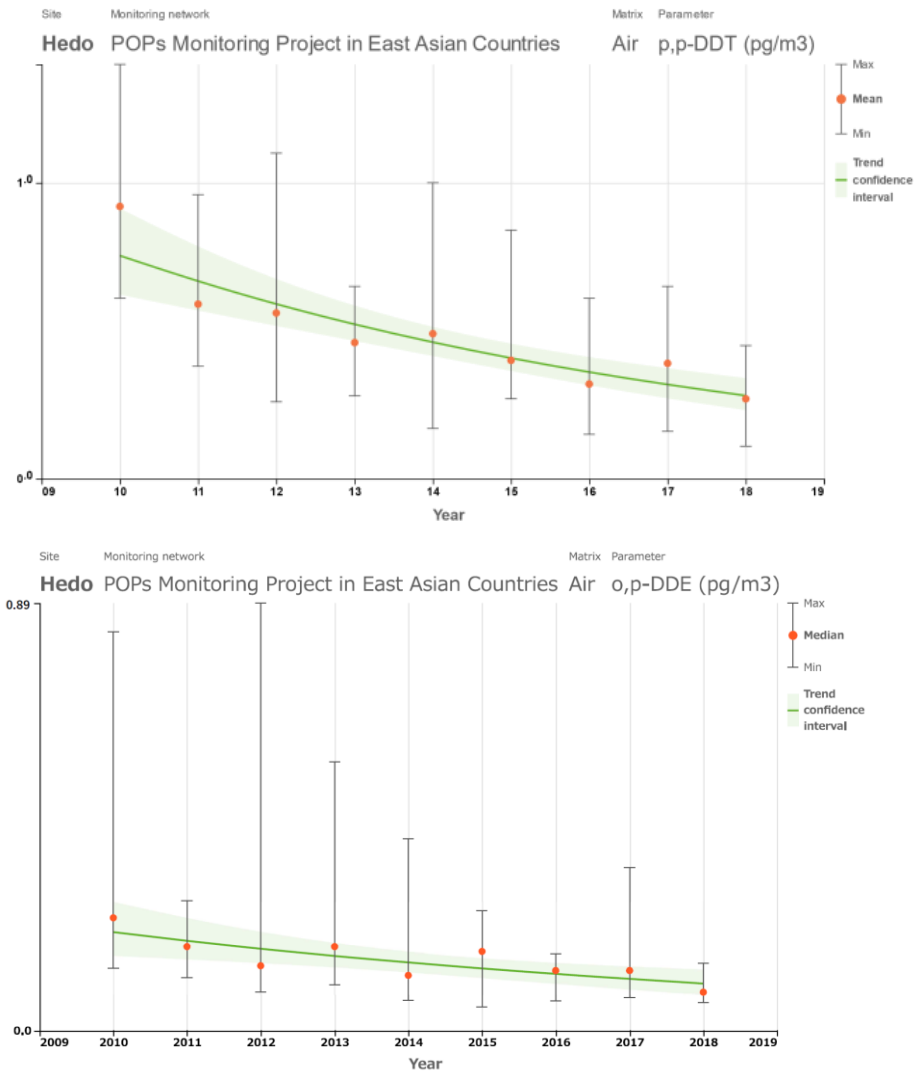


Figure 7. Temporal trends (2010–2018) of *p,p'*-DDT and *o,p'*-DDE concentrations (pg/m^3) in air measured at Hedo, Japan.

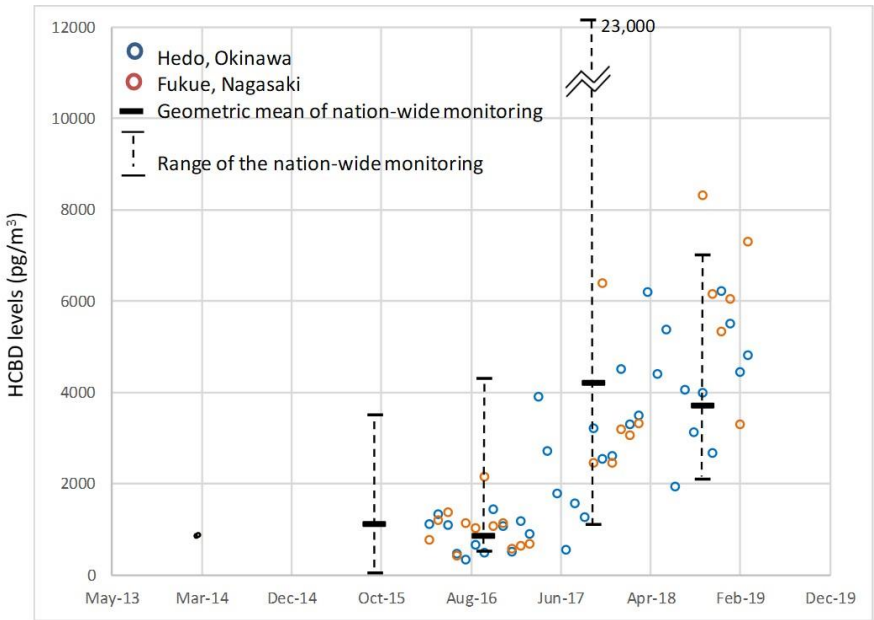


Figure 8. Temporal trends (2014–2019) of HCBD concentrations (pg/m^3) in air measured in the nation-wide monitoring and background monitoring sites in Japan.

4.1.3.3 Eastern Europe

In the EE, POPs air monitoring data were collected through integrated monitoring based on active air sampling over a period of almost 30 years representing the Central European background; and the MONET-Europe and GAPS network based on passive air sampling, providing a comprehensive set of data since 2006 and 2004, respectively. The longest time-series were available for the 6 indicator PCB, and PCB-118, DDT, HCHs, HCB and PeCB that range over 25 years (1996–2019). Air monitoring also included some of the new POPs (PBDEs, HBCD) and PCDD/PCDF. More volatile chemicals were not yet covered by passive sampling.

At least some POPs data in air currently exist in 21 countries out of 25. No information is available for Albania, Azerbaijan, Bosnia and Herzegovina, Georgia and limited information is available for the Russian Federation.

Air data are currently available for 21 chemicals. Available time-series of up to 16 years confirmed the decrease of the initial POPs and several newly listed POPs. Time series of 5–7 years-long exists for some of the new POPs. Otherwise, data indicated downward tendencies for newly listed brominated POPs (see example for BDE-47 in **Figure 9**). Where statistically significant trends could be observed, they were predominantly decreasing, with the exception of two dl-PCB congeners where increasing trends occurred. On the other hand, monitoring activities at some of the sampling sites have unfortunately been discontinued.

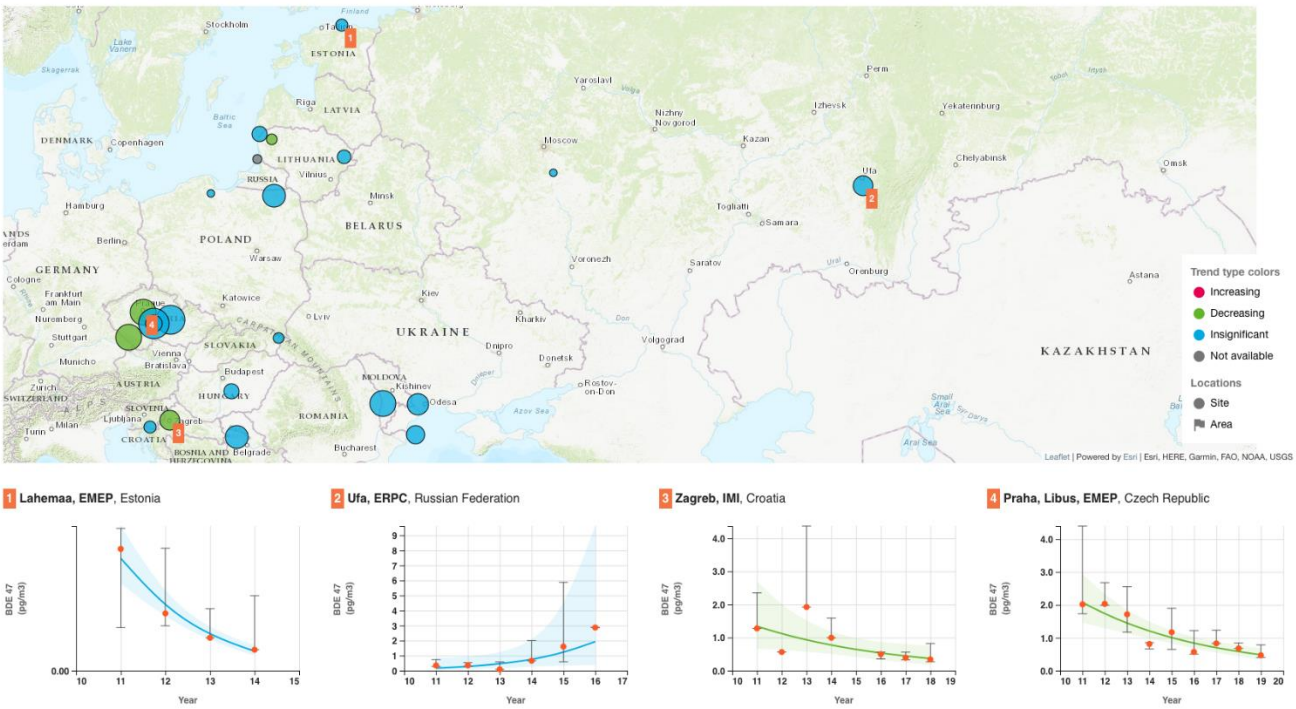


Figure 9. Temporal trends (2011–2019) of BDE-47 concentrations (pg/m^3) in ambient air measured at 19 MONET sites in the EE region.
(Upper panel: Colour of marker indicates the trends: ● increasing; ● decreasing; ● insignificant; ● not available. The diameter of the sampling site circle marker is related to the concentration level (mean) of BDE-47 measured at that site. Lower panel: Temporal trends in air concentrations measured at 4 sites corresponding to the location flag numbers on the map in the upper panel.)

4.1.3.4 Latin America and the Caribbean

Three air monitoring programmes, namely, UNEP/GFF GMP projects (2010–2012, 2016–2018), GAPS network (2004–2016) and LAPAN (2010–2016) conducted measurements in 19 countries, of which 9 monitoring sites were maintained to allow for assessment of concentration changes over time. Monitoring was mainly conducted using passive air sampling methods with one active air sampling site in Brazil under the UNEP/GFF GMP project.

There were great variations in both air concentrations and trends in the GRULAC region (see **Figure 10**). There was low recurrence in monitoring at many sites. Generally, the highest POP concentrations were measured at urban sites for all three programmes.

Under the UNEP/GFF GMP project, an increase in concentration was generally observed in 2013–2018 compared to 2004–2012 for the following: cyclodienes, DDT, dl-PCB, HCB, HCHs and PBDEs; and a decrease for the following: PCB, PCDD/PCDF. Baseline concentrations were measured for the first time for 13 POPs. During the period 2016–2018, PeCB was increased and polybromobiphenyls were generally not detectable.

The GAPS network found significant reduction in the concentrations of the following chemicals measured at urban and non-classified sites: cyclodienes, PCB, HCHs and BDE. The remote sites presented an increase in the following: cyclodienes, PCB and HCHs. Concentrations were higher in the period 2013–2016 compared to 2010–2012. Only aldrin, HCB and BDE-153 showed a decrease in concentrations in the three groups of sites.

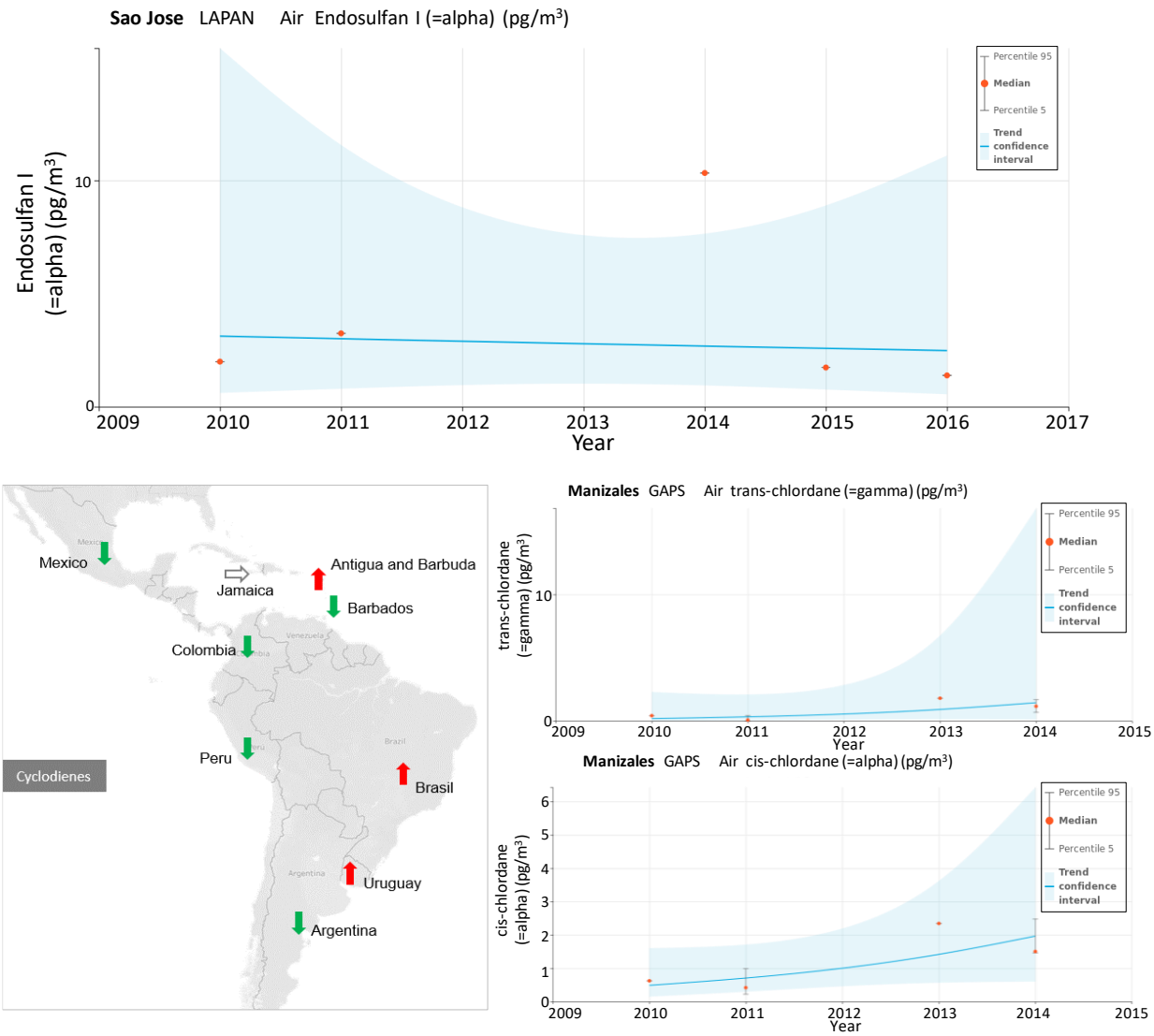


Figure 10. Temporal trends of endosulfan, cyclodienes and chlordane concentrations (pg/m³) in air in the GRULAC region.
(Upper panel: Temporal trends of endosulfan I concentrations in air measured at Sao Jose, Brazil, reported by the LAPAN Programme. Left lower panel: Temporal trends of cyclodiene concentrations in air. Red arrows: increase; Green arrows: decrease; White arrows: no change. Right lower panel: Temporal trends of trans- and cis-chlordane concentrations in air measured at Manizales, Colombia, reported by the GAPS network.)

4.1.3.5 Western European and Others Group

In the WEOG region, 15 national or regional long-term monitoring programmes contributed air monitoring data to the current GMP report, of which 9 programmes have collected more than 20 years of data (mostly using active sampling methods). Several passive air sampling programmes have now accumulated more than 10 years of data and have significantly increased the spatial coverage of temporal trend reporting in this region.

Temporal trends for some POPs are available at the global scale from the first 10 years of sampling under the GAPS network and show variable rates of decline with median half-lives ranging from 5 years to more than 20 years (e.g., endosulfan sulfate) (see **Figure 11**).

Temporal trends of some POPs (HBCD, SCCPs, PCP/PCA, HCBD, PeCB, and toxaphene) and air concentration data of HBB, chlordecone, dicofol and PFAS were lacking. This could be due to difficulties in chemical analysis, low or non-detectable concentrations in air, or sampling artefacts (e.g., breakthrough in active air sampling or high blank levels).

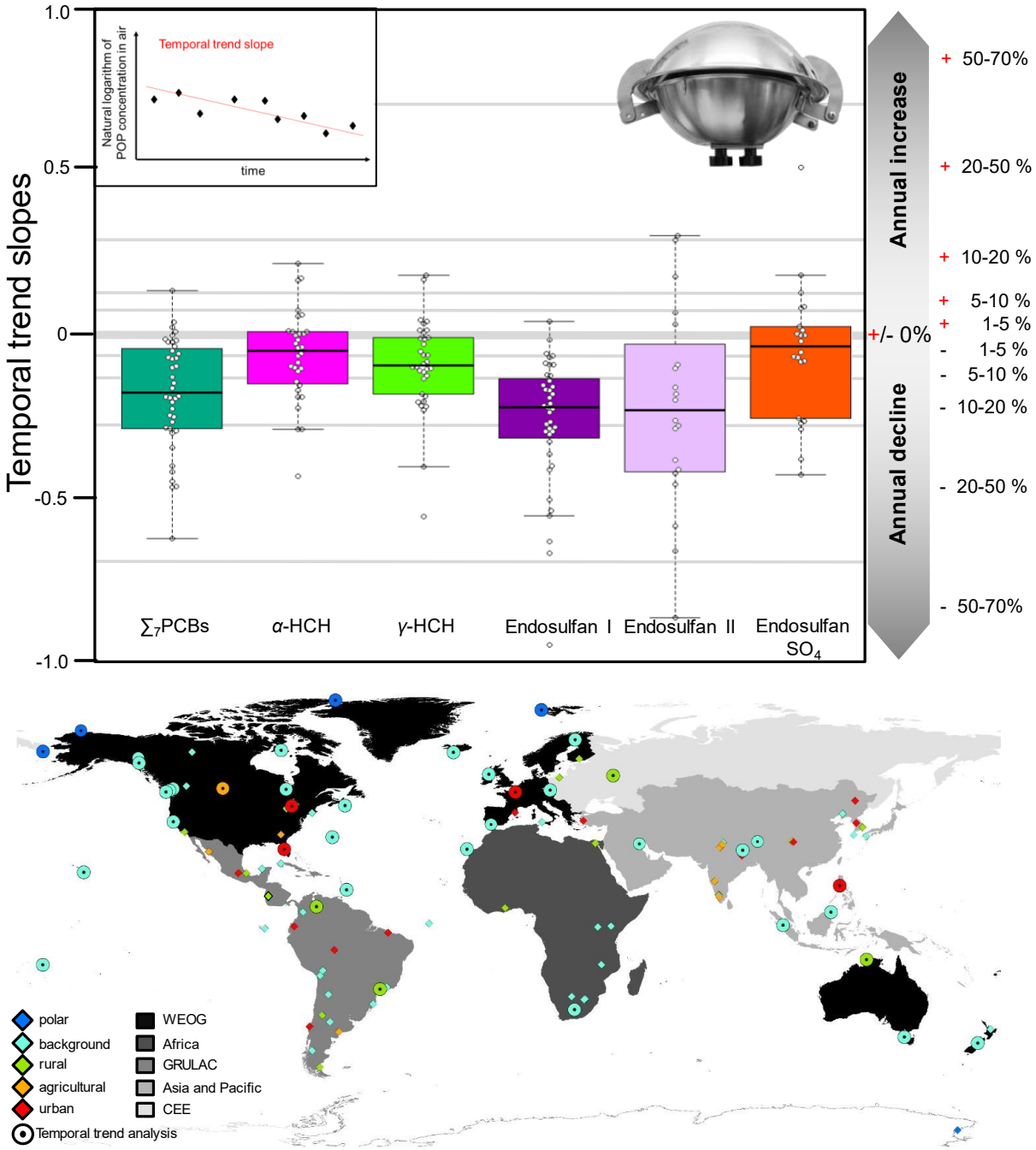


Figure 11. Temporal trend slopes and percent annual change (2005−2014) of ΣPCB7, alpha-HCH, gamma-HCH (lindane), endosulfan I, endosulfan II, and endosulfan sulfate concentrations in air by the GAPS network. *(The temporal trend slopes were estimated with Theil-Sen regression for the 40 GAPS network sites with sufficient data. Plot: single data points; Boxplots: median, 25th and 75th percentile; Whiskers: 10th and 90th percentile.)*

Most POPs that have been regulated for extended periods of time (>30 years), e.g., DDT, drins, PCB and chlordane were showing slower rates of decline or no further observable decreases in recent years, indicating that they were approaching steady state with other environmental media. Measurements at locations closer to urban centers indicated that primary sources of PCB stocked in cities (e.g., old transformers and electrical equipment and in waste streams) continued to contribute to measured air concentrations resulting in relatively slow decreases. Unintentionally released PCB (e.g., PCB in paints, combustion-related PCB) were found at some locations.

HCB showed slightly increasing trends at some Arctic, European and Antarctic stations which may be related to secondary emissions due to warming trends or associated with emissions as unintentional by-products from combustion, reflecting its high volatility and slow degradation in air. Accelerated decline of endosulfan was observed in air as its usage was phased out. PFOS, PFOA and their precursors were either showing accelerated declining trends or their concentrations have peaked (after earlier increasing trends) as a result of increased global restrictions of these chemicals.

In the last reporting period, PBDEs associated with the penta- and octaBDE commercial mixtures (i.e., tetra-, penta-, hexa- and heptaBDE) were not declining in North American air as was observed in Europe. Decreasing trends of these PBDEs were observed during this reporting period reflecting the effectiveness of the regulation of these commercial mixtures. On the other hand, decaBDE (BDE-209) was increasing or not changing in concentrations over time. This observation for BDE-209 likely reflects the fact that regulatory controls to restrict or reduce use and manufacture of decaBDE were not yet in place during this reporting period, while it continued to be used as a replacement for the penta- and octa-BDE mixtures, which were restricted earlier.

4.1.4 Summary

As the new monitoring efforts that have been implemented during the last reporting period (2009–2014), there was a significant improvement in the spatial coverage of air monitoring data and temporal trends of POPs in all five UN regions during the third phase of the GMP (2015–2020). **Table 5** below summarizes the global picture of availability of temporal trend information for the different POPs.

Table 5. Summary of temporal trends of POPs concentrations in air in the five UN regions.
Legends:

Generally decreasing trends
Generally increasing trends
No change, statistically insignificant trend, or cannot establish regional trend
No trend data

Chemical	Africa	Asia-Pacific	Eastern Europe	GRULAC	WEOG
Aldrin	Decrease at some sites (7.5%)	Not reliable due to poor recovery	Mostly decrease; 24 sites	Trends unclear; increase at UNEP/GEF project sites; decrease at LAPAN sites	Decrease
Chlordane	Decrease at some sites (2–4%); increase at some sites (2 %)	Decrease of oxychlordane in Hedo, Gosan, Japan Increase of some isomers in Gosan	Mostly decrease; 23 sites	Increase at UNEP/GEF GMP project sites and LAPAN sites; high levels at UNEP/GEF GMP project sites No change at GAPS sites	Decrease
Chlordecone	No data except for for 2 sites in 2014	Mostly below LOQ	No data	No data	No data
DDT	10-year trends	Decrease of levels and new input of DDT in Hedo, Gosan	Decrease in 5 countries; individual analytes increase (*o,p;*- DDT) at 4 sites; overall decreasing trend for sum parameters in 6 countries	Increase at UNEP/GEF GMP project sites and LAPAN sites	Decrease
Dicofol	No data	No data except for Japan in 2016	No data	No data	No data
Dieldrin	Decrease at some sites (2%)	Decrease in Fukue No trends in others	Mostly decrease; 23 sites	Decrease at GAPS sites Increase at UNEP/ GEF GMP projects sites and LAPAN sites; 10 times higher at UNEP/GEF GMP project sites	Decrease; no change at some sites
Endosulfan	Decrease at some sites (7%)	Decrease in Hong Kong SAR (China) and Fukue	Decreases for alpha endosulfan in 9 sites for 7 countries, beta	Unclear trends; decrease at GAPS	Decrease

Chemical	Africa	Asia-Pacific	Eastern Europe	GRULAC	WEOG
		No trends in others	endosulfan and endosulfan sulfate; data available only at 3 sites	sites; increase at LAPAN sites	
Endrin	Decrease at some sites (8%)	No trends	Mostly decrease; 21 sites	Unclear trends; increase at UNEP/GEF GMP project sites; decrease at LAPAN sites	Decrease; limited data
HBB	No trends	Not enough data (many below LOQ)	No data	No data	No data
HBCD	No trends	Not enough data (many below LOQ)	Data from 1 site; a baseline but below LOQ	Baseline data at GAPS sites	Few detections; decline at one site
HCB	No trends	No trends	Mostly decrease; other sites a baseline	Unclear trends; increase at UNEP/GEF GMP project sites; decrease at LAPAN sites	Slight increase at some polar sites
HCBD	No data	Dramatic increase after 2017 (Hedo, Fukue, Japan)	No data	Baseline data at GAPS sites	Decrease; limited data
Alpha-HCH	Decrease at some sites (6%)	Decrease in Hedo No trends in others	Decrease at 12 sites	Unclear trends; decrease at LAPAN sites; increase at UNEP/GEF GMP project sites for 2016–2018	Decrease
Beta-HCH	Decrease at some sites (4.6%)	Decrease in Hedo, Japan	Decrease at 6 sites	Increase at UNEP/GEF GMP project sites and LAPAN sites	No data
Gamma-HCH (Lindane)	Decrease at some sites (10%)	Decrease in Hedo, Japan	Decrease at 20 sites	Decrease at GAPS sites Increase at UNEP/GEF GMP project sites and LAPAN sites; 10 times higher values at UNEP/GEF GMP project sites	Decrease
Heptachlor	Decrease at some sites (9%)	Decrease of cis-heptachlor epoxide in Hedo, Fukue, Gosan, Japan	Decrease at 4 sites; downward tendencies at other 18 sites	Unclear trends; higher concentrations at UNEP/GEF GMP project sites	Unclear trends; decrease at some sites
Mirex	No trends	No trends	Information from 2 sites only; limited time span	Limited data from UNEP/GEF GMP project sites and LAPAN sites	No data
PBDEs	Decrease of some congeners at some sites (~3%)	Decrease of tetraBDE in Japan No trends in backgrounds (many below LOQ)	Decrease at 4 sites; downward tendencies at other 18 sites	Unclear trends; most congeners increased at UNEP/GEF GMP project sites during 2016–2018	Decrease; no change at some sites
BDE-209 (DecaBDE)	No trends	No trends	No data	Unclear trends; increase at LAPAN sites.	Unclear trends; increase at some sites
PCB	Decrease of some congeners at some sites	Decrease in Japan, China	Decrease at 14 sites; baseline well established	Decrease at UNEP/GEF GMP project and GAPS sites; much higher levels at UNEP/GEF GMP project sites	Mostly decrease

Chemical	Africa	Asia-Pacific	Eastern Europe	GRULAC	WEOG
		Increase in Hedo		Increase at LAPAN sites; dl-PCB (TEF) increase at UNEP/GEF GMP project sites	Increase in the Alps
PCDD/PCDF	Variable trends across sites	Decrease in China, Japan	Decrease at 4 sites; overall decreasing tendency at additional 15 sites	Unclear trends from UNEP/GEF GMP project sites; baseline data available at GAPS sites	Decrease
PCNs	No data	Limited data; too short period to develop trends	No data	No data	No data
PCP	No data	Limited data; too short period to develop trends	No data	No data	Limited data with no trends; reported as PCA
PFOA	Limited data at one site (2014, 2018)	No trends	No data	Baseline data available at GAPS sites	Decrease; limited data
PFOS	No trends	Decrease in Japan Increase in Hedo and Hong Kong SAR (China)	Baseline data available at 1 site	Baseline data available at GAPS sites	Decrease; limited data
PeCB	No trends	No clear trends	Decrease at 10 sites with a trend; statistically non-significant at 20 sites	Data available from UNEP/GEF GMP project, GAPS and LAPAN; increase at LAPAN sites; 10 times higher levels at UNEP/GEF GMP project sites	Decrease in the Alps
SCCPs	No data	Limited data; too short period to develop trends	No data	No data	No trend; limited data
Toxaphene	No data	Mostly below LOQ	No data	No data	No data

Notes: LOQ = level of quantification.

- Africa: Trends from data collected over 10 years are available for most POPs listed before and in 2009. Data primarily from passive air sampling under UNEP/GEF GMP project, GAPS and MONET-Africa. Limited data are available for the POPs listed after 2009. Air monitoring data are available from 19 out of 54 countries;
- Asia-Pacific: Longer term monitoring data are available in China, Japan and Korea. Baseline data are available in a limited number of other countries;
- Eastern Europe: Trends by active and passive sampling by international monitoring programmes EMEP, GAPS and MONET. Up to 30 years-long time-series and about 15 years from passive sampling. The air monitoring activities currently cover 21 countries out of 25 described in this report. Limited information for Russian Federation;
- GRULAC: Data are almost entirely from passive air sampling under UNEP/GEF GMP project, GAPS and LAPAN with good coverage of the region. Only one site (Brazil) reports active sampling data. Additional active air sampling sites are identified as a future need;
- WEOG: Long-term monitoring data are available for most POPs listed before and in 2009 from several active and passive sampling programmes. Newer POPs listed after 2009 are being reported by some existing programmes.

4.1.5 Main findings

Most of the initial POPs and several new POPs have shown continued declining trends or the trends have leveled off at most monitoring stations worldwide, with some exceptions that showed increasing trends:

(a) Increases in air for HCB and some PCB observed at a few locations in the WEOG region are possibly explained by re-emissions from environmental reservoirs due to warming trends or associated with emissions as unintentional by-products (e.g., from combustion or PCB in paints);

(b) Increased levels of several POPs were observed in many sites in the GRULAC region; however, reasons for these increases could not be explained;

(c) HCBD in the Asia-Pacific region showed dramatic increase at background sites of the national monitoring in Japan after spring in 2017 when it was listed in Annex C to the Convention.

Some of the newly listed POPs (e.g., endosulfan, c-pentaBDE, c-octaBDE) started to show declining trends, reflecting effectiveness of control measures. Other new POPs such as PFOS, PFOA and their precursors showed declining trends, or their concentrations have peaked (after earlier increasing trends) possibly as a result of increased global restrictions of these chemicals.

Long-term monitoring data are available for most of the initial POPs through active air sampling programmes that predated the Stockholm Convention (e.g., AMAP, EMEP, Northern Contaminants Programme (NCP), the Integrated Atmospheric Deposition Network (IADN), the Great Lakes Basin Monitoring and Surveillance Program (GLB), and the national monitoring in Japan). Based on the recommendation of the second GMP report in 2015,[28] the GRULAC region has implemented an air monitoring in Brazil as part of the UNEP/GEF GMP II project which has collected data for the period of 2016–2018. Baseline air monitoring data have become available in several East Asian countries through one-time measurements using active air samplers under the POPsEA project. Some new programmes have started to report temporal trends, including Jeju Island (Republic of Korea), Fukue (Japan) and Hedo (Japan).

4.1.6 Conclusions and recommendations

Conclusions	Recommendations
Further to the UNEP/GEF GMP II project, the global coverage of air monitoring data and temporal trends has been expanded and capacities for POPs monitoring have been strengthened in all regions. These improvements are largely attributed to adoption of passive sampling techniques, the development of successful partnerships with existing passive monitoring programmes such as the GAPS network, MONET, LAPAN and through the implementation of the two rounds of UNEP/GEF GMP projects and Strategic Approach to International Chemicals Management (SAICM) projects.	Continue passive air sampling and capacity building in a sustainable manner to enhance information on temporal trends and to improve spatial coverage. Ensure the continuity of new sampling programmes and activities to make available long-term measurement data for the assessment of temporal trends. Continue air monitoring using active and passive samplers according to QA/QC protocols to ensure data consistency.
For most of the initial POPs, concentrations in air have declined and continue to decline or remain at low levels thanks to restrictions on POPs that predated the Stockholm Convention. Primary emissions are believed to be the main driver for POPs levels in air. For some chemicals, e.g., pesticides, PCB, PBDEs, PFOS, PFOA and their precursors, emissions seem to continue from obsolete stockpiles, continued use of products and waste disposal/dismantling/recycling practices. Open burning of wastes and biomass continue to release unintentional POPs to the atmosphere.	Better waste management practices, management of contaminated sites, elimination of obsolete stockpiles and public education is needed to further reduce the emission of POPs related to commercial use, present in stockpiles and waste streams and unintentionally emitted via open burning.
Baseline and temporal data for PFOS and PFOA in air are limited as those chemicals tend to partition to water.	Future GMP should consider bridging this data gap with available long-term precipitation data and historical records found in ice cores which solely reflects atmospheric deposition over time.
Data on POPs are still limited in some areas (e.g., Russia and subregions of Asia-Pacific). The continuation of newly established passive sampling efforts to support the GMP in developing regions is uncertain over the long-term.	Regional strategies for POPs monitoring using passive and active air sampling should be developed in all regions through regional commitment and expertise, as well as through consultation with established programmes, in order to better address data gaps and the long-term and growing needs of the Convention.
Air monitoring for newly listed POPs has continued and expanded in all regions. However, some of the new POPs (e.g., HCBD, PCP/PCA, PCNs, SCCPs, dicofol, HBB) have limited or no data due to analytical difficulties, low concentrations in air, lack of methodologies and resources in many labs, or sampling artefacts (e.g., breakthrough in active air sampling or high blank levels).	Air monitoring for newly listed POPs should be initiated or continued. Collaboration with expert laboratories with existing and recognised analytical methods for POPs in air should be enhanced. GMP guidance should be updated to further support such data gaps.
Data for toxaphene and mirex is limited likely due to limited past uses and low abundance in air, declining air	Regional experts should define monitoring priorities based on available resources and information on

[28] UNEP/POPS/COP/8/INF/38, http://chm.pops.int/tabid/525.

Conclusions	Recommendations
concentrations coupled with the low volatility and relatively high analytical costs. The priority for measuring those chemicals could be considered low.	concentrations in air and emissions, while considering the GMP guidance.[29]
In addition to the regional and global monitoring reports, international and global databases such as EBAS[30] and the GMP Data Warehouse[31] are important in compiling and making monitoring data accessible to international and national policy makers, modelers assessing fate and transport, and the public. These databases provide a long-term, publicly available data repository.	Databases should be maintained and updated to ensure data quality, consistency, data continuity, and ease of access. Improvements to compatibility among databases to facilitate data exchange and compilation is especially relevant to the GMP.
The increasing number of POPs continue to add pressure on monitoring programmes and analytical laboratories in terms of funding, resources and need for development of new sampling and analytical methodologies.	The next phase of GMP should include work to develop a monitoring strategy such that the long-term temporal trends of POPs can be assessed with a reduced sampling or analytical schedule. Archived air samples or extracts can be used to retrospectively analyze POPs to rebuild temporal trends when funding and resources become available in the future.[32]
There is growing awareness and relevance to the GMP of urban sources of POPs, consideration of chemical mixtures in air, and recognition of the importance of transformation products of POPs in air, which themselves can be POP-like and contribute to human and environmental exposure and effects (toxicity).	Monitoring programmes and studies on POPs should consider urban sources of POPs and employ high resolution analysis (non-target and suspect screening) to investigate chemical mixtures in air, including transformation products of POPs. Advances in *in-silico* approaches and assays for assessing toxicity should be explored as a complementary means for tracking the toxicity of entire air mixture of POPs and related POP-like chemicals in air. These new developments have implications beyond the scope of GMP but are important for understanding hazards and risks associated with POPs, which could inform regulation of chemicals and the effectiveness evaluation.

[29] UNEP/POPS/COP.10/INF/42.

[30] http://ebas.nilu.no/.

[31] https://pops-gmp.org.

[32] For example, the Australian monitoring programme, Passive Air XAD Monitoring and Archiving Network (PAXMAN), archived passive air samples over the period 2010–2020. The Government of Australia commissioned analysis of a subset of these samples for POPs, including PCB, PBDEs, PCNs, chlorinated paraffins and HBCD in samples spanning the years 2010–2020. These data are expected to be available in early 2022.

4.2 Human tissues (milk and blood)

Key messages:

Significant concentrations were detected for all POPs, except for aldrin, chlordecone and endrin. The concentrations measured varied by an order of magnitude.

The levels of initial POPs were decreasing over time in human milk and/or blood. The levels of PCDD/PCDF and PCB in human milk have fallen steadily from their earlier high levels, indicating that the measures implemented to reduce environmental releases combined with regulations and recommendations on food and changes in diet have led to declining levels of those chemicals in humans. For several organochlorine compounds, the results were low or below the limit of quantification. This indicates that restrictions and banning of production and use of those chemicals and measures taken to mitigate releases of and contamination with unintentional POPs were successful in reducing contamination and human exposure.

Some of the newly listed POPs showed an increase over time followed by a decrease. This was the case for brominated flame retardants such as PBDEs and HBCD and PFAS such as PFOS and PFOA, which could be attributed to adequate risk management measures for those chemicals.

On the other hand, increasing trends over time were observed for PFHxS in blood samples from the WEOG region and for HBCD in some countries from the EE region.

There are some initial biomonitoring data on SCCPs available under the UNEP/WHO Human Milk Survey. More monitoring data for SCCPs is necessary as the production and use of those chemicals are known to be high volume and information on human exposure is limited.

Trend information, particularly in human samples, plays a key role in the effectiveness evaluation. The current assessment shows that trend data for human samples are limited. Continuation of ongoing biomonitoring as well as expansion of long-term monitoring is therefore necessary.

Understanding the major exposure routes of POPs is important in order to reduce exposure and body burden of POPs. While foodstuffs (and water) are one of the major exposure routes of many of the POPs, house dusts are also important for some of the newly listed POPs. With the addition of new chemicals to the Convention, different exposure routes could be considered in the future design of monitoring for the GMP.

4.2.1 Human milk

4.2.1.1 The UNEP/WHO Human Milk Survey

(1) Introduction

Comprehensive human milk monitoring programmes have been initiated by WHO. Early WHO surveys were performed mainly in Europe and North America in 1987–1989 and 1992–1993 exclusively focusing on PCB, PCDD and PCDF. In 2001–2003, a larger global survey was implemented, covering the initial 12 POPs. Following the entry into force of the Stockholm Convention in 2004, WHO and UNEP started their collaboration, and three additional global surveys were completed in 2004–2007, 2008–2011 and 2012–2015. These studies significantly enlarged the geographical scope providing representative results for all regions of the globe. A follow-up survey started in 2016 is currently ongoing and covers 30 of the 31 POPs listed under the Stockholm Convention.

WHO has developed a protocol for sampling and sample preparation methodology for exposure studies of POPs (Malisch and Moy 2006; WHO 2007). This protocol forms the basis for the human milk component of the GMP (UNEP 2017). Results of the WHO/UNEP Human Milk Survey for PCDD, PCDF, PCB and DDT were evaluated with particular focus on benefit-risk evaluation of breastfeeding (van den Berg et al. 2017).

(2) Overview of results

<u>PCDD/PCDF, PCB, PCNs</u>

Concentrations of PCDD/PCDF and dl-PCB (reported as TEQ) were found at relatively similar levels worldwide, in both industrialized and less industrialized regions. While it is well-known that combustion and industrial processes are major sources of PCDD/PCDF and dl-PCB, equal attention should be given to relevant sources in less-industrialized areas, such as open burning or geophagy, and promote measures to reduce releases and exposures from such sources.

The range of concentrations of total TEQ in samples from 82 countries collected between 2000 and 2019 varied between 1.29 and 49 pg WHO-2005-TEQ/g, with a median of 7.24 pg/g (see **Figure 12**) (Malisch et al. in press, a). The highest median WHO-2005-TEQ concentrations were found in EE and WEOG with 12.0 pg/g and 10.3 pg/g, respectively. The widest variation was in Africa (range 1.29 to 49 pg/g). With median concentrations between 4 and 5

pg/g and maximum levels between 10 to 12 pg/g, the Pacific sub-region in the Asia-Pacific region and GRULAC were at the lower end of the distribution.

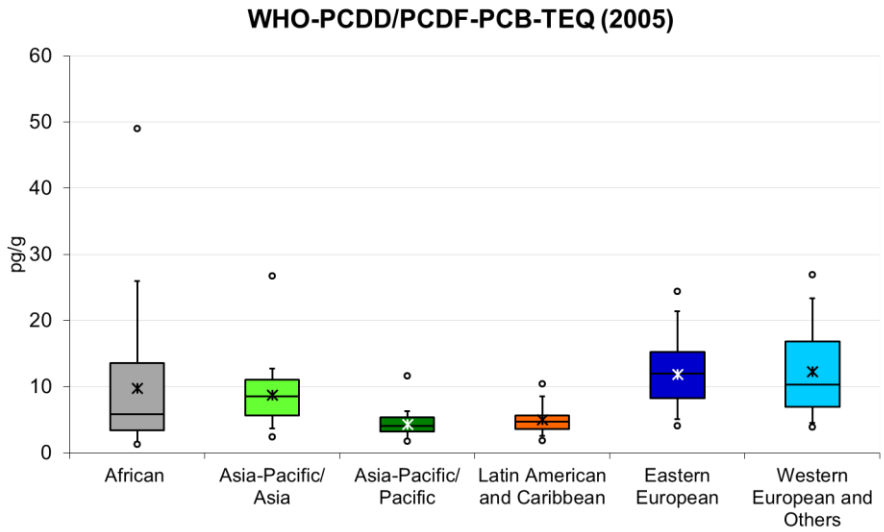


Figure 12. Median and range of WHO-PCDD/PCDF-TEQ concentrations (pg/g lipid) in human milk by region (2000–2019).
(Upper bound (n=232). Box plot: Minimum and maximum as circles; Whiskers: 5th and 95th percentile; Lower (25–50%) and upper (50–75%) quartiles separated by the line for the median as box and mean as asterisk. Source: Malisch et al. in press, a.)

EE and WEOG had a higher contribution of dl-PCB to the total TEQ than countries from other regions. While in European countries the contribution of the median of dl-PCB to the total TEQ was about 42%, in non-European countries this was about 30%.

The range of concentrations of the sum of 6 indicator PCB (ΣPCB_6) varied between approximately 1 and 1000 ng/g lipid, with a median of about 30 ng/g lipid (see **Figure 13**) (Malisch et al. in press, a). The highest concentrations were observed in EE (median of about 120 ng/g lipid and maximum of about 1000 ng/g lipid), followed by WEOG (median about 75 ng/g lipid, maximum 467 ng/g lipid). In the other regions, considerably lower PCB levels were found (with a maximum concentration below 100 ng/g lipid, and a median approximately between 8 and 22 ng/g). This supports the conclusion that PCB concentrations were considerably higher in Europe than in the other geographic regions.

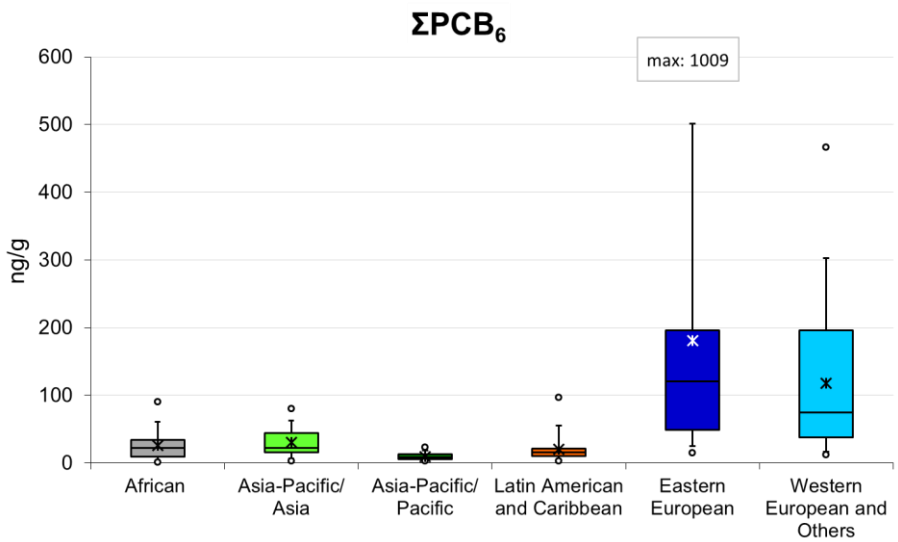


Figure 13. Median and range of ΣPCB_6 concentrations (ng/g lipid) in human milk by region (2000–2019).
(Upper bound (n=232). Box plot: Minimum and maximum as circles; Whiskers: 5th and 95th percentile; Lower (25–50%) and upper (50–75%) quartiles separated by the line for the median as box and mean as asterisk. Source: Malisch et al. in press, a.)

Over 20 years of biomonitoring under the UNEP/WHO Human Milk Survey, the median and range of total TEQ concentrations in the five rounds (2000–2003, 2004–2007, 2008–2011, 2012–2015, 2016–2019) went gradually down from initially 12.4 pg/g as median (range from 4.4 to 23.0) in the period 2000–2003 to 3.9 pg/g (range 1.3 to 11.6) in the period 2016–2019, a reduction of the median concentrations by 69% (Malisch et al. in press, a). However, the variation in regional participation in the survey over these periods also has to be considered (indicated by colored circles above the box plots in **Figure 14**). Whereas in the 2000–2003 period the majority of participating countries were from EE and WEOG, in the 2016–2019 round, the majority were from Africa, followed by GRULAC and Asia-Pacific.

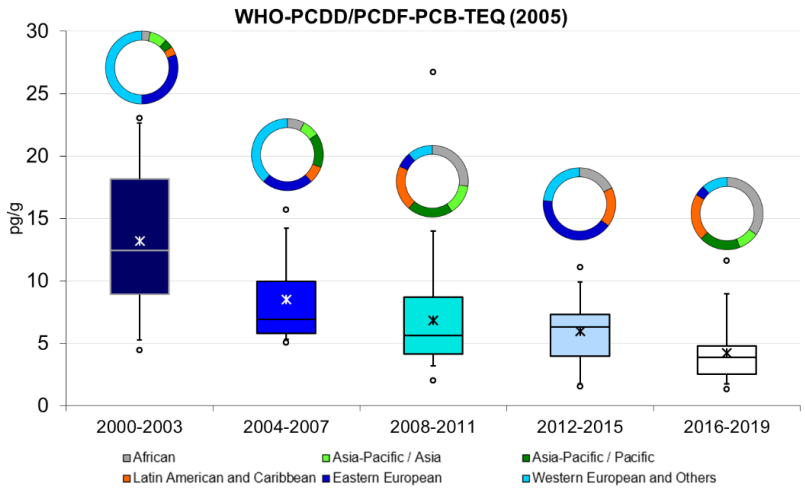


Figure 14. Median and range of WHO-PCDD/PCDF-TEQ concentrations (pg/g lipid) in human milk (5 rounds in 2000–2019).
(Country results with aggregated data. Box plot: Minimum and maximum as circles; Whiskers: 5th and 95th percentile; Lower (25–50%) and upper (50–75%) quartiles separated by the line for the median as box and mean as asterisk. Source: Malisch et al. in press, a.)

For the sum of the 6 indicator PCB (ΣPCB_6), the highest concentrations were likewise measured in the period 2000–2003 with a median 123 ng/g (range 16–502), followed by the period 2004–2007 with a median 49 ng/g (range from 10 to 376 ng/g). In comparison, the other three rounds had considerably lower concentrations: The 2008–2011 round had a median of 18 ng/g (range from 4–79 ng/g); the 2012–2015 round had a median of 24 ng/g (range 2–158 ng/g); the 2016–2019 round had a median of 13 ng/g (range 1–109 ng/g). Thus, a considerable downward trend from 2000–2003 to 2008–2011 was observed, with a reduction of about 85%; the subsequent rounds showed a leveling out. This finding has to be considered along with country participation pattern in the five rounds, whereas in the 2000–2003 period the majority of participants were from industrialized countries, with higher PCB concentrations (see **Figure 15**) (Malisch et al. in press, a).

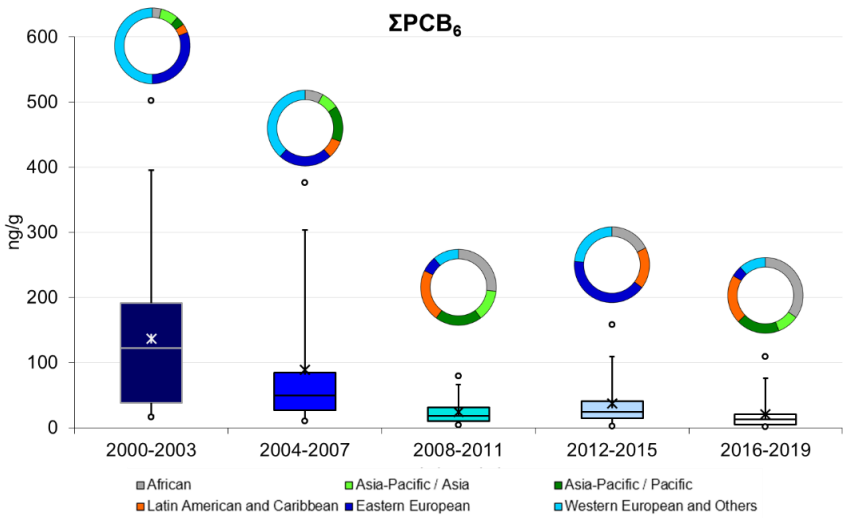


Figure 15. Median and range of ΣPCB_6 concentrations (ng/g lipid) in human milk (5 rounds in 2000–2019).

(Country results with aggregated data. Box plot: Minimum and maximum as circles; Whiskers: 5th and 95th percentile; Lower (25–50%) and upper (50–75%) quartiles separated by the line for the median as box and mean as asterisk. Source: Malisch et al. in press, a.)

Overall, global human milk data from the last two decades suggest that the concentrations of PCDD/PCDF and PCB have fallen steadily from their earlier high levels, indicating the effectiveness of measures implemented to reduce environmental releases (see **Figure 16**). The higher levels observed before or in the early 2000 have been successfully mitigated, showing that the measures implemented to address releases of and contamination with PCDD/PCDF and PCB have been, and continue to be, successful in achieving their objectives to reduce contamination and human exposure.

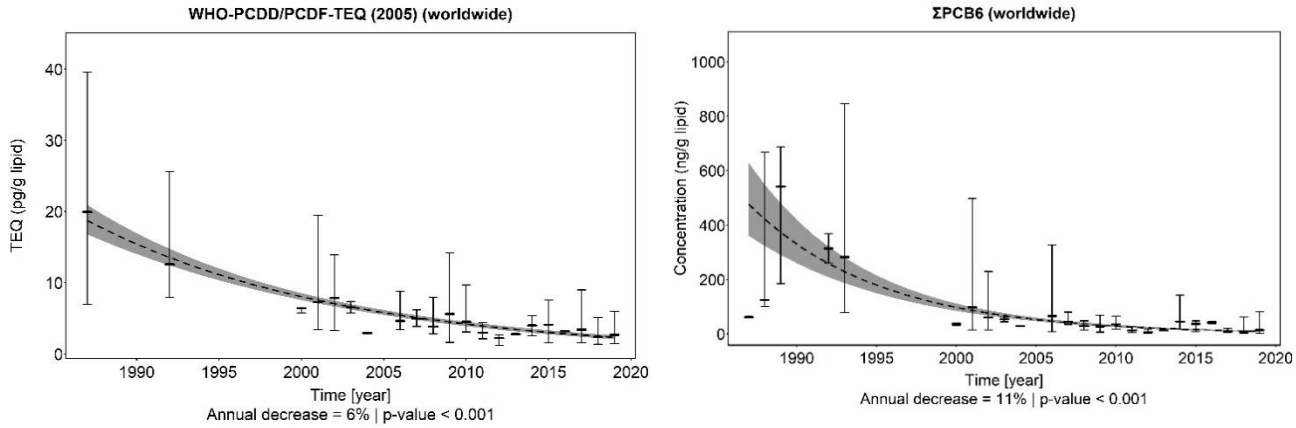


Figure 16. Global Theil-Sen exponential trends of WHO-PCDD/PCDF-TEQ concentrations (pg/g lipid) (left) and ΣPCB_6 concentrations (ng/g lipid) in human milk.
(Source: Malisch et al. 2021 as cited in the Third Global Monitoring Report)

Levels of PCNs in human milk were determined for the first time in the round 2016–2019 in 40 pooled human milk samples from 39 countries (covering all UN regions). The outcome represents a baseline. The median concentration of the sum of 26 PCNs was 55 pg/g lipid (range 27–170 pg/g). Human milk from European countries showed considerably higher levels than those found in countries in Africa, Asia-Pacific and Latin America and the Caribbean. The most abundant congeners were PCNs 52/60 and PCNs 66/67, and to a lesser extent PCNs 28/36, PCN 42, PCN 46, PCN 48, PCN 59 and PCN 69 (Tschiggfrei et al. in press).

Organochlorine pesticides

A detailed global analysis of results obtained under the UNEP/WHO Human Milk Survey since the early 2000s on OCPs can be found in Malisch et al. (in press, c). The following summarizes the findings pertaining to individual chemicals/classes of analytes.

DDT is found in human milk samples with a minimum of 17 µg DDT complex/kg lipid measured in one sample from 2019 and a maximum of 23,500 µg DDT complex/kg lipid in one sample from 2012; both minimum and maximum concentrations were measured in two countries in Africa (median of 134 country results: 255 µg DDT complex/kg lipid). Over the five rounds of the human milk survey, the median of the DDT complex concentrations of all country results showed a decrease of 72 % from the 2000–2003 period (median for 16 countries: 445 µg/kg lipid) to the 2016–2019 period (median for 43 countries: 125 µg/kg lipid). In all regions, the median of the DDT complex concentrations was higher in the 2000–2003 period than in the 2016–2019 period. The downward trend between these two end periods was observed in all regions, but differences among regions and variations in the three intermediate rounds were noted.

Due to metabolization of HCHs in humans, the concentrations of alpha-HCH and gamma-HCH were, in most human milk samples, below the limit of quantification (<0.5 µg/kg lipid) with a median of quantifiable residues of about 1 µg/kg lipid for alpha-HCH and gamma-HCH, and with maxima of 10.5 µg/kg for alpha-HCH and 16 µg/kg for gamma-HCH. In samples with sum of HCH isomer concentrations above 10 µg/kg lipid, 95-100% is due to beta-HCH, that mainly bioaccumulates in humans. Based on the median of the beta-HCH concentrations of all samples, a decrease of 91% was observed from the 2000–2003 period (median for 16 countries: 25.3 µg beta-HCH/kg lipid) to the 2016–2019 period (median for 43 countries: 2.4 µg beta-HCH/kg lipid).

Other OCPs and/or their metabolites were mostly found at low levels; some were below the limit of quantification for the analytes of interest. Aldrin was not detected in any sample (limit of quantification 0.5 µg/kg lipid; aldrin is rapidly metabolized to dieldrin). Dieldrin was found at low levels (below 5 µg/kg lipid) in most samples. Only four samples had dieldrin concentrations above 10 µg/kg with a maximum of 37.8 µg/kg lipid.

For the chlordane complex, determined as sum of cis- and trans-chlordane and oxychlordane, 23% of the samples analyzed had levels below the limit of quantification (0.5 µg/kg lipid), 61% in a low range below 5 µg chlordane complex/kg lipid and 16% of the samples analyzed between 5 and 17 µg chlordane complex/kg lipid. Nonachlor concentrations were below 5 µg nonachlor/kg lipid in most samples.

Endrin and its metabolite endrin ketone were not detected in any sample of the 2000–2019 period (limit of quantification 0.5 µg/kg lipid).

Heptachlor is rapidly metabolized to heptachlorepoxide. In about half of the samples, heptachlorepoxide was below the limit of quantification (0.5 µg/kg lipid). In most cases of quantifiable residues, cis-heptachlorepoxide was found with concentrations below 5 µg/kg lipid. Three samples were slightly above these low levels with a maximum of 14.1 µg cis-heptachlorepoxide/kg lipid.

Mirex was not detected in the majority (about 80%) of the samples (limit of quantification 0.5 µg/kg lipid); most of the remaining 20 % of samples had concentrations in the range up to 3 µg/kg lipid.

Toxaphene was found in a range between 0.5 and 5 µg toxaphene complex/kg lipid, calculated as sum of P26, P50 and P62. Chlordecone was not detected at all in the period 2016–2019 (limit of quantification 0.5 µg/kg lipid).

Most samples did not have quantifiable residues of endosulfan (limit of quantification 0.5 µg/kg lipid). Only two samples worldwide had small traces of about 1 µg endosulfan complex/kg, while one sample had 6.3 µg endosulfan complex/kg.

PCP could not be found in human milk samples; however, the metabolite PCA could be found. None of the samples collected over 2016–2019 had residues of PCP, only two samples had residues of PCA (limit of quantification 0.5 µg/kg lipid). One sample had traces of PCA (1.1 µg/kg lipid), and another sample had 33.3 µg/kg lipid. However, PCP can be detected in human blood (see **4.2.2 Human blood**).

Dicofol was detected in only one sample from 2016–2019 (limit of quantification 0.5 µg/kg lipid). The concentration was 3 µg/kg lipid. PeCB was found in only nine samples collected over 2008–2019 (limit of quantification 0.5 µg/kg lipid); traces between 0.5 µg/kg and 1.2 µg/kg lipid were found. HCBD was not detected in any of the 2016–2019 samples (limit of quantification 0.5 µg/kg lipid).

These results demonstrate that for most POPs, including some of the newly listed organochlorine compounds, the levels in human milk have generally fallen over the last 20 years with relatively higher levels seen only in a limited number of cases. For several of the organochlorine compounds, the results were low or below the limit of quantification.

Brominated flame retardants

The levels of listed brominated flame retardants were determined in pooled human milk samples between 2000 and 2019. Large differences in levels were found in PBDEs. The concentration of the sum of 6 PBDEs congeners ($\sum PBDE_6$) ranged between 0.3 and 352 ng/g lipid (median 1.6 ng/g lipid). The highest concentrations were detected in WEOG (including Australia, Israel, New Zealand and USA) in 2003. Temporal trends were assessed for 36 countries with repeated participation. Decreasing tendencies were observed in nearly all countries.

DecaBDE (BDE-209) was analyzed in the 2016–2019 round. BDE-209 contributed on average 13% to $\sum PBDE_6$. The contribution of octaBDE (BDE-197) and nonaBDEs (BDE-206, BDE-207 and BDE-208) to the sum of 25 PBDEs was in the range of the six recommended analytes and BDE-209. Therefore, their addition to the list of recommended analytes should be considered.

The hexabromocyclododecane was analyzed in samples between 2006-2019. Observed levels for alpha-HBCD ranged between < 0.1 and 15 ng/g lipid (median: 0.5 ng/g lipid). Beta-HBCD and gamma-HBCD were mostly below the limit of quantification (LOQ for 90% of the samples: < 0.1 ng/g lipid) or around the LOQ (max: 0.8 ng/g lipid). Thus, it can be concluded that alpha-HBCD is the predominant stereoisomer in human milk.

Hexabromobiphenyl (PBB 153) was found below the limit of quantification (0.5 ng/g lipid) in 96 % of analyzed samples. If analyzed, low concentrations between 1.0 ng/g lipid and 1.7 ng/g lipid were found.

Per- and polyfluoroalkyl substances

PFOA and PFOS have been detected with a frequency of 100% and 92%, respectively (Fiedler et al. 2022). Correlation between PFOA and PFOS was only moderate (r=0.58). Whereas median values were almost identical (18.9 pg/g f.w. for PFOS; 18.6 pg/g f.w. for PFOA), PFOS showed larger ranges (<6.2–212 pg/g f.w.) than PFOA (<6.2–63.4 pg/g f.w.). The range of concentrations for PFOS is slightly larger than for PFOA. The highest mean and median values of PFOS, PFOA, and PFHxS are found in the intermediate survey round (2010–2014), showing an increase over time followed by a decrease (see **Figure 17**) (Fiedler et al. 2022).

The rising and then decreasing trend could indicate that the risk management measures for those newly listed POPs were taken later than for the initial POPs. It should be noted that there are different countries participating in different years.

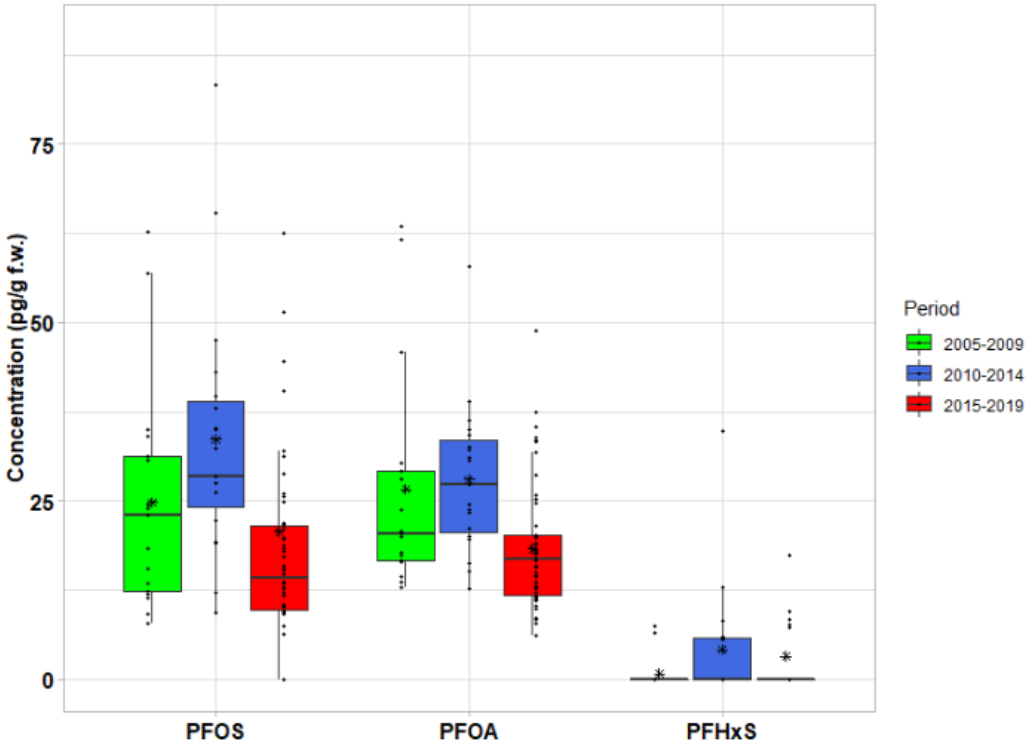


Figure 17. Median and range of PFOS, PFOA and PFHxS concentrations (pg/g fresh weight) in human milk (n=86) from the UNEP/WHO Human Milk Survey in 2005–2009, 2010–2014, 2015–2019.
(Source: Fiedler et al. 2022.)

Short-chained chlorinated paraffines

For SCCPs, baseline data have become available from the last round of the survey (2016–2019); the median of the concentrations in all samples was of 48 ng/g lipid, with a minimum of 10.5 ng/g lipid and a maximum 188 ng/g lipid; upper range concentrations were found in Asia-Pacific (see **Figure 18**).

SCCPs accounted for 0.8–50% of the total POPs concentration expressed as ng/g lipid in the individual pooled samples (Krätschmer et al. 2021). Overall, the four analyte groups contributing most to total POPs concentrations in human milk were SCCPs, MCCPs, DDT and PCB. DDT accounted for the largest proportion of POPs in every region, although concentrations vary to a large extent within and among geographic areas (Krätschmer et al. 2021).

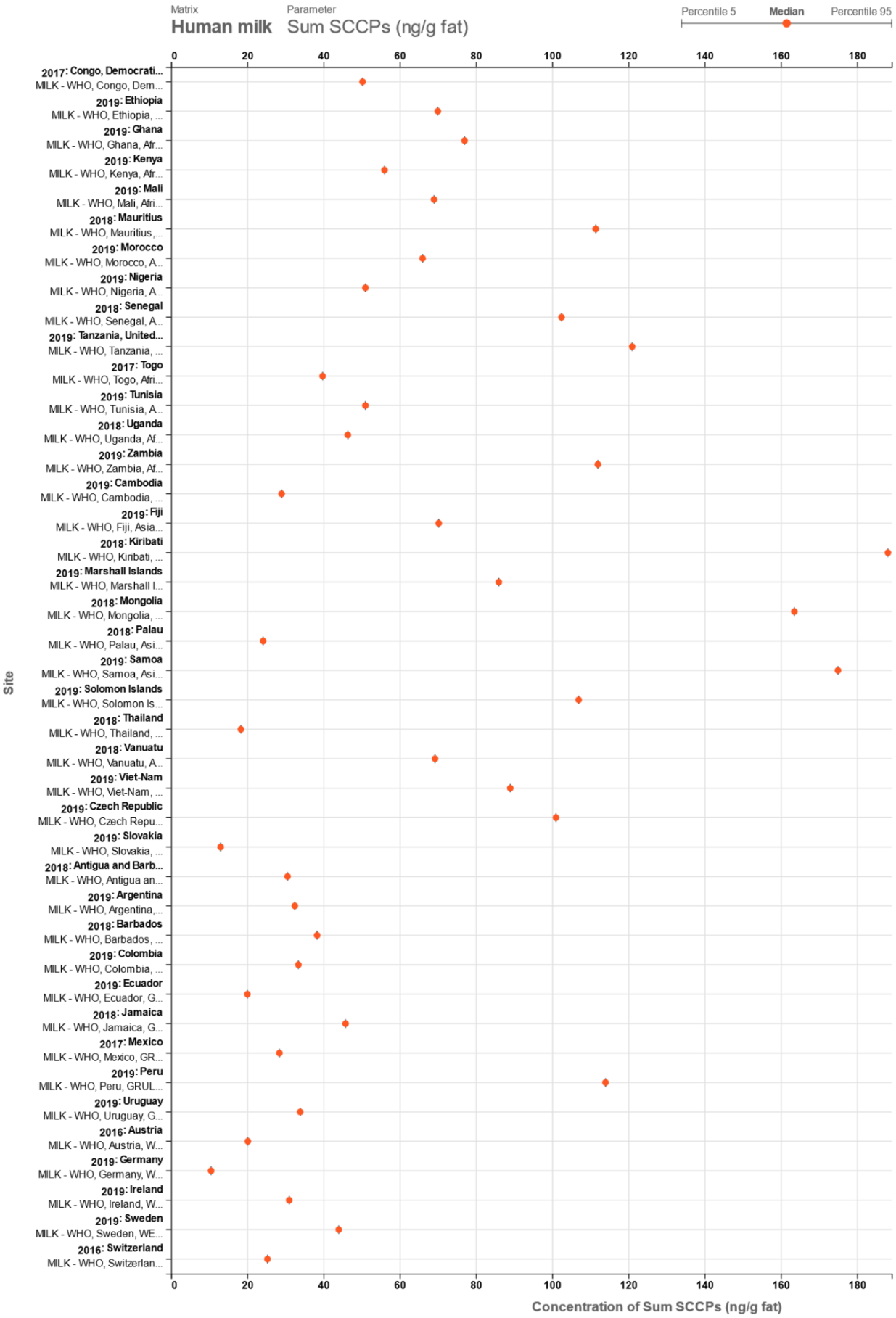


Figure 18. Short-chain chlorinated paraffins (ΣSCCPs) concentrations (ng/g fat) in human milk (2016–2019).

4.2.1.2 Regional and national human milk monitoring

(1) Introduction

At the regional and national levels, a number of programmes generated human milk data for trend assessment. Further detailed information is available in the third regional monitoring reports.[33]

(2) Overview of results

PCDD/PCDF, PCB, PCNs

In Asia-Pacific, Fiji and Kiribati participated in four and three rounds of the UNEP/WHO Human Milk Survey, respectively, and showed gradual decrease of both PCDD/PCDF and dl-PCB as well as indicator PCB (ΣPCB_6). Several countries also participate the survey once or twice, and these data, together with national monitoring data submitted from China, will be basis for future trend analysis. Japanese data on PCDD, PCDF and dl-PCB in human milk during 1998–2015 as well as those in blood in 2002–2016 surveys also showed steady decrease (see **Figure 19**). These trends are consistent with the decrease of dioxins in Japanese foodstuffs (see **4.4 Other media**).

In a long-term monitoring in milk of primipara mothers in Osaka, Japan during 1972–2008, PCB showed nearly an order of decrease during the period (Second regional monitoring report for Asia-Pacific,[34] Table E.2-1, annex E).

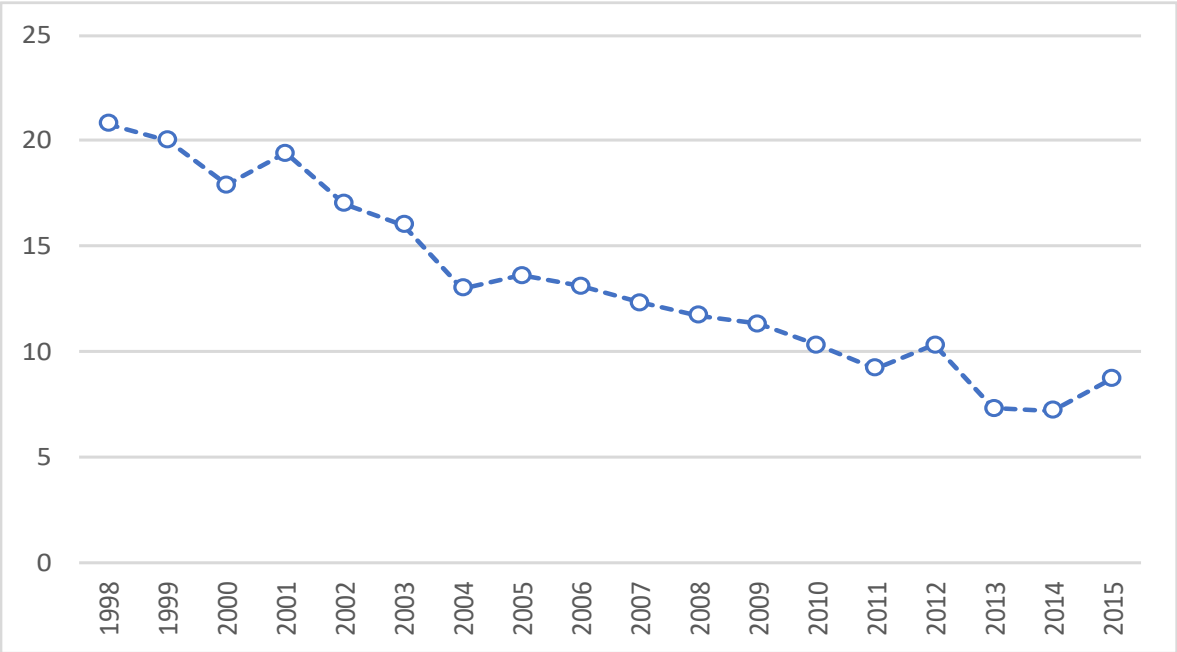


Figure 19. Temporal trend (1998–2015) of dioxin concentrations (pg TEQ/g fat) in human milk in Japan. *(Averages of each year's data are plotted. Dioxins: sum of PCDD (7 isomers), PCDF (10 isomers) and dl-PCB (12 isomers). Source: Third regional monitoring report for Asia-Pacific.)*

In WEOG, a total of 58 and 35 mean/median values for total TEQ were reported in WHO-TEQ-1998 and WHO-TEQ-2005, respectively. The median/mean values ranged from 0.0065–0.10 ng/g lw (WHO-TEQ-1998) and 0.0063–0.072 ng/g lw (WHO-TEQ-2005). When examining regional differences in concentrations, Europe exhibits slightly higher concentrations than North America and Australasia during the sampling period. A decreasing trend can be observed for total TEQ, during the sampling period 1972–2010 (see **Figure 20**).

[33] http://chm.pops.int/tabid/525.

[34] UNEP/POPS/COP.7/INF/38, http://chm.pops.int/tabid/525

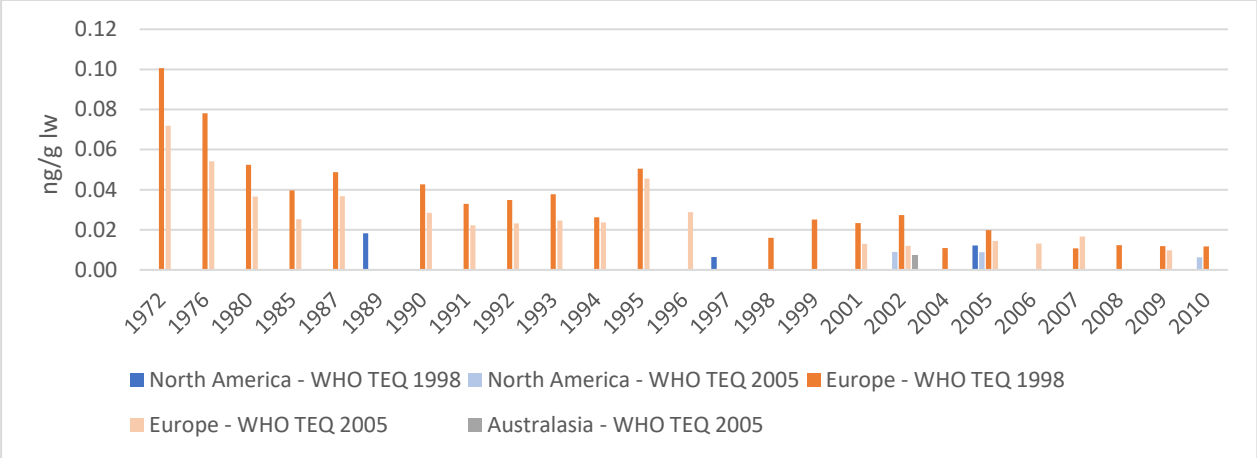


Figure 20. Temporal trend (1972–2010) of total TEQ concentrations (ng/g lipid weight) in human milk in North America, Europe and Australasia.

Trend information in the EE region for PCB is available. Decreasing trends were observed in several countries in the region as shown in **Figure 21**.

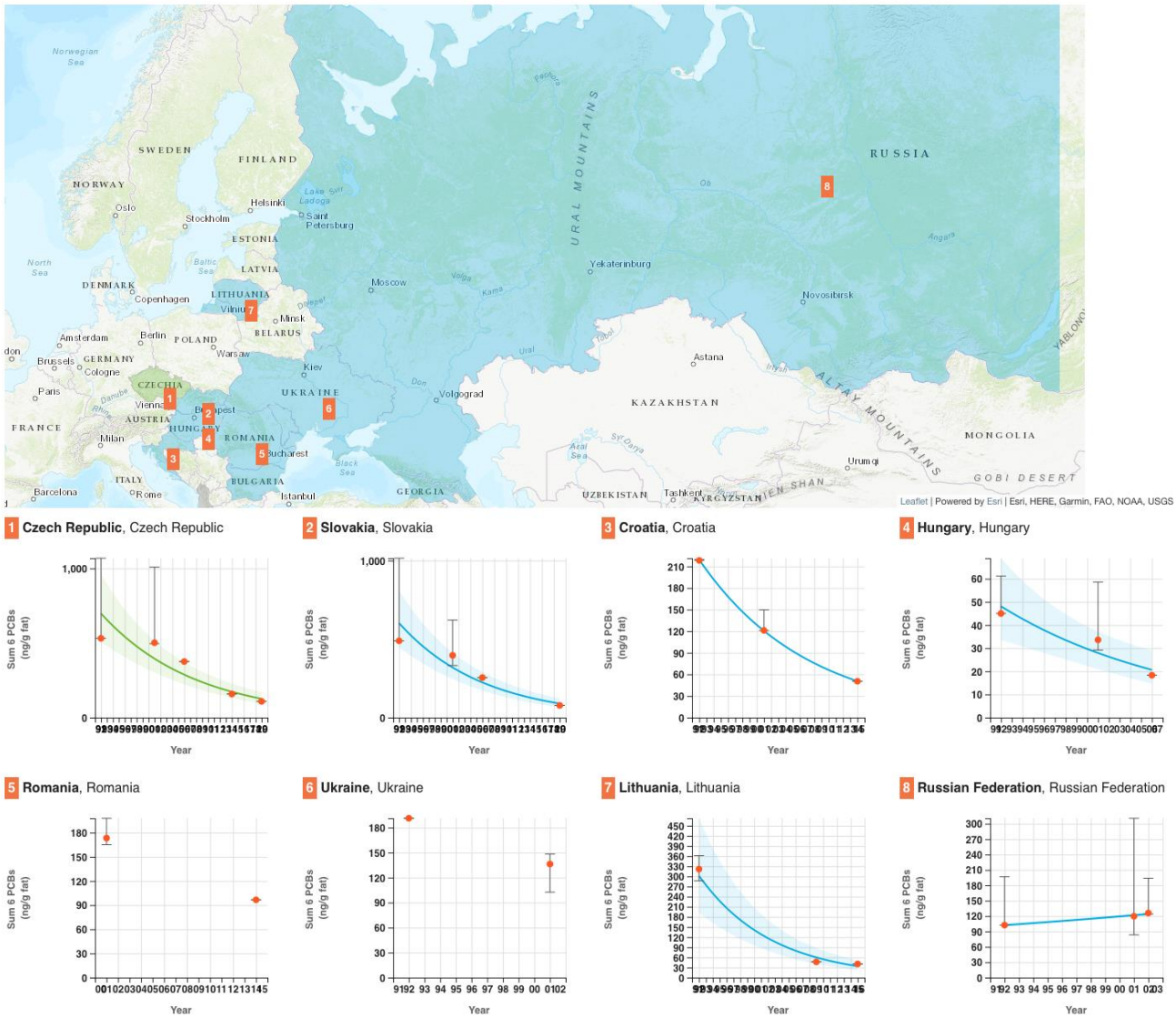


Figure 21. Temporal trend of PCB (6 congeners) concentrations (ng/g fat) in human milk in the EE region. *(Upper panel: Participating countries are shaded, and the colour of the shading represents the type of trend. Red: increasing; Green: decreasing; Blue: statistically insignificant; Grey: not available. Lower panel: The chart number correspond to the numbers on the map in the upper panel.)*

Organochlorine pesticides

Although there are many reported data on OCPs in human breast milk in Asia-Pacific, only limited trend information is available. In both Fiji and Kiribati, not only total DDT (ΣDDT_6) but also *p,p'*-DDT/ΣDDT_6 showed steady decrease, indicating decrease/stop of new input of DDT in these Pacific countries (see **Figure 22**).

Some other OCPs, such as chlordane, dieldrin as well as PBDEs also showed decreasing trends in the countries. It is noted that several POPs management programmes, including those supported by Australia and the UNEP/GEF GMP project were conducted in Pacific countries in the period. In Japanese monitoring on primipara mothers' milk, sum of DDT as well as beta-HCH and dieldrin showed one or more orders of decrease during 1972–2008 (dieldrin: 1973–2005). HCB also showed a decrease in the period while the sum of chlordane did not change so much during 1986–2008.

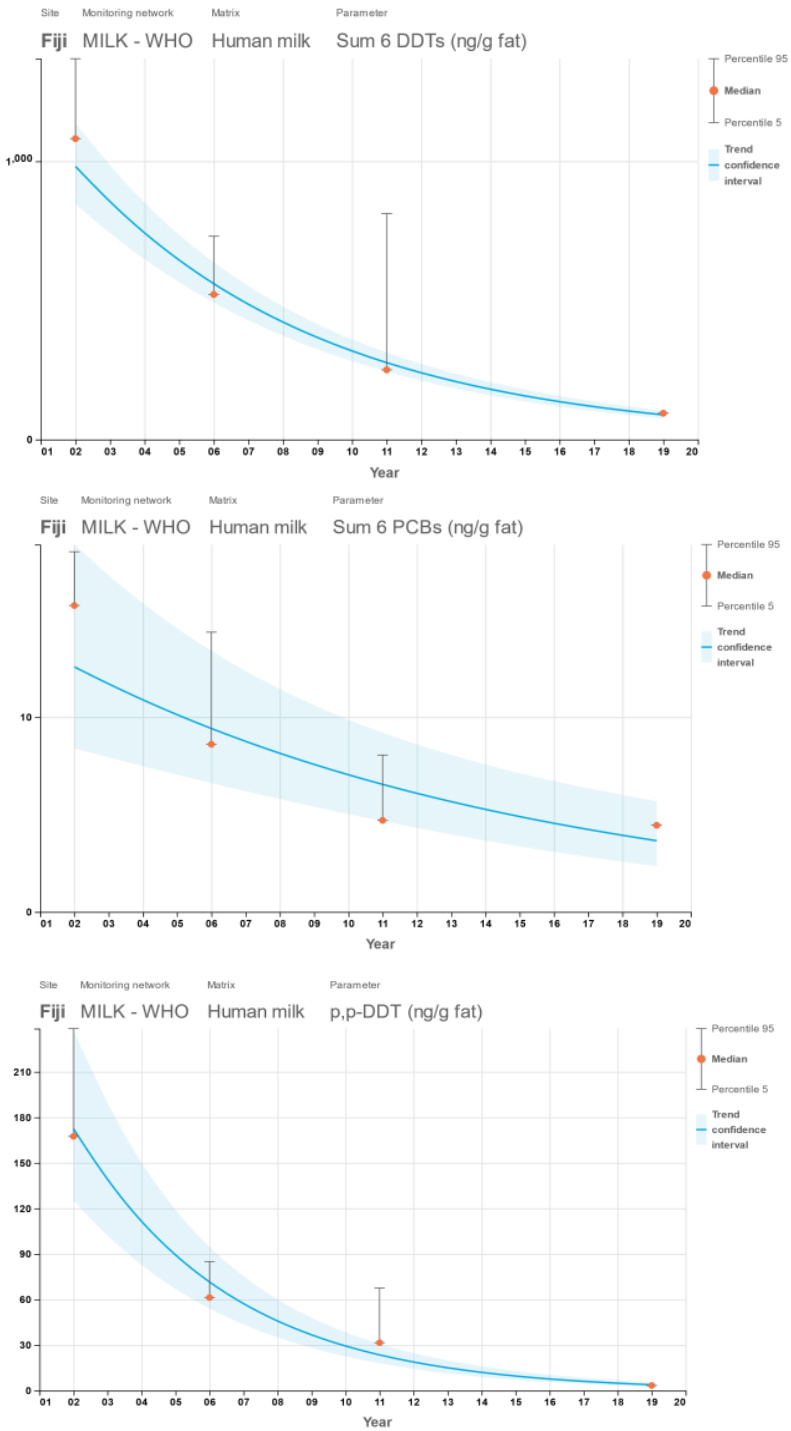


Figure 22. Temporal trend (2002–2019) of DDT (6 isomers), PCB (6 isomers), and *p,p'*-DDT concentrations (ng/g fat) in human milk in Fiji.
(Source: Third regional monitoring report for Asia-Pacific.)

Figure 23 illustrates regional trends of the DDT metabolite, *p,p'*-DDE, in human milk in WEOG. The trend is based on 170 reported mean/median values, out of which 45 values originate from the Swedish monitoring program, 112 values from scientific articles and 13 from UNEP/WHO survey.

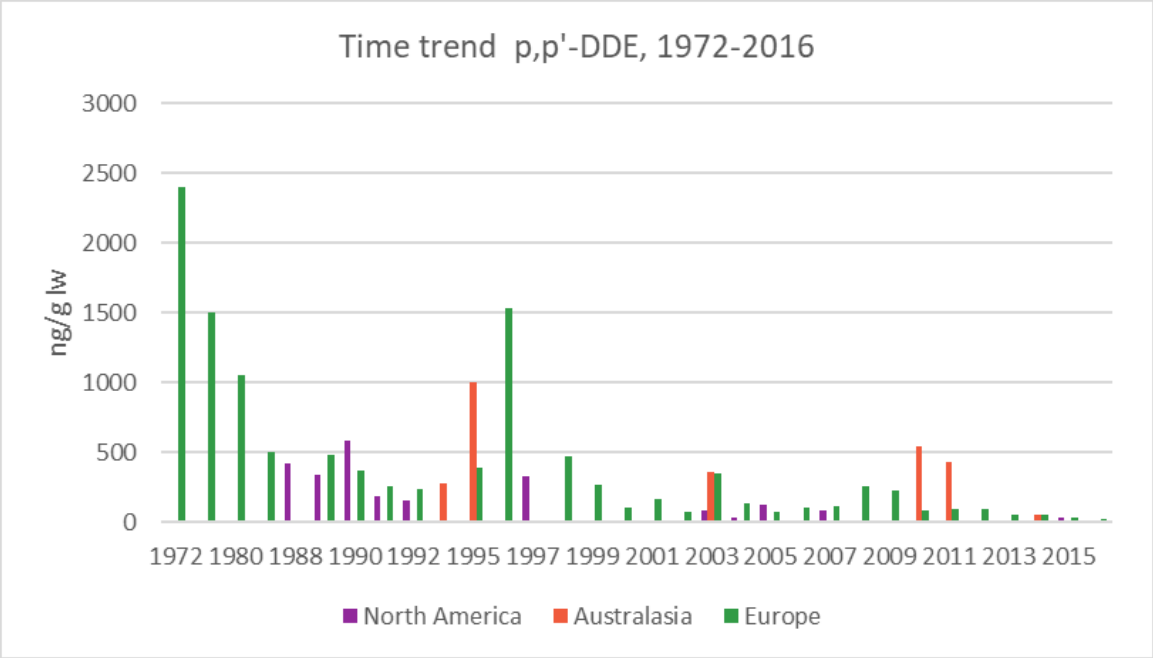


Figure 23. Temporal trend (1972–2016) of *p,p'*-DDE concentrations (ng/g lipid) in human milk in the WEOG region.
(Source: Third regional monitoring report for WEOG.)

Brominated flame retardants

In the Japanese primipara milk survey, clear increase of HBCD during 1970–2005 was shown (see **Figure 24**). As the programme ended in 2005, no further follow-up data was available.

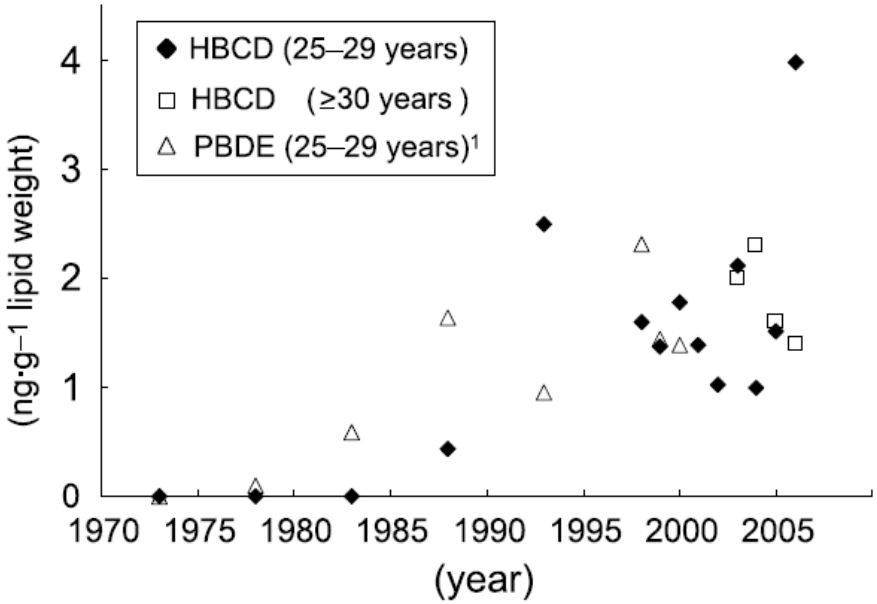


Figure 24. Temporal trend (1970–2005) of HBCD (25–29 year), HBCD (over 30 year), PBDE (25–29 years) concentrations (ng/g lipid) in human milk from primipara milk survey in Japan.
(Source: Second regional monitoring report for Asia-Pacific.)

In the EE region, a mild increase was observed prior to listing of PBDEs, followed by a decrease observed in subsequent survey rounds as shown in **Figure 25** (Schächtele et al. in press).

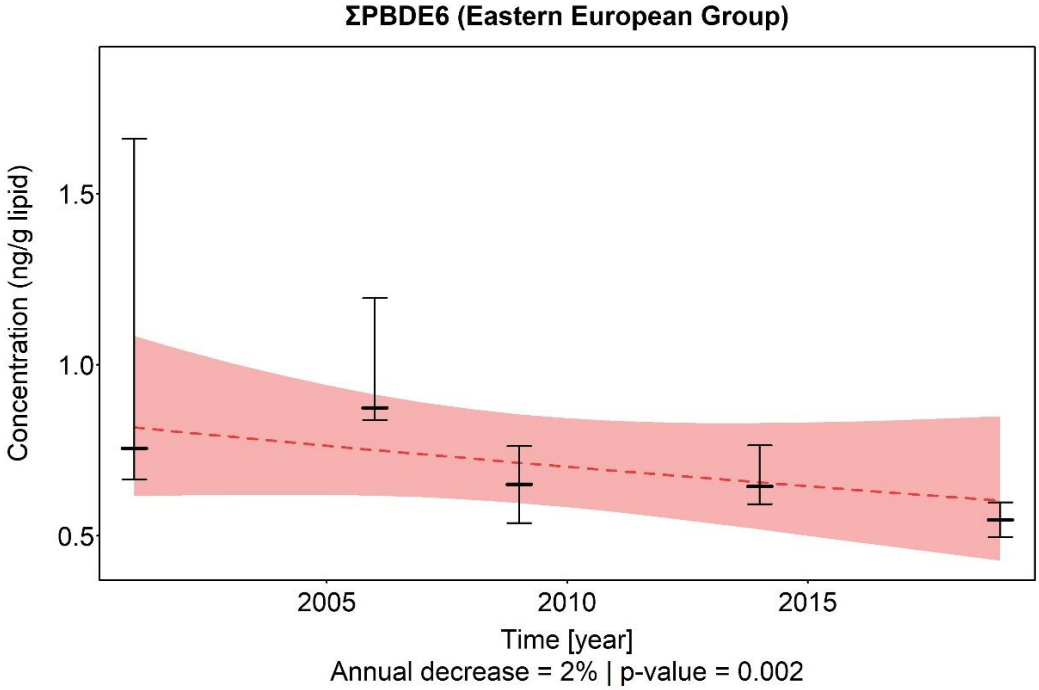


Figure 25. Theil-Sen exponential trends of ∑PBDE$_6$ concentration (ng/g lipid) in human milk in the EE region.
(Thick lines in the middle: Median; Whiskers: 5th and 95th percentiles. ∑PBDE$_6$ includes BDE-47, BDE-99, BDE-100, BDE-153, BDE-154, BDE-175/183. Source: Schächtele et al. in press.)

In WEOG, a trend of increasing HBCD concentrations in breast milk was observed for the period 1980–2014 in 13 countries, where the highest average of median value of HBCD in milk was in year 2007. After 2011, a decreasing trend was observed (see **Figure 26**).

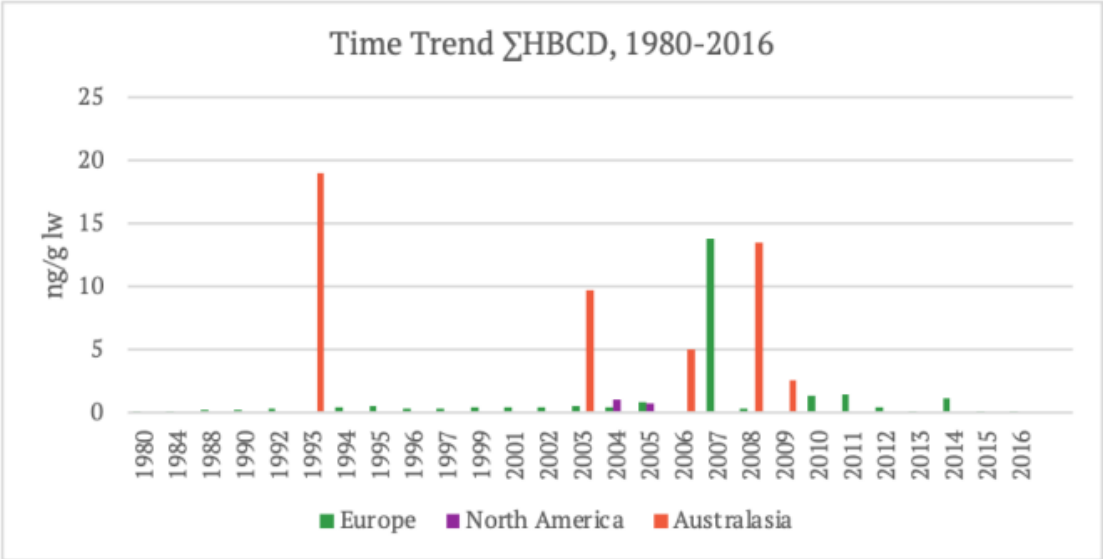


Figure 26. Temporal trend (1980–2016) of ∑HBCD concentrations (ng/g lipid) in human milk in the WEOG region.
(Temporal trend is based on 69 reported mean/median values, out of which 45 values originate from Swedish monitoring program and 24 values from scientific articles. Source: Third regional monitoring report for WEOG.)

4.2.2 Human blood

(1) Introduction

For some POPs, blood serum or plasma is an equally or more preferred matrix to measure POPs. Temporal trends for POPs in blood from national and regional monitoring programmes are summarized in the WEOG and Asia-Pacific regional monitoring reports.[35] In other regions, time-series information on POPs concentrations in blood is limited.

In WEOG, several countries e.g., Australia, Canada, Germany, Spain and Sweden, have national monitoring programmes for human exposure to POPs. Since the early 1990s, the the Arctic Monitoring and Assessment Program (AMAP) has been organizing a comprehensive human maternal blood plasma monitoring programme with standardized protocols for specimen collection and analysis in the Arctic region. Maternal blood plasma, supplemented with human milk data, has been used in assessing PCB and OCP levels and their impacts on human health. An international QA/QC programme for human maternal blood analysis has been developed through this monitoring programme (CTQ, Quebec, Canada).

In Asia-Pacific, POPs monitoring programmes on human blood are available. In Japan, a national monitoring programme on human blood is performed. The POPs concentrations in human blood in Japan are reported in the regional monitoring report.

(2) Overview of results

Organochlorine pesticides

Mirex showed a decreasing trend in blood over the period 1992–2015 in the WEOG region (see **Figure 27**). The high average value for Europe in 2007 mainly includes samples from Greenland.

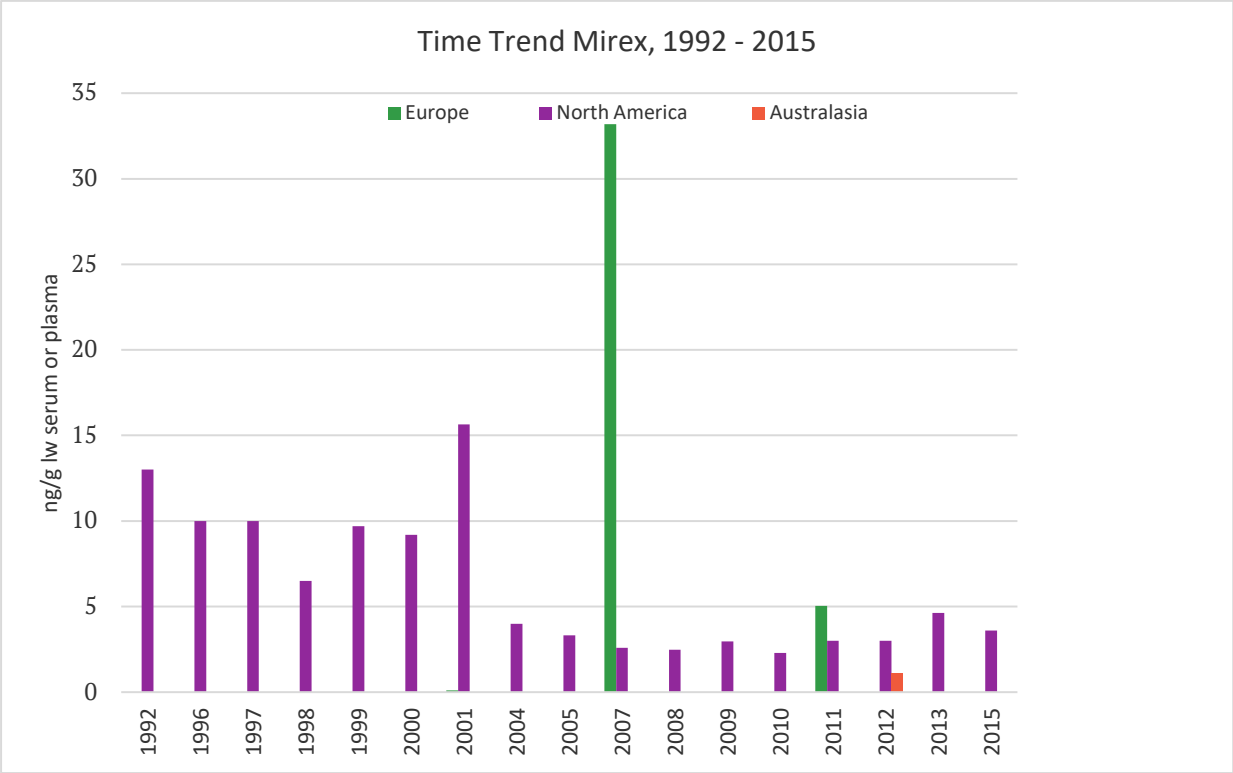


Figure 27. Temporal trend (1992–2015) of mirex concentrations (ng/g lipid) in human blood (serum or plasma) in the WEOG region.
(Temporal trend is based on the average of 57 reported mean/median values. Source: Third regional monitoring report for WEOG.)

[35] UNEP/POPS/COP.10/INF/41, http://chm.pops.int/tabid/525.

PCP showed a decreasing trend in blood over the period 1985–2012 in human blood samples from Germany (see **Figure** 28).

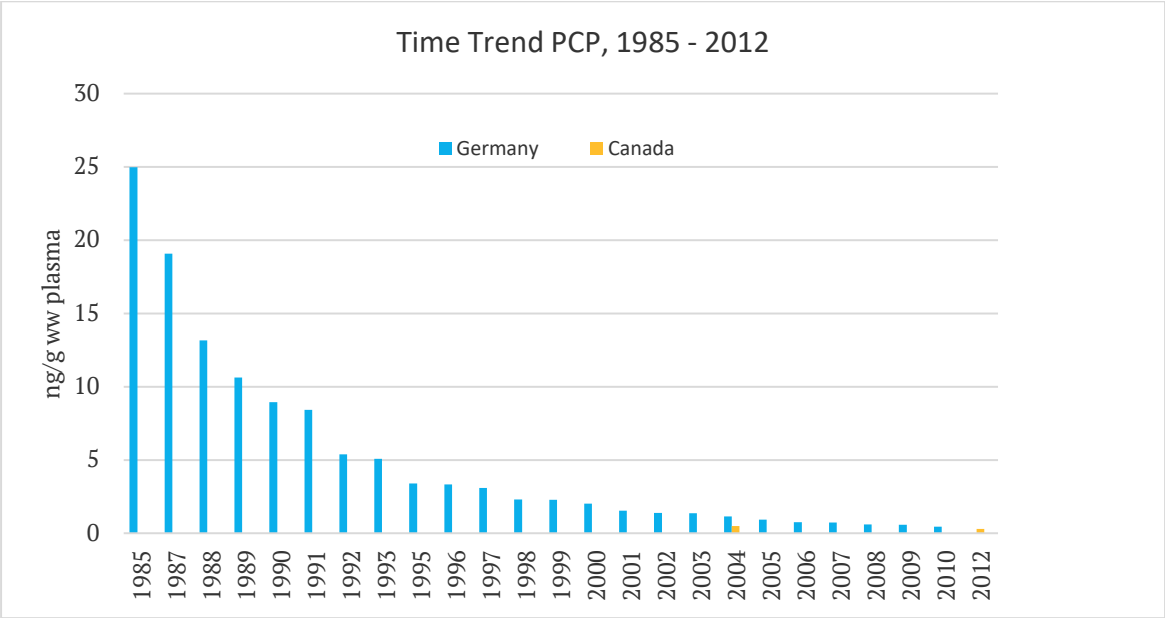


Figure 28. Temporal trend (1985–2012) of PCP concentrations (ng/g wet weight) human blood (plasma) in the WEOG region (Germany and Canada).
(Temporal trend is based on the average of 215 reported mean/median values. Source: Third regional monitoring report for WEOG.)

Brominated flame retardants

In serum, polybromobiphenyls (BB-153) were measured every second year between 2005 and 2015 through the National Health and Nutrition Examination Survey (NHANES) in the USA. As shown in **Figure 29**, the trend seems to be downwards, although a more recent data are needed to statistically confirm the tendency.

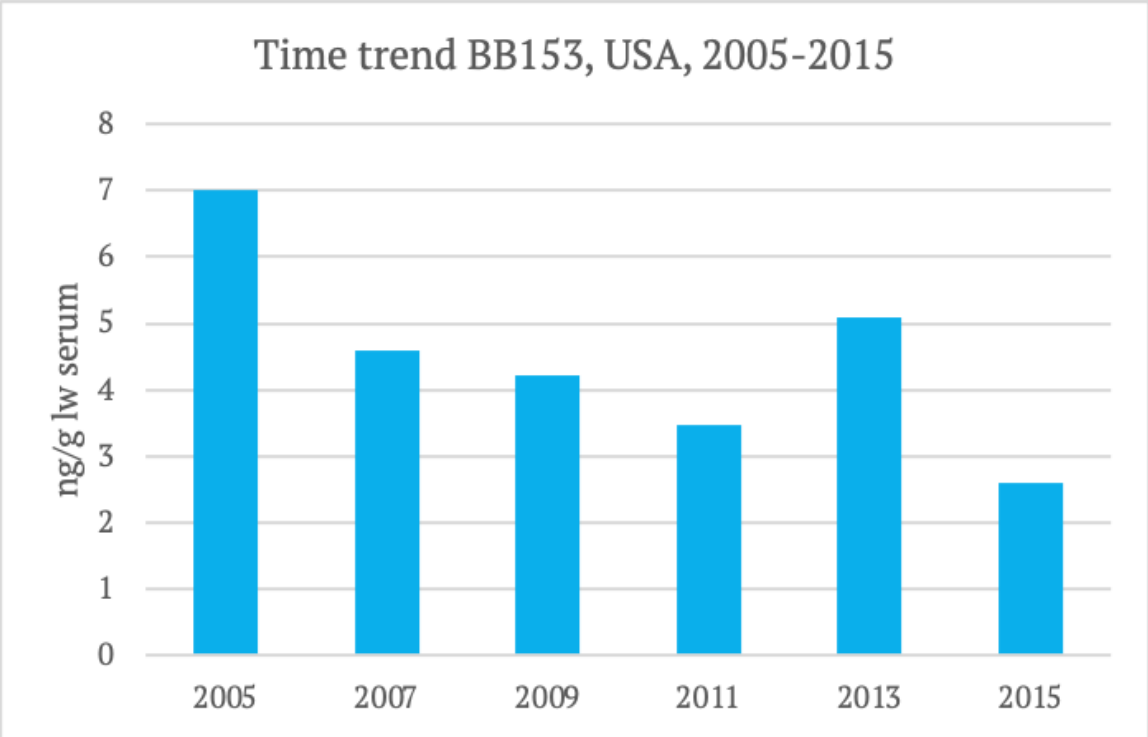


Figure 29. Temporal trend (2005–2015) of BB-153 concentrations (ng/g lipid) in human blood (serum) in North America (geometric mean values).
(Source: National Health and Nutrition Examination Survey, USA; Third regional monitoring report for WEOG.)

Per- and polyfluoroalkyl substances

During the period 1982–2017, PFOA and PFOS in blood have been reported in ten countries in the WEOG. The highest average concentration for PFOA and PFOS is in the Australasia region with 6.6 ng/mL (n=68) and 19 ng/mL (n=68), respectively. The lowest average concentration could be observed in North America with 2.2 ng/mL (n=43) for PFOA and 5.7 ng/mL (n=43) for PFOS.

Since 2009, the trend of PFOA and PFOS in human blood has decreased as a result of the ban/restriction of these chemicals in commercial use as well as industrial products. Levels of PFOA and PFOS in human blood since 1982 until 2009 did not show any significant trend but rather kept stable (see **Figure 30**; **Figure 31**).

Figure 30. Temporal trend (1982–2017) of PFOA concentrations (ng/mL) in human blood in Europe, North America, Australasia.
(Source: Third regional monitoring report for WEOG.)

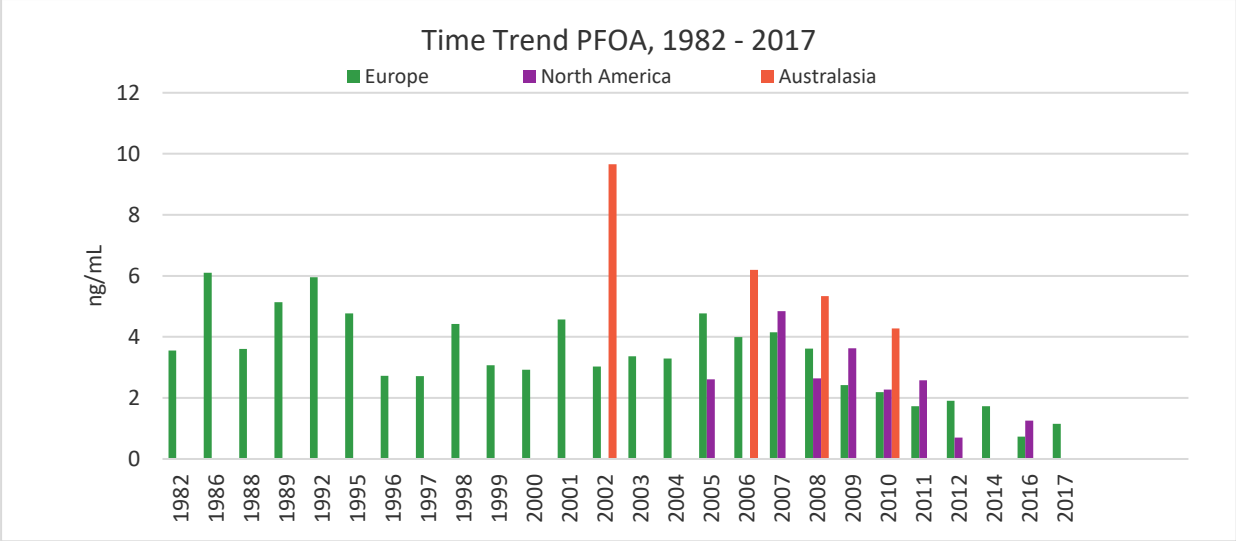


Figure 31. Temporal trend (1982–2017) of PFOS concentrations (ng/mL) in human blood in Europe, North America, Australasia.
(Source: Third regional monitoring report for WEOG.)

Interestingly, a slightly increasing trend in PFHxS concentrations was observed in human blood (see **Figure 32**). This might be due to the increasing use of PFHxS as a replacement for PFOA and PFOS since the usage of these compounds started to be phased out in the 2000s. At its tenth meeting in 2022, the Conference of the Parties listed PFHxS, its salts and PFHxS-related compounds were listed in Annex A to the Convention.

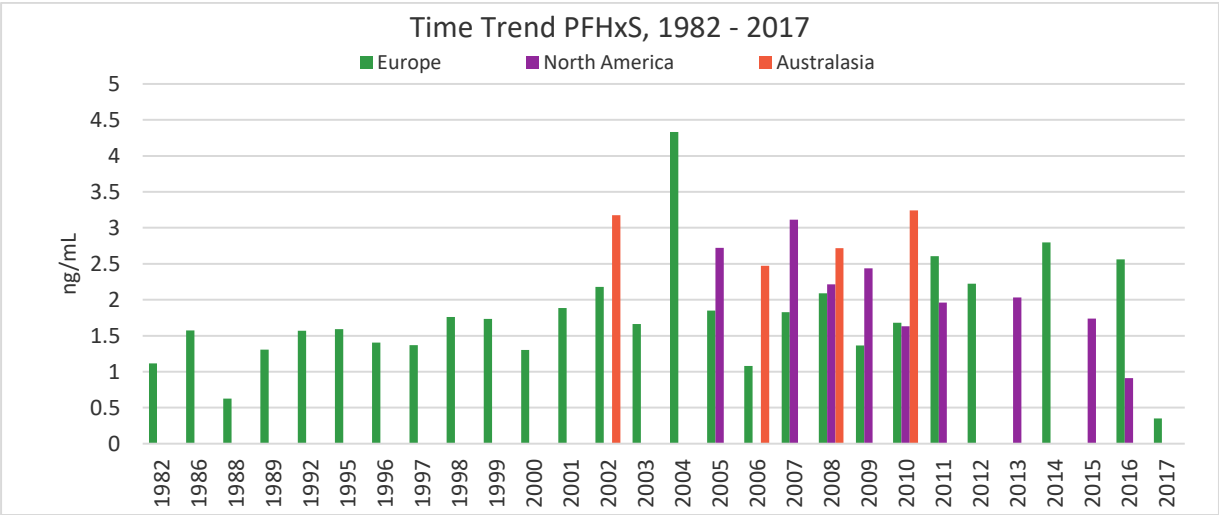


Figure 32. Temporal trend (1982–2017) of PFHxS concentrations (ng/mL) in human blood in Europe, North America, Australasia.
(Source: Third regional monitoring report for WEOG.)

A statistically significant decreasing trend was observed for PFOS concentrations in blood in samples collected over 2008–2016 in Japan ($p<0.05$, **Figure 33**). For PFOA, a statistically significant trend could not be observed.

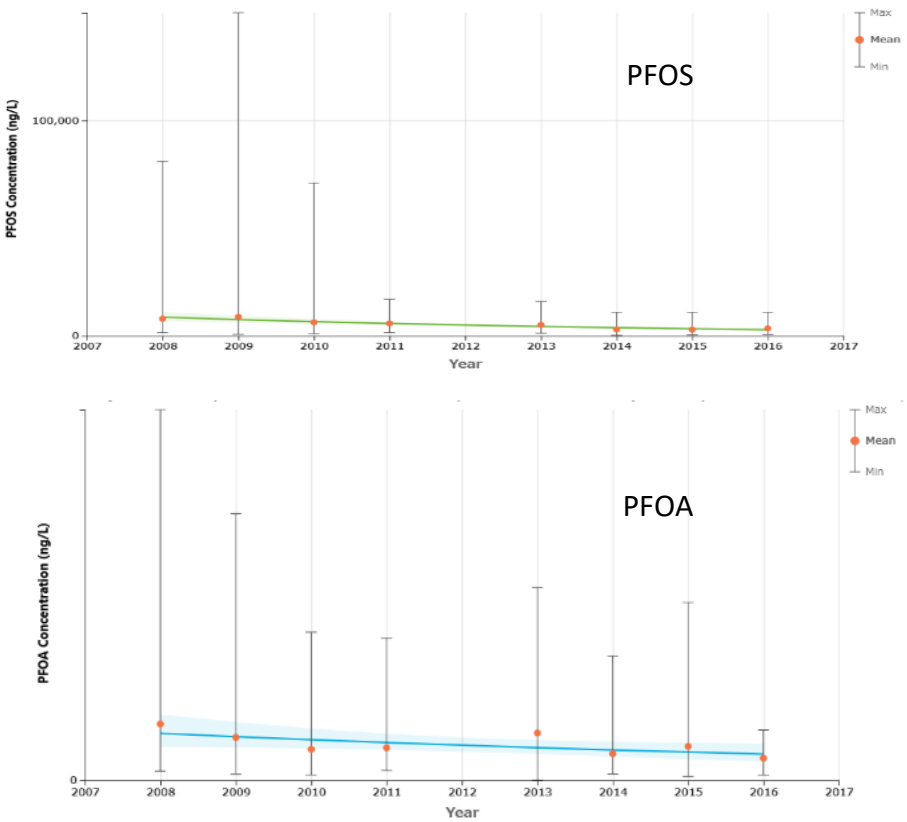


Figure 33. Temporal trend (2008–2016) of PFOS and PFOA concentrations (ng/L) in human blood in Japan. *(Source: Third regional monitoring report for Asia-Pacific.)*

4.2.3 Summary

The amount of available information on levels of POPs varies for different chemicals and regions. **Table 6** below provides an overview of the changes over time in POPs concentration measured in human matrices for the five UN regions.

Table 6. Summary of temporal trends of POPs concentrations in human tissues in the five UN regions.

Legends:

Generally decreasing trends
Generally increasing trends
No change, statistically insignificant trend, or cannot establish regional trend
No trend data

Chemical	Africa	Asia-Pacific	Eastern Europe	GRULAC	WEOG
Aldrin	No data	No data	Below LOQ for 10 countries over 2001–2019	No data	Insufficient trend data
Chlordane	No data	Fiji, Kiribati Japan	Decreasing tendencies observed for 5 countries in western part of the region (oxychlordane)	No data	Generally decreasing trends
Chlordecone	No data	No data	Below LOQ for 2 countries in 2019	No data	No data
DDT	No data	Fiji, Kiribati, Japan	Decreasing tendencies observed for 5 countries for all analyses	No data	Generally decreasing trends
Dicofol	No data	No data	Below LOQ for 2 countries in 2019	No data	Not included

Chemical	Africa	Asia-Pacific	Eastern Europe	GRULAC	WEOG
Dieldrin	No data	Kiribati, Japan Fiji	Decrease observed for 5 countries otherwise no trend data (partly green)	No data	Generally decreasing trends
Endosulfan	No data	No data	Below LOQ for 10 countries	No data	Insufficient trend data
Endrin	No data	No data	analyzed in 2001–2019, all samples below LOQ	No data	Insufficient trend data
HBB	No data	No data	Below LOQ 2009-2019, 6 countries	No data	No change or cannot establish trend
HBCD	No data	No data	For alpha-HBCD an increasing tendency observed for 3 countries–short time-series (2 rounds)	No data	Generally decreasing trends
HCB	No data	Japan Fiji, Kiribati	Decreasing tendencies observed for five countries in the region	No data	Generally decreasing trends
HCBD	No data	No data	Below LOQ for 2 countries in 2019	No data	No data
Alpha-HCH	No data	Fiji	Decreasing tendencies or below LOQ observed for 10 countries	No data	Not investigated
Beta-HCH	No data	Japan	Significantly decreasing tendencies observed for 10 countries	No data	Decrease in milk but not in blood
Gamma-HCH (Lindane)	No data	No data	Decreasing tendencies confirmed or decrease to below LOQ observed for 10 countries	No data	Not investigated
Heptachlor	No data	No data	Below LOD for heptachlor and trans-heptachlorepoxide; decrease for cis-heptachlor observed for 5 out of 10 countries	No data	No change or cannot establish trend
Mirex	No data	No data	Analyzed in 2006-2019, all samples below LOQ	No data	No change or cannot establish trend
PBDEs	No data	Fiji, Kiribati, Japan	Declining concentrations over time observed in human milk (with a peak in cases)	No data	Generally decreasing trends
BDE-209 (DecaBDE)	No data	No data	Samples for 2019 not yet analyzed	No data	No change or cannot establish trend
PCB	No data	Fiji, Kiribati, Japan	Statistically significant trend + decreasing tendencies observed for 10 countries in the region	No data	Generally decreasing trends
PCDD/PCDF	No data	Fiji, Kiribati, Japan	Statistically significant trend + decreasing tendencies observed for 10 countries in the region	No data	Generally decreasing trends
PCNs	No data	No data	No data available when preparing the report	No data	Insufficient trend data
PCP	No data	No data	Below LOQ for 2 countries in 2019	No data	Only German data; limited data

Chemical	Africa	Asia-Pacific	Eastern Europe	GRULAC	WEOG
PFHxS	No data	No data	Below LOQ for 2 countries in samples of 2019	No data	Increasing trends
PFOA	No data	Japan (slight decrease) Others	Baseline available for 2 countries in samples of 2019	No data	Generally decreasing trends
PFOS	No data	No trends	Baseline data available for four countries in the region–two in 2009 and two in 2019	No data	Generally decreasing trends
PeCB	No data	No data	Analyzed in 2009-2019, all samples below LOQ	No data	Insufficient trend data
SCCPs	No data	No data	First data available for 2 countries in 2019	No data	Insufficient trend data
Toxaphene	No data	No data	Analyzed in 2001–2019, Parlar 62 predominantly below LOQ, Parlar 26 and 50 decreased to below LOQ over time.	No data	Generally decreasing trends; limited data

4.2.4 Main findings

Significant concentrations were detected for all POPs, except for aldrin, chlordecone and endrin. The concentrations measured varied by an order of magnitude.

The levels of initial POPs such as DDT, HCB, toxaphene, chlordane and dieldrin were decreasing over time in human milk and/or blood. PCP seems to be on a downward trend as well, although time-series data were scarce. The levels of PCDD/PCDF and PCB in human milk have fallen steadily from their earlier high levels, indicating that the measures implemented to reduce environmental releases combined with regulations and recommendations on food and changes in diet have led to declining levels of those chemicals in humans. For several organochlorine compounds, the results were low or below the limit of quantification. This indicates that restrictions and banning of production and use of those chemicals and measures taken to mitigate releases of and contamination with unintentional POPs were successful in reducing contamination and human exposure.

Some of the newly listed POPs showed an increase over time followed by a decrease. This was the case for brominated flame retardants such as PBDEs and HBCD and PFAS such as PFOS and PFOA, which could be attributed to adequate risk management measures for those chemicals. The rising and then decreasing trend could indicate that the risk management measures for those newly listed POPs were taken later than for the initial POPs.

On the other hand, increasing trends over time were observed for PFHxS in blood samples from the WEOG region and for HBCD in some countries from the EE region.

No monitoring data could be found for chlordecone and HCBD in human milk or blood. No clear trend over time could be observed for heptachlor, PeCB and mirex. Due to limited data, no clear trend could be determined for polybromobiphenyls (including HBB), PCNs and endosulfan. For heptachlor and mirex, no clear trend was observed, possibly due to the variability among data sources, but this needs to be further investigated.

There are some initial biomonitoring data on SCCPs available under the UNEP/WHO Human Milk Survey. More monitoring data for SCCPs is necessary as the production and use of those chemicals are known to be high volume and information on human exposure is limited. SCCPs accounted for up to 50% of the total POPs concentration expressed as ng/g lipid in pooled milk samples.

Trend information, particularly in human samples, plays a key role in the effectiveness evaluation. The current assessment shows that trend data for human samples are limited. Continuation of ongoing biomonitoring as well as expansion of long-term monitoring is therefore necessary.

It is important to carefully interpret the trends; some available trends information supports views that measures taken in specific countries played key roles to reduce their exposure levels, which had occurred prior to the adoption of the Stockholm Convention. POPs with up and down trends in human tissues, such as PBDEs or PFOS, can be seen as representative indicators for the effectiveness of the Convention.

Comparison of POPs levels, not only among regions but also among different media and their temporal trends, could contribute to prioritizing the efforts to efficiently reduce POPs exposure and their harmful effects, and provide goals for such efforts. For example, human dioxin levels in Japan have been decreasing in the recent two decades, which accompany the decrease of dioxin levels in foodstuffs. Dioxin levels in each of the foodstuffs, on the other hand, did not show a clear decrease; this is partly because of high year-to-year variation in the data. Decrease in dioxin levels in foodstuffs, however, may, at least partly, be caused by change of food sources to less dioxin-containing feed. Dioxin levels in air decreased dramatically in recent years while those in water, soil and sediments did not decrease as much. Decrease in soils and sediments were marginal and less than that in foodstuffs. This type of information is important in order to understand the fate of POPs in the environment, and to design actions to efficiently reduce exposure levels of POPs in each country. It also provides an important contribution to environmental monitoring.

Understanding the major exposure routes of POPs is important in order to reduce exposure and body burden of POPs. While foodstuffs (and water) are one of the major exposure routes of many of the POPs, house dusts are also important for some of the newly listed POPs. With the addition of new chemicals to the Convention, different exposure routes could be considered in the future design of monitoring for the GMP.

4.2.5 Conclusions and recommendations

Conclusions	Recommendations
Biomonitoring data are important to show how restrictions and banning of production and use of hazardous chemicals and measures taken to mitigate releases of and contamination with unintentional POPs are successful in reducing contamination and human exposure. Long-term biomonitoring to obtain temporal trends is a prerequisite for the effectiveness evaluation. The global assessment of POPs concentrations in human matrices is largely made possible through the long-term implementation of the UNEP/WHO Human Milk Survey that generated comparable data to evaluate changes over time. In addition, national and regional long-term programmes (e.g., AMAP) monitoring chemicals in milk and/or blood samples are also important.	It is of great importance that the global, regional and national programmes evaluating temporal trends of both POPs and other environmental pollutants in blood and/or milk continue. This data is needed to be able to follow the effectiveness of the Stockholm Convention and to see that regulations and other actions taken in order to reduce the exposure to POPs are purposive and efficient. The UNEP/WHO Human Milk Survey should be continued but with a timing that is better synchronized with the cycle of the effectiveness evaluation under the Stockholm Convention to enable the GMP to use the latest available data. Participation from more countries in this survey would increase its representativeness.
Significant concentrations were detected for all POPs, except for aldrin, chlordecone and endrin. The concentrations measured varied by an order of magnitude. The levels of the initial POPs, including their transformation products, have generally declined. Newly listed POPs, such as PBDEs, HBCD, PFOS and PFOA showed an increasing trend followed by a decrease. This indicates that adequate risk management measures have led to declining levels of those chemicals in humans. Limited data are available for some of the new POPs such as SCCPs and PCNs.	Monitoring should be continued and expanded for newly listed POPs to provide the information needed to assess changes over time. To be able to follow up on these substances over time, it is important to start monitoring these substances now. And, in addition to measuring the classic POPs, that are already regulated, it is important to also monitor possible substitution substances.
In order to be able to use monitoring data to evaluate and compare levels and trends between countries, regions and continents it is crucial to be able to retrieve as much metadata and background information as possible (e.g., sampling strategies, information on cohorts and participants, analytical methods and statistical parameters) and to have proper identification of substances, and to store monitoring data in searchable and open databases. Biobanking samples for later analysis could be useful since it makes it possible to go back and produce temporal trends for new pollutants also in the future.	Archiving of human samples should be encouraged as a cost-effective means for conducting retrospective analysis for newly listed POPs, to generate baseline information and temporal trends for new pollutants as they are added to the Convention.

4.3 Water

Key messages:

Significant declines of PFOS were found in inland waters of several countries/regions including the Elbe and Rhine in Europe, lakes in Japan, and the North American Great Lakes.

Median PFOS concentrations exceeded European Union environmental quality standard (EQS) for inland surface waters of 0.65 ng/L in 21 of 45 countries for samples from 2015–2019 and in earlier time periods.

PFOS concentrations declined significantly in the North Atlantic and in the Mediterranean, but not in the North Sea. Significant declines were also observed in the Bohai and Yellow Seas and in the South East China Sea.

Median PFOA concentrations showed fewer declines compared to PFOS, although large differences from the mid-2000s to 2019 were seen at most sites in the Danube, as well as in the Elbe and the Rhine rivers.

Median concentrations of PFOA did not exceed a proposed EQS of 100 ng/L in any of the 45 country sites although some individual results exceeded this level.

PFOS/PFOA ratios, an indicator of legacy sources, were highest in WEOG and EE countries with the majority having ratios >1 in their inland waters for samples from 2015–2019. These results point to continued persistence of PFOS despite phase outs in mid-2000s.

The sampling and PFAS analysis undertaken by UNEP/GEF GMP II project in 22 countries in 2017–2019 provided a sound basis for assessment of prevailing concentrations in surface waters and excellent short-term temporal trends in selected locations.

Assessment of temporal trends at most locations was challenging due to year-to-year differences in sampling sites and to wide differences in detection limits among studies.

4.3.1 Introduction

The objective of this chapter is to summarize the current state of knowledge of PFOS, PFOA and PFHxS in water. Those are three PFAS currently listed under the Stockholm Convention in water.

Water is an important medium for regional and global transport of PFOS, PFOA, PFHxS and other perfluoro-alkyl acids due to their high water solubility and persistence (Yamashita et al. 2012). This is unlike the case for neutral chlorinated or brominated POPs which are hydrophobic and generally present at picogram per liter (parts per quadrillion) concentrations in background surface waters (Muir and Lohmann 2013). Direct emissions to water from wastewater treatment plants are thought to be the main sources of PFOS, PFOA and PFHxS to surface waters globally as a result of past or continuing industrial production and ongoing use and disposal of products containing their precursors and residuals (Earnshaw et al. 2014; Wang et al. 2014; Wang et al. 2017). The emissions of these PFAS to surface waters can be directly linked to exposure of fish, fish eating birds and mammals via food-chain bioaccumulation and biomagnification. Hence knowing dissolved concentrations in the water enables prediction and validates modelling of fate and bioaccumulation of PFAS in aquatic environments.

In addition to biomagnification in wildlife, which can lead to human dietary exposure, human exposure via drinking water contamination with PFAS is a major concern in some regions (Domingo and Nadal 2019; Post et al. 2017; US EPA 2016). Surface waters serve as major sources for drinking water globally. Thus, while this assessment does not deal directly with drinking water, a review of available data for surface waters is timely and provides information on potential human exposure.

Similar to the previous assessment of PFOS in water in the global report (see Chapter 6.3 of the second GMP report in 2015),[36] the focus in this report is mainly on sites not directly influenced by wastewater effluents. Two major questions for this second assessment of PFAS in water have been addressed:

(a) What are the prevailing concentrations of PFOS, PFOA and PFHxS in inland waters globally and in neighboring seas, as well as in oceans?

(b) Are concentrations of PFOS, PFOA and PFHxS declining as a result of national and international chemical management controls?

4.3.2 Data and methodology

Concentrations of PFOS measured until 2014 have been summarized and reported in the second GMP report in 2015.[37] In the current report, results from samples collected in the period from 2015 to 2019 in the five UN regions

[36] UNEP/POPS/COP/8/INF/38, http://chm.pops.int/tabid/525.

[37] UNEP/POPS/COP.8/INF/38, http://chm.pops.int/tabid/525.

are reported to assess temporal trends. Some results from samples collected in 2014 that were not included in the previous reports are reported in the current report. Qualitative assessment of temporal trends is now possible for some regions thanks to many individual measurements of PFOS, PFOA and PFHxS in inland waters as well as in coastal and open marine waters since the early 2000s.

Data for the assessment was mainly obtained from the GMP Data Warehouse. The UNEP/GEF GMP II project which included PFAS measurements in surface waters of 22 countries provided a large contribution for inland and coastal waters in Asia-Pacific, Africa and Latin America and the Caribbean (Baabish et al. 2021). The report also draws on a recent global survey of PFAS in coastal and open marine waters (Muir and Miaz 2021).

In WEOG, the majority of PFAS data available for inland waters were from peer reviewed scientific literature. Additional results were obtained from government laboratories that are involved in monitoring and surveillance of contaminants in water. PFAS results that were available on the NORMAN EMPODAT database website[38] were also downloaded. Results for rivers in Germany, Italy, Netherlands and Spain previously uploaded to the database from several agencies (e.g., State Office for the Environment, Agriculture and Geology and Germany Environment Agency (UBA-DE), Association of Rhine Water Works in the Netherlands, European Commission Joint Research Centre, Institute for Environment and Sustainability) were included. Data for PFAS in water were also available from national programmes in Canada, Finland, and Australia.

The criterion for selection of data was that the studies had >60% results above the reported MDLs for individual river basins. Data from the selected literature were inserted in a PostGIS database following the structure of the GMP Data Warehouse. Information on analytical methodology and quality assurance such as MDLs and brief descriptions of analytical methodology (instruments, columns, calibration, use of mass labelled standards) was also included in the database.

The contaminated character of sites was loosely assessed individually during inclusion of the reviewed articles based on the site description and on a conservative concentration threshold at 2000 ng/L for any PFAS at the site (122 sites excluded on post hoc). The remaining sites were labelled as urban/non-urban by computing the density of population in a 100 km radius (using minimum geodesic distance from PostGIS type geography) to the sites location and classifying with threshold 500 capita/km^2. The population size is taken from Natural Earth[39] represented pointwise for each large city.

Searches of the peer-reviewed literature also contributed to PFOS, PFOA and PFHxS data for inland and near coastal waters of Africa, Asia-Pacific and GRULAC regions. However, for those regions, the assessment of results for samples from 2014–2019 relied heavily on the data in the GMP Data Warehouse contributed by the UNEP/GEF GMP II project (Baabish et al. 2021).

With regard to analytical methodology, all studies included in this report used mass labelled internal standards of PFAS along with high performance liquid chromatography-tandem mass spectrometry (LC-MS/MS) or a high-resolution mass spectrometry. This had become standard methodology by the mid-2000s (Taniyasu et al. 2005; Yamashita et al. 2004) and is also described in an International Standards Organization method for PFOS and PFOA in water (ISO 2009). Thus, some early studies for surface waters were not included, although it has to be acknowledged that they were important for identifying the issue of water contamination in the first place (e.g., Hansen et al. 2002; Moody et al. 2002).

Concentrations reported as less than the method detection limit (<MDL) were substituted with MDL*√2/2 as recommended by Antweiler (2015) rather than being omitted from dataset. However, this was not sufficient to ensure comparability across as many studies had a wide range of MDL and limit of quantification (LOQs). For example, many studies had LOQ=1 ng/L for PFOS while others were reporting LOQs close to 1 pg/L using the same instrumentation and sample sizes. Due to the wide range of detection limits for PFOS, PFOA and PFHxS reported among the studies and the potential statistical biases of multiple MDLs, the single MDLs were used for each analyte taking into account the distribution of reported concentrations. The selected MDLs (PFOS and PFHxS=0.002 ng/L; PFOA=0.005 ng/L) were taken from studies on lake waters (De Silva et al. 2011) and seawater (Benskin et al. 2012, Yamashita et al. 2008) that reported MDLs in the low pg/L range. These MDLs are readily achievable using 1 L samples with LC-MS/MS analysis. This approach was used for the peer review article that included PFAS data for coastal and open ocean waters (Muir and Miaz 2021).

Medians and median absolute deviations (MAD) from the medians, were calculated for PFOS, PFOA and PFHxS for inland waters of individual countries. The same approach was used for coastal seas and open ocean waters. In a few cases, sample taken on the seashore and in estuaries were included with inland waters, for example those for Pacific Island nations from the UNEP/GEF GMP II project (Baabish et al. 2021). Median concentrations were used to compare spatial and temporal trends for samples collected during the periods 2000–2009, 2010–2014 and 2015–2019

[38] https://www.norman-network.com/nds/empodat/.

[39] naturalearthdata.com.

for each region. Data dispersion was estimated by dividing the MAD by the median value. It must be emphasized that the calculation of % declines or increases using medians provides only qualitative assessment of trends.

4.3.3 Spatial and temporal trends in inland waters

4.3.3.1 Africa

(1) Country by country comparison in Africa

Results for Africa were obtained from the UNEP/GEF GMP II project and from peer-reviewed studies reporting PFOS, PFOA and PFHxS in surface waters collected over the period from 2014 to 2019 (**Table 7**). All data are available from the GMP Data Warehouse. The UNEP/GEF GMP II project provided the most extensive coverage to date of PFAS in surface waters in African countries with sampling conducted over a two year period (2017–2018) in inland or estuarine waters of 6 countries (Baabish et al. 2021). In addition, nearshore surface seawater was collected in Senegal and included for comparison with other sites in Africa.

Table 7. Summary for surface water monitoring programmes primarily in rivers, lakes and coastal sea water in Africa (2014–2019).

Country	Years	Areas sampled	Sites/frequency	Analytes	Reference
Egypt	2017–2019	Surface water–River Nile	1 site (4 times/year)	PFOS PFOA, PFHxS	UNEP/GEF GMP II project, Baabish et al. 2021
Ethiopia	2014	Surface water–Lake Tana	7 sites	PFOS, PFOA, PFHxS	Ahrens et al. 2016
Ghana	2017–2019	Surface water–Volta River	1 site (4 times/year)	PFOS, PFOA, PFHxS	UNEP/GEF GMP II project, Baabish et al. 2021
Kenya	2015	Surface water–River Sosiani	3 sites	PFOS, PFOA, PFHxS	Shafique et al. 2017
Kenya	2017–2019	Surface water–Sabaki River estuary	1 site (4 times/year)	PFOS, PFOA, PFHxS	UNEP/GEF GMP II project, Baabish et al. 2021
Nigeria	2014–2015	Surface water–rivers SW Nigeria	9 sites	PFOS, PFOA, PFHxS	Ololade 2014, Ololade et al. 2018
Senegal	2017–2019	Surface seawater–coastal	1 site (4 times/year)	PFOS, PFOA, PFHxS	UNEP/GEF GMP II project, Baabish et al. 2021
South Africa	2014	Surface water–River Vaal, Thabela Thabeng	1 site	PFOS, PFOA, PFHxS	Groffen et al. 2018
Tunisia	2017–2018	Surface water–Qued Medjerda	1 site (4 times/year)	PFOS, PFOA, PFHxS	UNEP/GEF GMP II project, Baabish et al. 2021
Uganda	2015	Surface water–Murchison Bay, Lake Victoria	2 sites	PFOS, PFOA, PFHxS	Dalahmeh et al. 2018
Zambia	2017–2018	Surface water–Kafue/Zambezi River confluence	1 site (4 times/year)	PFOS, PFOA, PFHxS	UNEP/GEF GMP II project, Baabish et al. 2021

Median concentrations for inland waters of 11 countries ranged from 0.02–0.97 ng/L for PFHxS, 0.13–7.5 ng/L for PFOA and 0.11–7.6 ng/L for PFOS (see **Figure 34**). Highest concentrations were reported for Kenya, Nigeria and South Africa. While background sites were selected from the published data as well as for the UNEP/GEF GMP II project, there was nevertheless the potential for wastewater influence particularly at Murchison Bay (Lake Victoria) (Dalahmeh et al. 2018), in the River Sosiani in Kenya (Shafique et al. 2017), and in southwestern Nigerian rivers (Ololade et al. 2018).

PFOS/ PFOA ratios have been used to assess industrial influence (Wang et al. 2012). PFOS/ PFOA ratios ranged from 0.02 to 3.6, with two locations (rivers in southwest Nigeria, coastal water in Senegal) having ratios >1 (see **Figure** 34). A PFOS/PFOA ratio for the inland site in Kenya (River Sosiani) was <0.1 based on a non-detect PFOS for that location. The higher ratios imply legacy sources of PFOS still present in samples collected in the period 2014–2019.

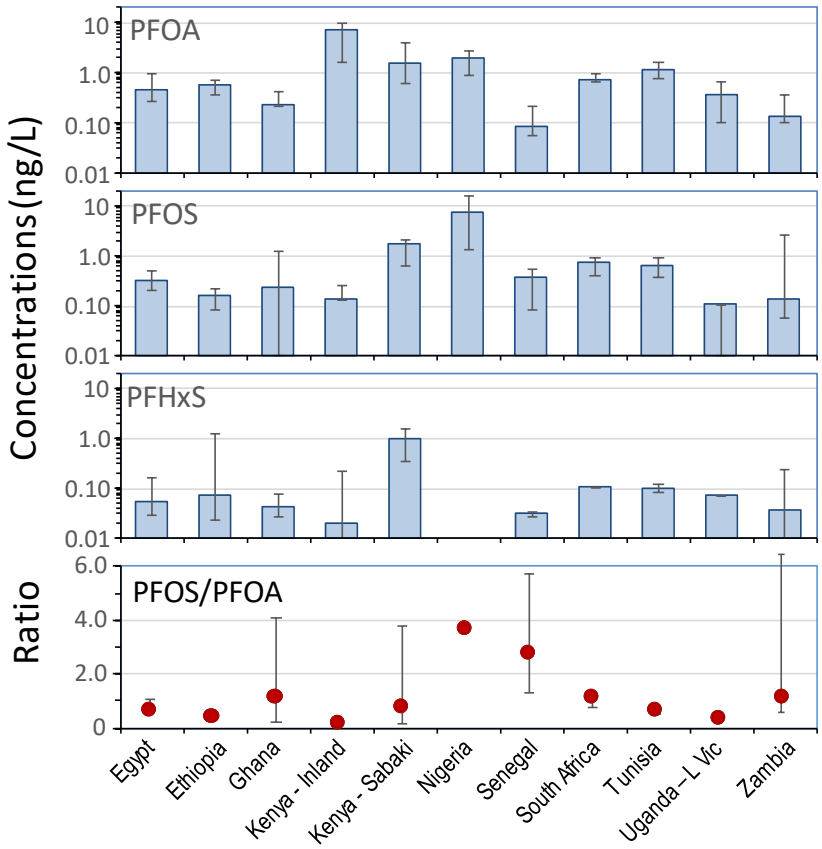


Figure 34. Median (min-max) of PFOA, PFOS, and PFHxS concentrations (ng/L) and PFOS/PFOA ratios in surface waters of rivers, lakes and estuaries in Africa.
(Source: Baabish et al. 2021; GMP Data Warehouse.)

(2) Temporal trends in inland waters of Africa

No long-term monitoring data were available for PFOS, PFOA and PFHxS in surface waters of Africa. However, the UNEP/GEF GMP II project produced short-term temporal information for up to 8 sampling times at sites in Egypt (River Nile in Cairo) and Kenya (Sabaki River mouth) from 2017 to 2019, as well as similar frequencies for 2017–2018 at 4 other locations (Baabish et al. 2021). At both the River Nile and Sakabi river sites, PFOA concentrations varied by up to 4-fold over the study period (see **Figure 35**), while PFOS concentrations varied less than 2-fold. The variation in concentrations may be influenced by seasonal flow. The lowest concentrations of both PFOA and PFOS on the Nile occurred during the high flow period in October while highest concentrations of PFOA in the Sabaki occurred during the dry season. However, further analysis would require hydrographs for the sampling period.

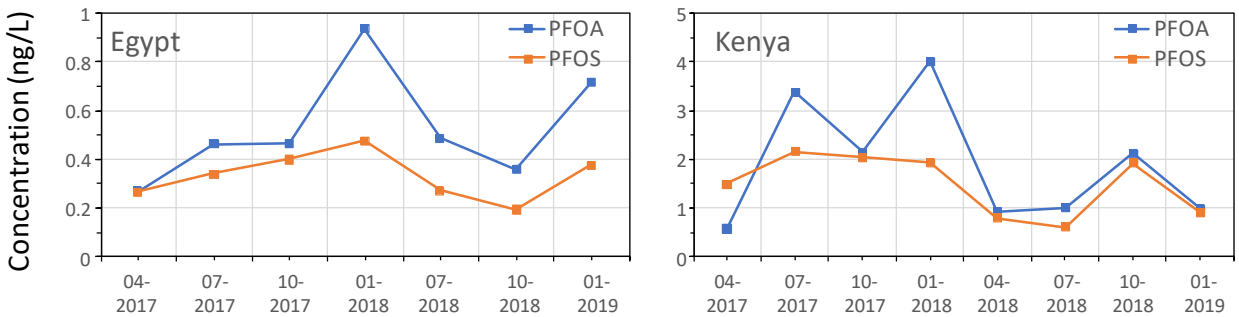


Figure 35. Temporal trends of PFOA and PFOS concentrations (ng/L) surface waters at sites in Egypt (Nile River, suburban Cairo) and Kenya (Sabaki river estuary).
(Sampling was conducted at the same location approximately every 3 months. Symbols represent single samples. Source: Baabish et al. 2021.)

4.3.3.2 Asia-Pacific

(1) Country by country comparison in Asia-Pacific

In the Asia-Pacific region, several monitoring programmes for PFAS in national surface waters were available and additional data were available from the GMP Data Warehouse (see **Table 8**).

Table 8. Summary of surface water monitoring programmes in lakes, rivers and coastal seawater in Asia-Pacific (2014–2019).

Country	Years	Areas sampled	Sites/frequency	Analytes	Reference
Asia					
Bangladesh	2015	Rivers and estuaries	14 sites	PFOS, PFOA, PFHxS	Habibullah-Al-Mamun et al. 2016
China	2014, 2016, 2018, 2019	Throughout the nation (lake and coastal)	26 sites	PFOS	National environmental monitoring center of China 2020
Japan	FY2014–2016, 2018	Throughout the nation (river, estuary, coastal, lake)	47–48 sites/year	PFOS, PFOA	Japan Ministry of the Environment 2020
Mongolia	2017–2018	Tuul River	1 site (4 times/year)	PFOS, PFOA, PFHxS	UNEP/GEF GMP II project, Baabish et al. 2021
Republic of Korea	2015–2019	Han River	6 sites	PFOS, PFOA, PFHxS	Pan et al. 2018
Viet Nam	2015–2019	8 regions (rivers)	11 sites	PFOS, PFOA, PFHxS	Baabish et al. 2021; Lam et al. 2017
Pacific					
Fiji	2017–2019	Waimanu River	1 site (4 times/year)	PFOS, PFOA, PFHxS	UNEP/GEF GMP II project, Baabish et al. 2021
Kiribati	2017–2019	Surface seawater	1 site (4 times/year)	PFOS, PFOA, PFHxS	UNEP/GEF GMP II project, Baabish et al. 2021
Niue	2017	Surface seawater	1 site (4 times/year)	PFOS, PFOA, PFHxS	UNEP/GEF GMP II project, Baabish et al. 2021
Palau	2017–2018	Surface seawater	1 site (4 times/year)	PFOS, PFOA, PFHxS	UNEP/GEF GMP II project, Baabish et al. 2021
Samoa	2017–2019	Vaisigano River	1 site (4 times/year)	PFOS, PFOA, PFHxS	UNEP/GEF GMP II project, Baabish et al. 2021
Solomon Islands	2017–2018	Surface water–Matanikau R. estuary (Honiara)	1 site (4 times/year)	PFOS, PFOA, PFHxS	UNEP/GEF GMP II project, Baabish et al. 2021
Tuvalu	2017–2018	Surface seawater Fongafale Islet	1 site (4 times/year)	PFOS, PFOA, PFHxS	UNEP/GEF GMP II project, Baabish et al. 2021
Vanuatu	2017–2019	Surface seawater, Mele Bay	1 site (4 times/year)	PFOS, PFOA, PFHxS	UNEP/GEF GMP II project, Baabish et al. 2021

Median concentrations of PFOS, PFOA and PFHxS for inland waters and estuaries of Asia-Pacific countries for which there is recent data (samples collected from 2014–2019) are shown in **Figure 36**.

China: PFOS was monitored in the waters (lake and coastal) during 2014–2019. The concentrations of PFOS in Taihu Lake and Qinghai Lake ranged from ND to 13 ng/L, and the concentrations of PFOS in marine water (Yellow Sea, Bohai Sea and South China Sea) ranged from ND to 6 ng/L. The PFOS level in marine water of Hong Kong SAR, China (South China Sea) continues to be low, largely below the reporting limit of 2.0 ng/L in 2014 to 2018 (National environmental monitoring center of China 2020).

Japan: Continuous monitoring of PFOS and PFOA has been conducted in the waters (river, estuary, coastal and lake) throughout the nation since FY2009 (Japan Ministry of the Environment 2020). The concentrations of PFOS and PFOA from FY2014 to FY2018 (except for FY2017) were from ND to 14 ng/L and from 0.14 to 28 ng/L, respectively. In Japan, the results of the inter-annual trend analysis from FY2009 to FY2018 throughout the nation, indicated a reduction tendency in lake water samples that was identified as statistically significant for PFOS. In addition, reduction tendency in samples from river mouth areas was identified as statistically significant for PFOA (Japan Ministry of the Environment 2020). However, further analysis of the increasing data is being conducted to give a better understanding of the current situation.

Other countries: Measurements of PFOS, PFOA and PFHxS were conducted during 2017 and 2018 in 11 Asian-Pacific countries as part of the UNEP/GEF GMP II project (see **Table 8**) (Baabish et al. 2021). Of the 11 locations, 6 were surface seawater from coastal sites while 5 (Fiji, Mongolia, Samoa, Solomon Islands, Viet Nam) were river or estuarine sites. Samples were taken at the end of each quarter of the year, enabling an assessment of seasonal variation over multiple years (see temporal trends section). During the period 2015–2019 studies of PFOS, PFOA and PFHxS

in surface waters were also conducted in Bangladesh, Republic of Korea and Viet Nam and published in the peer reviewed literature (**Table 8**). All data were obtained from the GMP Data Warehouse.

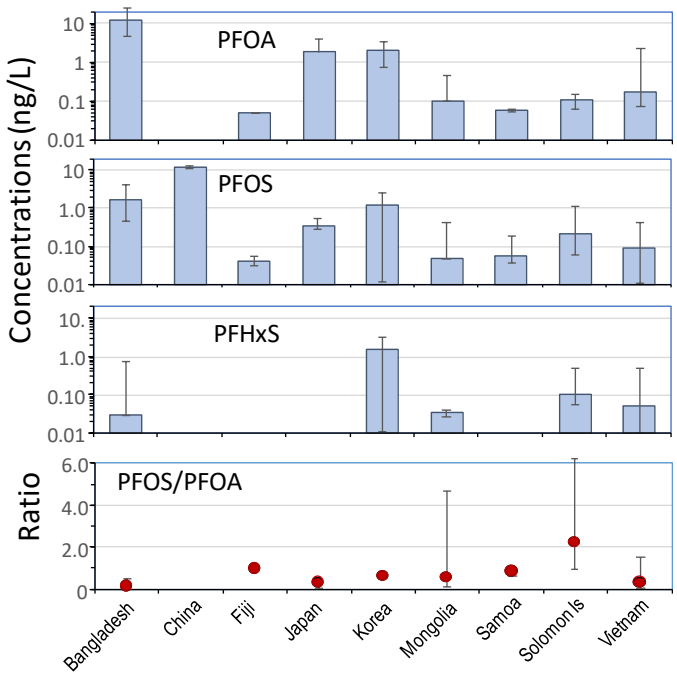


Figure 36. Median and range of PFOA, PFOS and PFHxS concentrations (ng/L) and PFOS/PFOA ratios in surface waters of river and lakes of East Asian countries.
(Source: Baabish et al. 2021; GMP Data Warehouse.)

The more heavily industrialized countries (China, Japan, Republic of Korea) generally had the highest concentrations, relative to Pacific Island nations. Baabish et al. (2021) have noted that lower-middle income countries (as defined by the World Bank) had the highest average PFOS and PFOA concentrations. However, Vanuatu was an exception, with highest median concentrations of PFHxS and relatively high PFOS in coastal seawater, compared to 11 other nations (Baabish et al. 2021).

All median PFOS/PFOA ratios for the 8 freshwater sampling sites in Asia-Pacific were <1 except for the Solomon Islands site (see **Figure 36**). That sampling site (Matanikau River estuary) is in the city of Honiara and may be influenced by local sources. The higher ratios imply legacy sources of PFOS.

(2) Temporal trends in inland waters of Asia-Pacific

Although there are a tremendous number of individual studies of PFAS in inland surface waters in Asia-Pacific (Podder et al. 2021), there are few ongoing temporal trend studies for PFOS, PFOA and PFHxS. An exception is Japan where the Ministry of Environment of Japan has conducted sampling of 4 lakes and 19 rivers since 2009 (Japan Ministry of the Environment 2020). The combined results for all locations (**Figure 37**) show a significant decline in PFOS (half-life=7.7 y; -9%/y) in lakes (**Table 9**). Median PFOA concentrations also declined in lakes from 2012 to 2019 but the trend was not statistically significant. Median concentrations of PFOA and PFOS showed no significant trends in rivers, while PFOA in river mouth areas showed significant decline with half-life=9 years. No significant trends were observed in bottom sediments of any of the area groups during the period for both PFOS and PFOA.

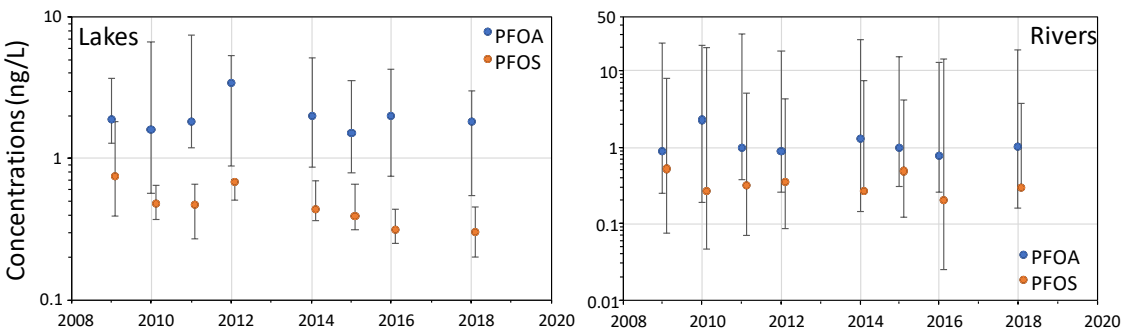


Figure 37. Temporal trend (2009–2018) of PFOA and PFOS concentrations (ng/L) in lakes (4) and rivers (19) in Japan.
(Symbols represent medians and vertical lines define the range.)

Table 9. Estimates of environmental half-lives for PFOA and PFOS based on simple regression of natural log of annual medians versus time (years).
(Significant P values <0.05 are bolded. Data are extracted from Table S7 in Muir and Miaz (Muir and Miaz 2021) except for lakes and coastal waters of Japan which were from the Japan Ministry of Environment.)

Region/sea	Analytes	Years	Number of years	slope	SE	r^2	P	$t_{1/2}$ (y)	%/y
Japan (lakes)	PFOA	2009–2018	8	-0.003	0.014	0.009	0.823	>50	–
	PFOS	2009–2018	8	-0.039	0.0094	0.741	**0.006**	-7.7	-9.0
Japan (coastal waters)	PFOA	2009–2018	8	-0.024	0.019	0.210	0.253	-39.5	-1.8
	PFOS	2009–2018	8	-0.008	0.017	0.034	0.662	-12.5	-5.5
Bohai & Yellow Seas	PFOA	2012–2018*	5	-0.056	0.018	0.762	0.053	-5.39	-13
	PFOS	2012–2018	6	-0.208	0.074	0.664	0.048	-1.45	-48
East China Sea	PFOA	2013–2019	3	0.004	0.062	0.004	0.959	>50	–
	PFOS	2013–2019	3	0.291	0.046	0.976	0.099	1.04	67
South East China Sea	PFOA	2011–2019	5	0.086	0.035	0.665	0.092	3.50	20
	PFOS	2013–2019	4	-0.226	0.013	0.994	0.003	-1.33	-52
Mediterranean Sea	PFOA	2012–2018	6	-0.446	0.049	0.954	**0.001**	-0.67	-103
	PFOS	2012–2018	6	0.189	0.062	0.700	**0.038**	1.59	44
North Atlantic	PFOA	2009–2014	4	0.057	0.018	0.839	0.084	5.29	13
	PFOS	2007–2014	6	0.018	0.005	0.061	**0.019**	17.2	4.0
North Sea	PFOA	2011–2018	5	-0.174	0.243	0.146	0.526	-1.73	-40
	PFOS	2011–2018	5	0.032	0.281	0.004	0.918	9.54	7.3
Baltic Sea	PFOA	2003–2015	5	-0.073	0.040	0.323	0.168	-4.15	-17
	PFOS	2003–2017	7	-0.049	0.032	0.341	0.183	-6.14	-11
Great Lakes	PFOA	2004–2017	12	-0.163	0.067	0.372	**0.035**	-1.84	-38
	PFOS	2004–2017	12	-0.179	0.073	0.374	**0.035**	-1.68	-41
Arctic Ocean	PFOA	2010–2018	5	0.025	0.023	0.287	0.352	12.0	5.8
	PFOS	2010–2018	5	0.007	0.050	0.006	0.902	44.7	–

Note: *Omitting outlier for 2017.

The UNEP/GEF GMP II project (Baabish et al. 2021) collected inland water samples over a 2 year period in Viet Nam and Samoa, while at other Asia-Pacific locations sampling was over a 2 year period. An advantage of this study was that samples were collected at the same location at up to 8 time periods. PFOS showed deviations of up to 3-fold in the Song Nam Dinh River while PFOA showed deviations of <2 fold. However, in Samoa, PFOS concentrations were lower in 2018–2019 than in the first sample collected in October 2017, while PFOA levels were near or at detection limits (see **Figure 38**).

The PFOS concentration from Taihu Lake was 31.0–32.9 ng/L in 2013 and 11–13 ng/L in 2019. The PFOS concentration in water from Taihu Lake decreased significantly (National environmental monitoring center of China 2020).

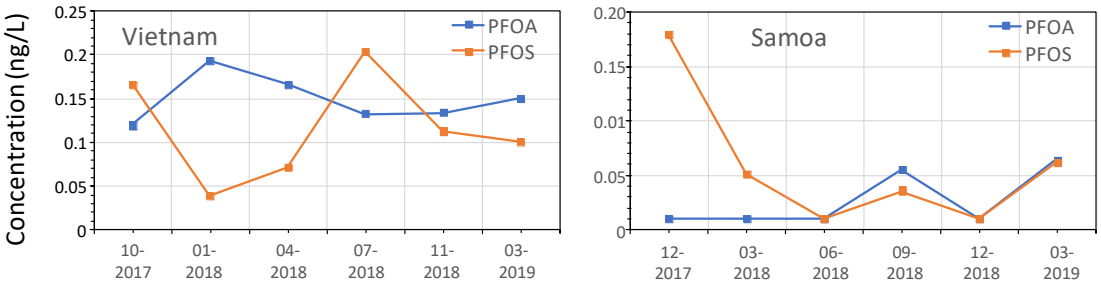


Figure 38. Temporal trend (2017–2019) of PFOA and PFOS concentrations (ng/L) in surface waters of Viet Nam (Song Nam Dinh River) and Samoa (Vaisigano River-Lelata Point).
(Sampling was conducted at the same location approximately every 3 months. Symbols represent single samples. Values of 0.01 ng/L represent non-detectable concentrations. Source: Baabish et al. 2021.)

4.3.3.3 Eastern Europe

(1) Country by country comparison in EE

Results for PFOS and PFOA in waters of the EE region were obtained from the GMP Data Warehouse and from the third regional monitoring report for EE (UNEP 2021c) (see **Table 10**). Only results for samples 2014–2019 were used. A substantial dataset exists from previous work based on samples from 2007 to 2013 which enabled qualitative assessment of temporal trends. Data sources for the earlier work include a detailed survey of the Danube and its major tributaries conducted by Joint Research Centre of the European Commission (Loos et al. 2009; Loos et al. 2010). The data for EE surface waters for 2014–2019 were also predominantly from the Danube (61%) or its tributaries (39%) and were based on the Joint Danube Survey (ICPDR 2020) which conducted water sampling in 2019. For simplicity they are referred to as Danube waters below. Results were also available for near shore surface waters of the Baltic Sea along the shorelines in Poland, Lithuania, Latvia, Estonia, and Russia, however, these are reported for the Baltic Sea.

Table 10. Summary of data available for PFAS in water in the Danube River basin of the EE region.
(Source: GMP Data Warehouse.)

Sites	2007	2013	2019
All sites	155	120	146
Danube river	88	88	89
% in the Danube	57	73	61
Sample and analysis numbers			
PFOA	76	61	64
PFOS	79	58	41
FOSA*	0	0	41
PFHxS	0	0	0

Note: *All FOSA results were non-detect.

Highest median concentrations of PFOA were found in Danube waters of Czech Republic (Morava River), and in the Danube River in Hungary and Slovenia (see **Figure 39**). Relatively high PFOA was also found in 2 samples collected in the Ukraine at the mouth of the Danube, while lowest medians were present in the Danube waters of Croatia, Serbia, Romania and Bulgaria.

PFOS concentrations in Danube waters had a different pattern from PFOA with samples in Croatia and Serbia having relatively high median concentrations (2.1 ng/L and 2.9 ng/L, respectively) similar to samples from Hungary (1.8 ng/L) and Ukraine (1.7 ng/L). PFOS/PFOA ratios were highest in Serbia (4.5), the Czech Republic (2.3), and Croatia (2.0) and lowest in Romanian Danube waters (0.24). The relatively high PFOS/PFOA ratios imply legacy sources of PFOS. However, identifying the sources from the current data is challenging due to the snapshot nature of the sampling in 2019. No data was available for PFHxS for EE waters for the period 2015–2019.

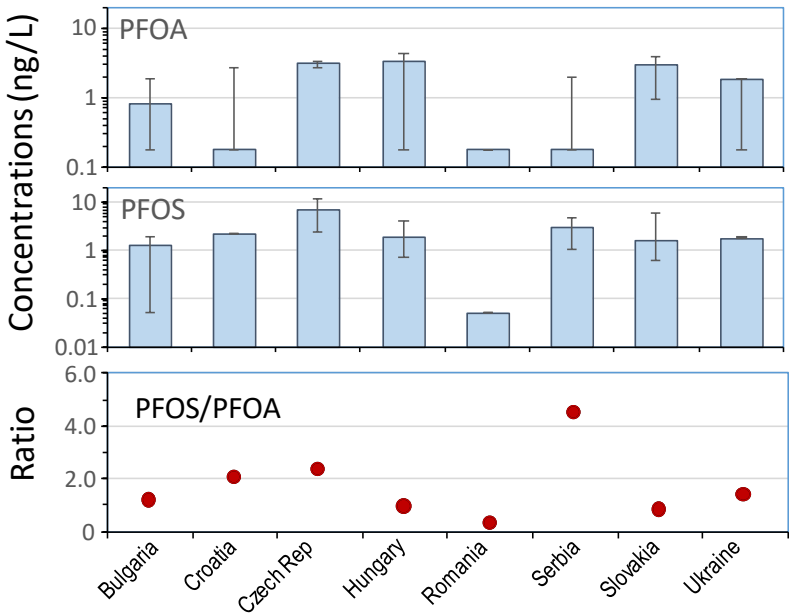


Figure 39. Median and range of PFOA and PFOS concentrations (ng/L) and PFOS/PFOA ratios in surface waters of rivers in the EE region.
(Source: GMP Data Warehouse, Joint Danube Survey of 2019 (ICPDR 2020). PFOS/PFOA ratios were calculated with arithmetic means for each country.)

(2) Temporal trends in waters of EE

Data for PFOS and PFOA in surface water were available from joint Danube surveys performed in 2007, 2013 and 2019 which included sampling of major tributaries and the main stem of the river. Although the same sampling sites were not sampled, and different laboratories were involved in the analysis, the same reaches of the Danube and tributaries were included. The proportion of sampling sites in the Danube was 56% in 2007, 73% in 2013 and 61% in 2019 was relatively similar. Thus, the relatively similar study design allowed qualitative assessments of temporal trends by country along the Danube.

Median PFOA concentrations were clearly much higher in 2007 than in 2013 or 2019 in samples from Croatia, Czech Republic, Hungary, Romania, Slovakia and Ukraine (see **Figure 40**). PFOA concentrations were higher in 2013 in Danube waters of Bulgaria and Serbia. PFOS median concentrations had quite different temporal trends from PFOA with only small changes between 2007 and 2013 at all locations (no samples were available for Czech Republic for 2013). However, levels of PFOS reported in 2019 were distinctly lower in 2019 than in 2013 at all sites. There is greater uncertainty in the 2019 data due to 46% having values <LOQ while for 2007 and 2013 only 5% of data were <LOQs. LOQ values were substituted with the lowest LOQ for each analyte. PFOS/PFOA ratios were generally higher in 2019 than in 2007 or 2013 (see **Figure 40**). This reflects the higher levels of PFOA in 2007 and 2013 and lack of major decline of PFOS as discussed above.

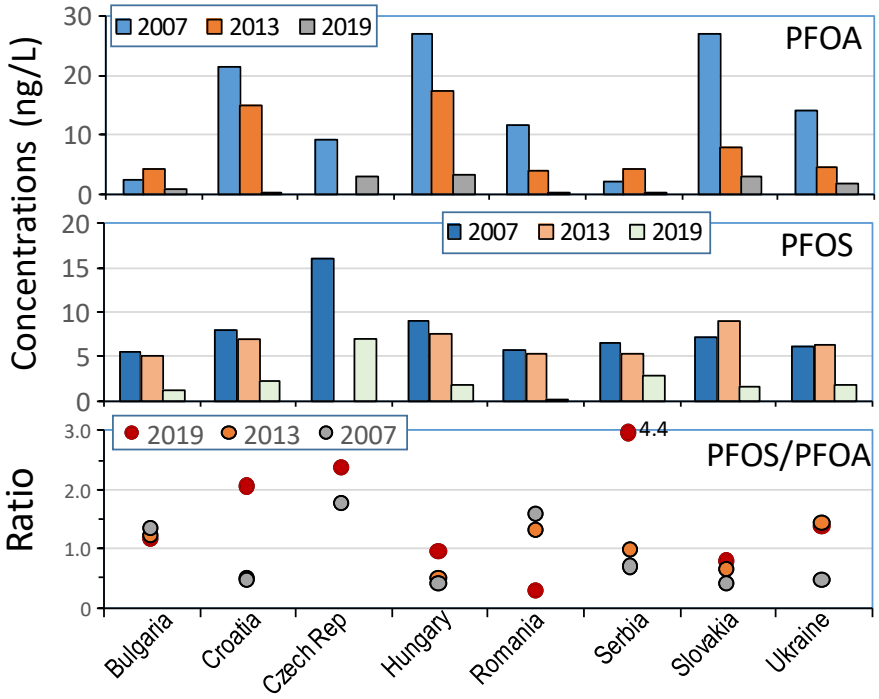


Figure 40. Temporal trends (2007, 2013, 2019) of PFOA and PFOS concentration (ng/L) and PFOS/PFOA ratios in surface waters of the Danube and tributaries based on Danube surveys.
(PFOS/PFOA ratios are based on arithmetic mean concentrations. Source: GMP Data Warehouse.)

4.3.3.4 Latin America and the Caribbean

(1) Country by country comparison in GRULAC

Results for the GRULAC were obtained from the UNEP/GEF GMP II project (Baabish et al. 2021) which reported PFOS, PFOA and PFHxS in surface waters from 6 freshwater and coastal seawater sites collected over the period from 2014 to 2019 (see **Table 11**). All data were available from the GMP Data Warehouse. Also included were results for the near shore marine waters of Todos os Santos Bay and its major tributary, Rio Paraguacu, in Bahia state (Löfstedt Gilljam et al. 2016). A single result for PFOS from an earlier GMP study which collected samples in Rio del Plata in Uruguay was also included (UNEP 2021b). The study in Todos os Santos Bay (Löfstedt Gilljam et al. 2016), represented near coastal marine waters and an inflowing river. The UNEP/GEF GMP II project represented the most extensive coverage to date of PFAS in surface waters in this region. Studies had previously been conducted on PFAS in the Paraiba do Sul River of southeastern Brazil in 2008 (Quinete et al. 2009) but no other published data were available for the GRULAC region.

Table 11. Summary for surface water monitoring programmes primarily in rivers, lakes and coastal sea water in the Latin America and the Caribbean region, 2014–2019.

Country	Years	Areas sampled	Sites/frequency	PFAS	Reference
Argentina	2017–2018	Rio de la Plata (Buenos Aires)	1 site (4 times/year)	PFOS, PFOA, PFHxS	UNEP/GEF GMP II project, Baabish et al. 2021
Brazil	2017	Amazon River (upstream of Itacoatiara)	1 site (4 times/year)	PFOS, PFOA, PFHxS	UNEP/GEF GMP II project, Baabish et al. 2021
Brazil	2018	São Paulo São Vicente channel	1 site (4 times/year)	PFOS, PFOA, PFHxS	UNEP/GEF GMP II project, Baabish et al. 2021
Brazil	2015	Baia Todos os Santos, Bahia state	7 sites	PFOS, PFOA, PFHxS	Löfstedt Gilljam et al. 2016
Ecuador	2017–2018	Daule and Babahoyo River Junction (Guayaquil)	1 site (4 times/year)	PFOS, PFOA, PFHxS	UNEP/GEF GMP II project, Baabish et al. 2021
Jamaica	2017–2018	Hunts Bay River estuary	1 site (4 times/year)	PFOS, PFOA, PFHxS	UNEP/GEF GMP II project, Baabish et al. 2021
Mexico	2017–2018	Ohuira Bay	1 site (4 times/year)	PFOS, PFOA, PFHxS	UNEP/GEF GMP II project, Baabish et al. 2021
Uruguay	2014	Río de la Plata	1 site	PFOS	UNEP 2021b

Highest median concentrations of PFOS, PFOA and PFHxS were found in samples from Argentina (Rio del Plata at Buenos Aires), the São Vicente channel in São Paulo and the Hunts Bay River estuary at Kingston, Jamaica (see **Figure** 41). These sites all are within or close to urban areas. The samples from Ecuador (Daule and Babahoyo River Junction; city of Guayaquil) had lower concentrations of PFOS, PFOA and PFHxS despite being from an urban area. However, this may be explained by river flow at that site. Similarly, the samples from the Amazon River (collected upstream of the city of Itacoatiara and about 270 km downstream of the large city of Manaus) had the lowest median concentrations of PFOS (0.13 ng/L) and PFOA (0.11 ng/L) and PFHxS at detection limits (0.01 ng/L). This undoubtedly reflects the relatively low population density of the Amazonia region and the tremendous river flow volume.

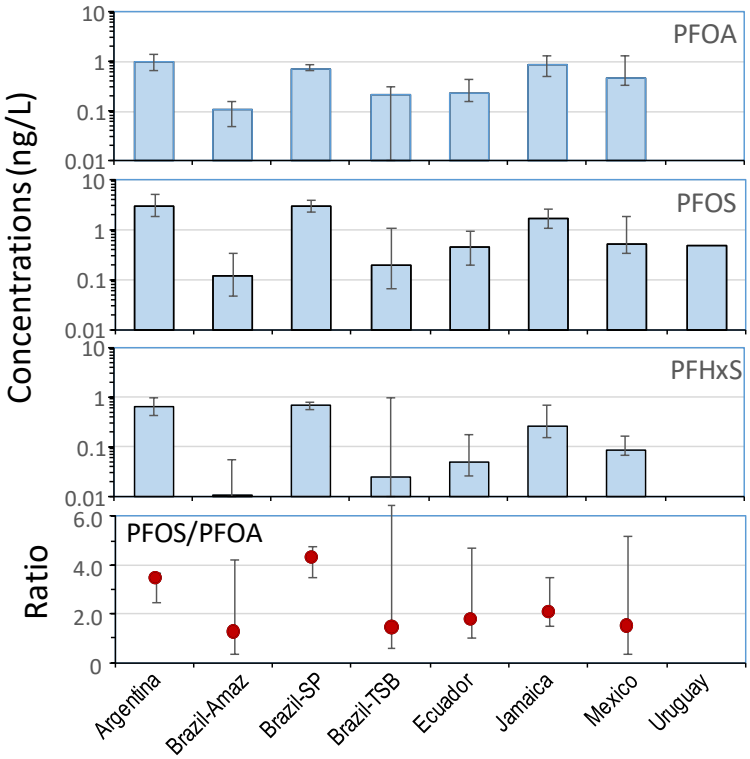


Figure 41. Median and range of PFOA, PFOS and PFHxS concentrations and PFOS/PFOA ratios in surface waters of rivers and coastal seawater of countries in the Latin America and the Caribbean region.
(Source: Baabish et al. 2021; Löfstedt Gilljam et al. 2016. Brazil-Amaz=Amazon River, Brazil-TSB=Baia Todos os Santos, Brazil-SP=Brazil São Paulo. The PFOS/PFOA for Uruguay (Rio del Plata, 2014) could not be calculated due to lack of data.)

Median PFOS/PFOA ratios ranged from 1.4 to 4.3 at 7 sites for which there was sufficient data. The highest ratio was for the São Vicente channel near São Paulo which is heavily influenced by urban activities.

A unique aspect of PFOS in Brazil and other countries in the region is the use of the insecticide sulfluramid in which the PFOS-precursor *N*-ethyl perfluorooctane sulfonamide (EtFOSA) is the active ingredient (Löfstedt Gilljam et al. 2016). The study by Löfstedt Gilljam et al. (2016) found high concentrations of perfluorosulfonamide (FOSA), the transformation product of EtFOSA (0.02−3.36 ng/L), in surface waters of Rio Paraguacu, a major inflow to Baia Todos os Santos. Use of EtFOSA in Brazil and export to other countries in the region (notably Argentina, Ecuador) may explain the higher PFOS/PFOA ratios in GRULAC compared to Africa and Asia-Pacific.

(2) Temporal trends in inland waters of GRULAC

No long-term monitoring data were available for PFOS, PFOA and PFHxS in surface waters of Latin America and the Caribbean countries. However, the UNEP/GEF GMP II project produced short-term temporal information for up to 8 sampling times at sites in 2017 and 2018 (Baabish et al. 2021). Trends for two sites are provided in **Figure 42**. The Hunts Bay River at Kingston Jamaica site had variations of <2 fold for PFOA and PFOS over the 21-month sampling period. In Ecuador PFOA variation was also <2-fold. However, PFOS concentrations varied by up to 5-fold, peaking in late June 2017 and in March and June 2018. The reason for the greater variation of PFOS is unknown and would require more detailed study. However the higher concentrations correspond roughly to the period of high river flow on the Babahoyo River in March-May (Barrera Crespo et al. 2019).

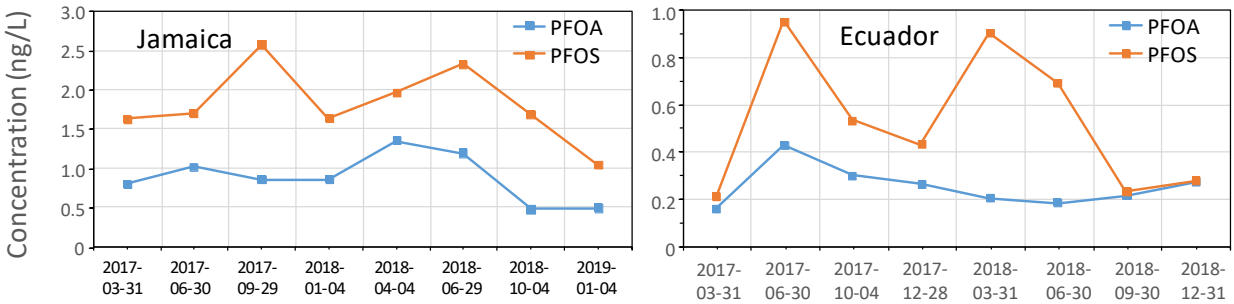


Figure 42. Temporal trend (2017–2018) of PFOA and PFOS concentrations (ng/L) in surface waters at sites in Jamaica (Hunts Bay River estuary, Kingston) and Ecuador (Daule and Babahoyo River Junction, Guayaquil). *(Sampling was conducted at the same location approximately every 3 months. Symbols represent single samples. Source: Baabish et al. 2021.)*

4.3.3.5 Western Europe and Others Group

(1) Country by country comparison in WEOG

Results for PFOS and PFOA in waters of the WEOG region for the period 2015–2019 are available in appendix 2 to the third regional monitoring report for WEOG (UNEP 2021d). Most of the available data were from peer reviewed scientific literature with additional results from government laboratories involved in monitoring and surveillance of contaminants in water. Based on data available to mid-2020 (see Table 12), 1,985 individual results were available for PFOS, PFOA and PFHxS of which 1,720 were for inland waters of WEOG. The other results were for adjacent seas and oceans.

Table 12. Summary of data available for PFAS in water in the WEOG region (to June 2020) including samples collected during 2015–2019.
(Source: Third regional monitoring report for WEOG, appendix 2.)

	Urban and non-urban sites (3,002)			Non-urban sites (2,435)		
	All 2000-2019	>MDL	2015–2019	All measurements	>MDL	2015–2019
PFOA	4,747	2,840	645	3,485	2,211	5,35
PFOS	3,812	2,598	808	2,979	2,040	6,97
PFHxS	2,711	1,250	582	2,171	1,087	472
Total	11,270	6,688	2,035	8,635	5,338	1,704

Note: MDL: Method detection limit.

Highest median concentrations of PFOA for the period 2015–2019 were reported for samples from the USA (1.96 ng/L; n=86), Canada (1.6 ng/L; n=67), and Germany (1.35 ng/L; n=28) (see **Figure 43**). In contrast samples from Italy (n=7) and Spain (n=16) had the lowest medians (<0.01 ng/L) due to a high proportion of non-detect values. PFOS concentrations were in the sample range as those for PFOA, with Canada (2.8 ng/L) and the USA (1.7 ng/L)

having the highest medians (see **Figure 43**). Median PFOS at detection limits were reported for Australia, Italy and Spain. The pattern of concentrations of PFHxS differed from PFOS and PFOA with highest values in samples from Malta (1.39 ng/L, n=41) and France (0.51 ng/L, n=28), while median concentrations reported for Canada and the USA were below detection limits. The study in Malta surveyed surface runoff water in 41 valleys during the wet season; precipitation as well as local road runoff were regarded as the main sources (Sammut et al. 2017). Thus, the study in Malta is rather unique, as it focused on precipitation events. Samples from other countries were generally from permanent and much larger waterbodies.

PFOS/PFOA ratios in the results from 2015–2019 ranged from 0.06 (Australia) to 3.5 (Canada). Values <1 were anticipated given the phase out of PFOS in WEOG countries in the early 2000s. However, the results point to continuing legacy sources of PFOS at the sampling locations.

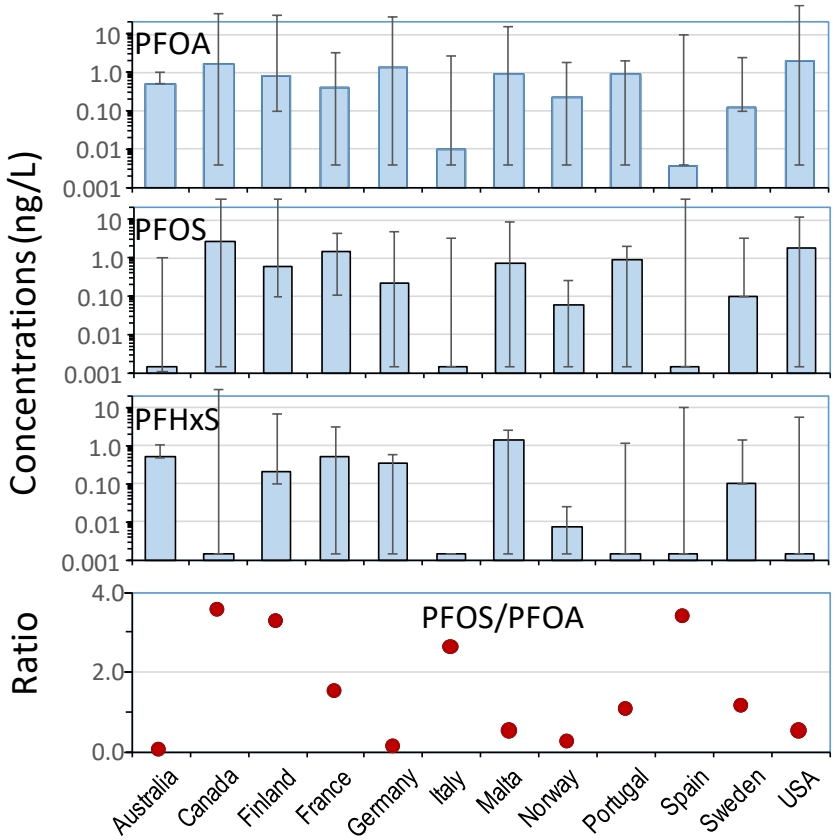


Figure 43. Median and range of PFOA, PFOS and PFHxS concentrations (ng/L) and PFOS/PFOA ratios in surface waters of rivers and lakes in the WEOG region.
(Third regional monitoring report for WEOG, appendix 2.)

(2) Temporal trends in waters of WEOG

Temporal trends for inland waters in WEOG were assessed using the full datasets for Western Europe and Canada/USA rather than by individual country. This was because sampling locations were not in the same region or body of water, unlike the case for Danube waters, or the sites used in the GMP study in 2017–2019. The large number of samples for each time period (**Table 13**) enabled a robust estimate of the variation around the median values. For this assessment, urban and non-urban results were combined, however, they are discussed separately in the WEOG report (UNEP 2021d).

Median PFOS concentrations were 2-fold higher in Europe than Canada/USA for the period 2000–2009; for more recent measurements (2015–2019) North American medians were 4-fold higher (see **Table 13**; **Figure 44**). Similarly median concentrations for PFOA were 2.9-fold higher in Western Europe waters than in Canada/USA for the 2000–2009 period but 3-fold lower for 2015–2019. PFHxS concentrations were distinctly different for all time periods with higher medians in Western Europe than North America in 2000–2009 and in 2015–2019.

Median PFOS concentrations in Western Europe sites declined 72% between samples collected in 2000–2009 and in 2015–2019 but were 90% higher in Canada/USA waters over the same period. Median PFOA in 2015–2019 was 76% lower than in 2000–2009 in Europe and but much higher (130%) in Canada/USA samples. Median PFHxS concentrations at non-urban sites in Europe increased 185% between 2000–2009 and 2015–2019 and had a huge increase in North American waters (from 0.007 to 0.68 ng/L) over those time periods (see **Table 13**). The increased

level of PFOS, PFOA and PFHxS in North America may not reflect an overall regional trend. Instead, it was more likely due to the locations being sampled. The 2015–2019 period included site specific surveys of relatively small water bodies in rural and suburban surface waters in New Jersey (Procopio et al. 2017), Rhode Island and New York (Zhang et al. 2016), and in Washington State (Mathieu and McCall 2017). Nevertheless, the results suggest continued significant PFAS emissions to the aquatic environments in both rural and urban regions in North America.

Data for PFOS and PFOA in Australian and New Zealand rivers and streams were available but too limited temporally to effectively evaluate temporal trends. Recent (2015–2019) measurements show low background concentrations of PFOS in Australian river waters compared to earlier measurements which were mainly from urban influenced areas (see **Table 13**). Limited sample numbers for PFOA and PFHxS and a high proportion of non-detect values for PFOS precluded robust temporal comparisons.

Table 13. Summary of available data for PFOA, PFHxS and PFOS in inland waters of Western Europe, Canada/USA and Australia (ng/L).
(All sites within each region included. Comparison of medians, data dispersion (median absolute deviation (MAD)/median) and number of measurements # by region, pre-2010, 2010–2014 and 2015–2019, where available.)

	Period	PFOA			PFHxS			PFOS		
		Median	MAD/ Median	#	Median	MAD/ Median	#	Median	MAD/ Median	#
Western Europe (rivers and lakes)	**2000–2009**	2.67	0.99	1053	0.07	0.98	378	1.82	1.00	888
	2010–2014	3.00	1.00	1537	0.001	0.00	451	0.90	1.00	534
	2015–2019	0.63	0.84	339	0.20	0.99	282	0.50	0.86	381
% change (2000–2009 vs 2015–2019)		-76%			184%			-72%		
Canada/USA (rivers and lakes)	**2000–2009**	0.91	1.00	429	0.007	0.80	357	0.90	1.00	425
	2010–2014	0.95	1.00	263	0.001	0.00	199	0.03	0.94	263
	2015–2019	2.09	1.00	117	0.68	1.00	117	1.71	1.00	117
% change (2000–2009 vs 2015–2019)		130%			9577%			90%		
Australia	**2010–2014**	1.20	0.83	13	2.50	0.90	13	3.10	0.74	14
	2015–2019	0.50	0.00	14	0.50	0.00	14	0.001	0.00	134
% change (2010–2014 vs 2015–2019)		-58%			-80%			-100%		

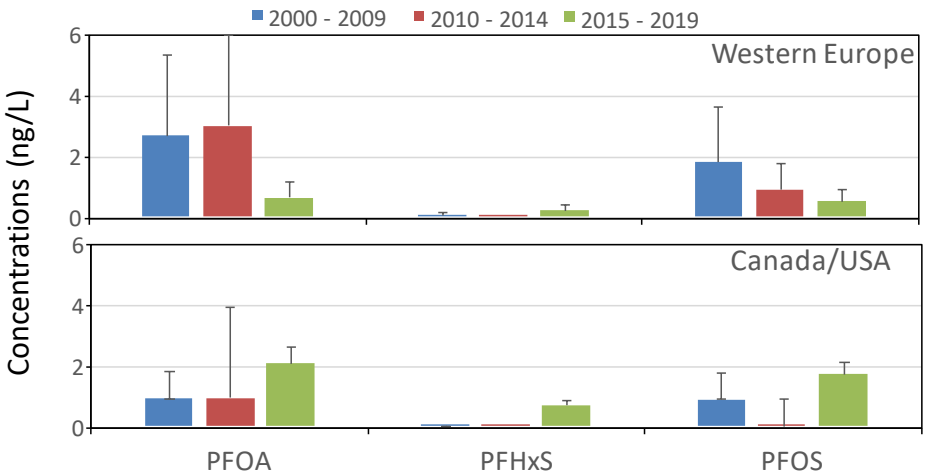


Figure 44. Temporal trend (2000–2009, 2010–2014, 2014-19) of PFOA, PFHxS and PFOS median concentrations (ng/L) in river and lake waters in Western Europe and North America (Canada/USA).
(Vertical lines represent the range of median absolute deviation.)

The largest PFOS, PFOA and PFHxS datasets for Western European inland waters are samples from the Ebro, the Elbe, and the Rhine rivers and their tributaries. This enabled assessment of annual median concentrations (see **Figure** 45). A 4-fold decline of PFOA and PFOS, and a 7-fold decline of PFHxS, from about 2008 to 2016 occurred in the Rhine coinciding with phase out of most uses of PFOS-related products in Europe. Much lower concentrations of PFOS, PFOA and PFHxS were found in the Elbe in 2014–2015 compared to 2007–2008. However, in the Ebro, higher median concentrations were found in 2011 compared to 2007–2009. Temporal trends in these rivers are discussed in more detail in the third regional monitoring report for WEOG (UNEP 2021d).

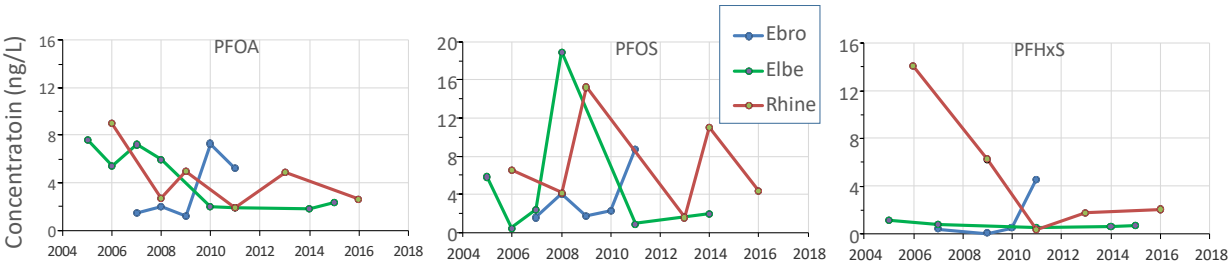


Figure 45. Temporal trends of PFOA, PFOS and PFHxS median concentrations in the Ebro, Elbe, and Rhine Rivers in Europe.
(These rivers were selected due to having 5 or more annual sampling years. Non-urban influenced sampling locations were used. See also the third regional monitoring report for WEOG.)

4.3.4 Spatial and temporal trends in coastal seas and open ocean waters

4.3.4.1 Asia-Pacific

A large number of oceanographic cruises in coastal seas and open ocean waters since the early 2000s have resulted in a substantial number of measurements of PFAS in the Asia-Pacific region, (~700 samples reported to be analyzed) (Muir and Miaz 2021; Podder et al. 2021). In addition, the UNEP/GEF GMP II project included coastal seawater samples from 6 island nations in Asia-Pacific (see **Table 8**) (Baabish et al. 2021). China's national environmental monitoring also includes data for seawater collected near Hong Kong SAR (China) and in the Bohai and Yellow Seas. A long-term monitoring program in Japan for PFAS in water includes coastal seawater samples (Japan Ministry of the Environment 2020). The available data for 2014–2019 for seawater and ocean water in Asia-Pacific are discussed below and compared to earlier time periods where possible.

Long-term monitoring of seawater from coastal Japan has provided insights into the status of PFAS in surface waters in this region. Annual median concentrations of PFOA and PFOS in the period 2015–2018 ranged from 0.62–1.1 ng/L and 0.21–0.48 ng/L, respectively. No statistically significant declining trends for median PFOA or PFOS concentrations were observed (see **Figure 46**; **Table 9**).

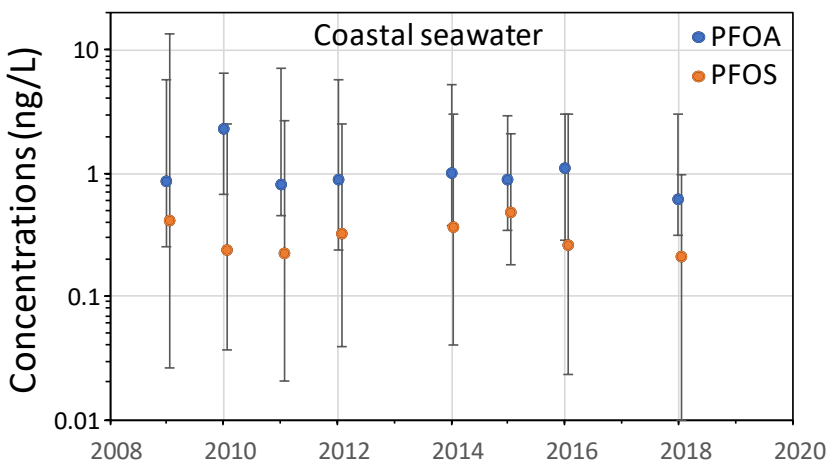


Figure 46. Temporal trends (2009–2019) of PFOA and PFOS concentrations (ng/L) in coastal seawater of Japan.
(Symbols represent medians and vertical lines define the range (min-max). Results are from the long-term monitoring program of the Ministry of the Environment of Japan (Japan Ministry of the Environment 2020).)

The UNEP/GEF GMP II project (Baabish et al. 2021) provided the first data for surface waters of 9 Pacific Island nations of which 6 (Kiribati, Marshall Islands, Niue, Palau, Tuvalu, Vanuatu) were coastal seawater samples over a 2 year period (2017–2019). Sampling at Kiribati and Vanuatu was conducted at approximately 3-month intervals resulting in short-term trends of PFOA, PFOS and in near shore coastal waters (see **Figure 47**). Higher concentrations were observed at Mele Bay in Vanuatu which may reflect the urban influence of nearby Port Vila. PFOS was higher than PFOA at both locations as well as in Palau, suggesting the predominance of legacy sources of PFOS. Limited sampling in Niue, Palau and Tuvalu prevented assessment of temporal trends.

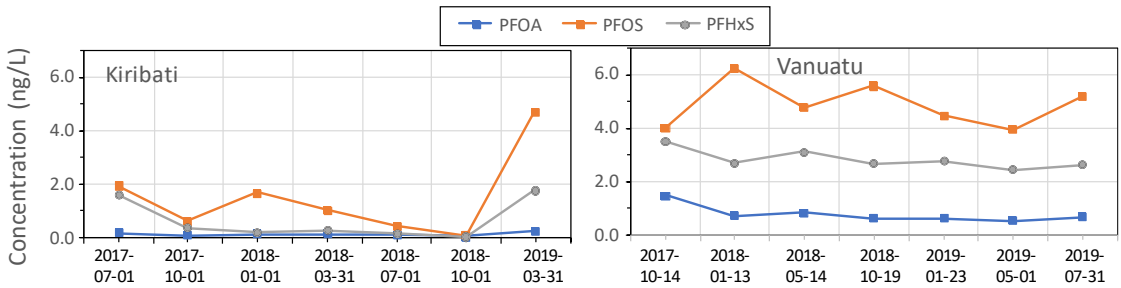


Figure 47. Temporal trends (2017–2019) of PFOA, PFOS and PFHxS concentrations (ng/L) in coastal surface seawaters of Kiribati (Bonriki, Tarawa atoll) and Vanuatu (Mele Bay).
(Source: Baabish et al. 2021. Symbols represent single samples collected at the same location approximately every 3 months.)

Measurements of PFOS, PFOA and PFHxS have been made in surface waters of the Sea of Japan (including Sea of Okhotsk), the Bohai and Yellow Seas, the East China, and South East China Seas as well as in the North Pacific and Indian Oceans. These sampling programmes involve collections at sites ranging from a few km to hundreds of km offshore and have been conducted from coastal and ocean-going research vessels. The extensive dataset permits assessment of spatial and temporal trends in offshore coastal waters of this region. A recent review summarized results for these seas and compared them with coastal seas of Europe (Muir and Miaz 2021).

PFOA was the most prominent PFAS in coastal seas of the Western Pacific Ocean region with median concentrations in 2015–2019 at 0.05 ng/L (n=38) in the Sea of Japan (see **Figure 48**; **Table 14**). Due to non-detect concentrations at many offshore sites, PFOS/PFOA ratios could not be calculated for every time period. PFHxS concentrations were higher in the Sea of Japan in 2015–2019 than in earlier periods.

Median PFOS and PFHxS concentrations in the North Pacific and the Indian Ocean were higher in 2010–2014 than in 2015–2019, while PFOA was lower (see **Figure 48**). In general concentrations of PFOS, PFOA and PFHxS were near or at detection limits (<0.01 ng/L) in 2015–2019 in the North Pacific and the Indian Ocean. However, given the huge area, comparison between time periods is problematic as concentrations are likely to be influenced by the route of the oceanographic cruise and its proximity to regional seas where concentrations may be higher.

A more detailed view of these temporal trends is seen in the annual medians which are plotted in **Figure 49** for North Pacific Ocean with 5 or more sampling years. The decline trend was evident for PFOA (P=0.053) after omitting a very high median value for 2017 (see **Figure 49**; **Table 9**). A sharp decline of PFOA and PFOS in the North Pacific was also observed from 2009 to 2014, however, sample numbers were limited for some years (n=1 in 2014; n=19 in 2011).

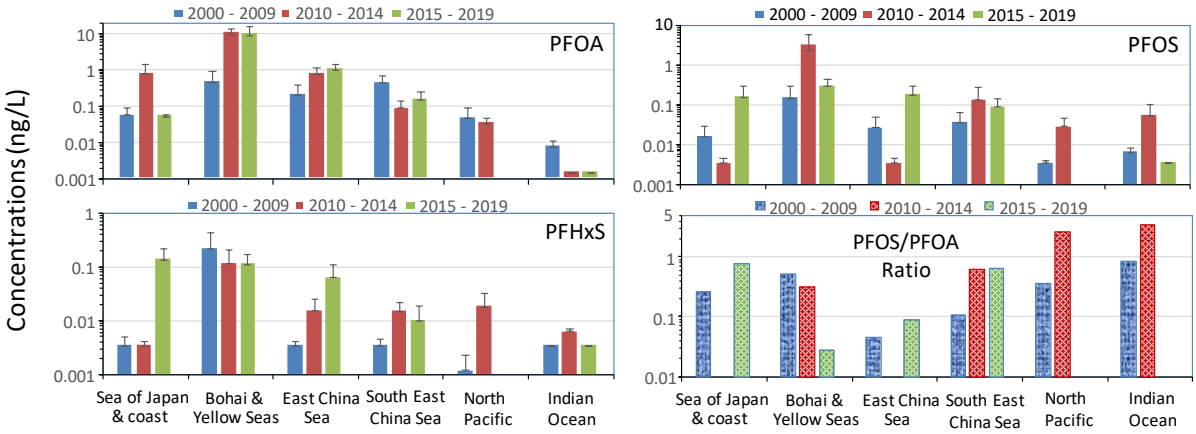


Figure 48. Temporal trends (2000–2009, 2010–2014, 2015–2019) of PFOA, PFOS, PFHxS median concentrations (ng/L) and PFOS/PFOA ratios in coastal seas and ocean waters of the Asia-Pacific region.
*(Error bars are Median absolute deviations. Missing results are due to insufficient data for the time period. Results including sample numbers for each time period are provided in **Table 14**.)*

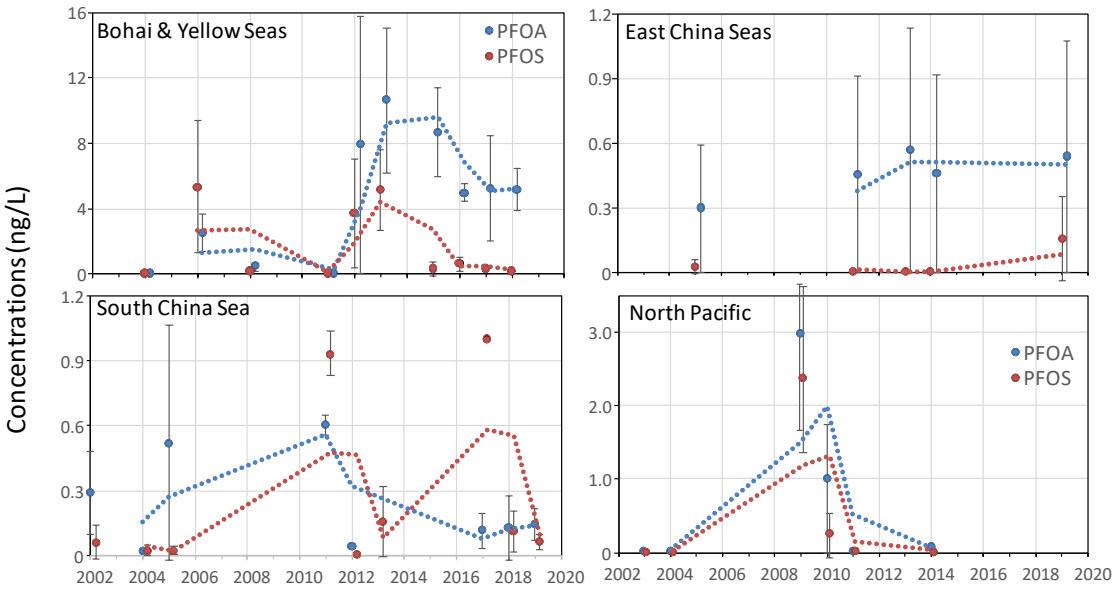


Figure 49. Temporal trends (2002–2019) of PFOA and PFOS median concentrations (ng/L) in the North Pacific Ocean.

(These locations were selected due to having 5 or more years of data. However, samples are limited in some years especially for the North Pacific. Error bars are median absolute deviations. Dotted lines are 2-year moving averages.)

Table 14. Summary of available data for PFOA, PFHxS and PFOS as well as PFOS/PFOA ratios in offshore coastal seas and oceans waters (ng/L).

(Comparison of medians, data dispersion (MAD/median) and number of measurements # by region, 2000–2009, 2010, 2010–2014, and 2015–2019 and % change from 2000–2009 to 2015–2019. % change is omitted where medians are non-detects.)

Water body	Period	PFOA			PFHxS			PFOS			PFOS/PFOA		
		Median	Mad/med	#	Median	Mad/med	#	Median	Mad/med	#	Median	Mad/med	#
North Sea	2000–2009	0.72	1	111	0.092	0.96	104	0.7	3.37	199	0.529	3.37	94
	2010–2014	1.09	0.53	107	0.25	0.44	107	0.31	1.13	107	0.267	1.13	49
	2015–2019	0.45	0.4	43	0.14	0.36	43	0.054	4.36	51	0.098	4.36	43
% change (2000–09 vs 2015–19)		-38%	–		52%	–	–	-92%	–	–	-81%	–	–
Baltic Sea	2000–2009	0.42	0.19	97	0.09	0.56	97	0.21	3.67	107	0.469	3.67	97
	2010–2014	0.52	0.26	18	0.42	0.4	18	0.73	6.26	18	1.35	6.26	18
	2015–2019	0.28	0.64	55	0.2	0.4	31	0.2	2.38	75	0.162	2.38	43
% change (2000–09 vs 2015–19)		-33%	–	–	122%	–	–	-5%	–	–	-65%	–	–
Mediterranean Sea	2000–2009	0.39	0.82	25	0.004	0	25	0.14	1.13	25	0.517	1.13	25
	2010–2014	0.07	0.33	45	0.007	0.9	37	0.023	3.83	45	0.665	3.83	24
	2015–2019	0.001	0	18	0.004	0	12	0.12	10	18	ND	10.1	3
% change (2000–09 vs 2015–19)		-100%	–	–	0%	–	–	-14%	–	–	ND	–	–
Sea of Japan and Sea of Okhotsk	2000–2009	0.051	0.61	38	0.004	0.43	36	0.016	3.54	42	0.276	3.54	26
	2010–2014	0.75	0.89	66	0.004	0	66	0.004	1.02	94	0.005	1.02	60
	2015–2019	0.05	0	13	0.134	0.63	13	0.16	1.07	13	0.797	1.07	13
% change (2000–09 vs 2015–19)		-2%	–	–	ND	–	–	900%	–	–	189%	–	–
Bohai & Yellow Seas	2000–2009	0.43	1	43	0.216	1	12	0.15	1.3	43	0.548	1.3	43
	2010–2014	9.595	0.3	56	0.115	0.83	28	3.3	2.29	58	0.314	2.29	41
	2015–2019	9.046	0.61	131	0.11	0.55	131	0.29	1.39	131	0.028	1.39	128
% change (2000–09 vs 2015–19)		2004%	–	–	-49%	–	–	93%	–	–	-95%	–	–
East China Sea	2000–2009	0.193	0.87	14	0.004	0	15	0.027	4.49	15	0.047	4.49	14
	2010–2014	0.736	0.53	26	0.016	0.65	26	0.004	1.15	26	0.014	1.15	22
	2015–2019	0.975	0.41	4	0.063	0.72	4	0.184	8.78	4	0.094	8.78	4
% change (2000–09 vs 2015–19)		405%	–	–	ND	–	–	581%	–	–	100%	–	–
	2000–2009	0.42	0.62	19	0.004	0	15	0.036	1.06	19	0.112	1.06	17

Water body	Period	PFOA			PFHxS			PFOS			PFOS/PFOA		
		Median	Mad/med	#	Median	Mad/med	#	Median	Mad/med	#	Median	Mad/med	#
South-East China Sea	**2010–2014**	0.08	0.55	95	0.015	0.51	85	0.133	1.63	117	0.635	1.63	90
	2015–2019	0.141	0.67	198	0.01	0.9	152	0.09	2.27	198	0.658	2.27	162
% change (2000–09 vs 2015–19)		-66%	–	–	ND	–	–	150%	–	–	488%	–	–
Indian Ocean	**2000–2009**	0.0074	0.00325	25	0.004	0.0000	25	0.007	0.0021	27	0.88	–	27
	2010–2014	0.0014	0	59	0.006	0.0006	22	0.055	0.0504	59	ND	–	60
	2015–2019	0.0014	0	24	0.004	0.0000	24	0.004	0.0000	24	ND	–	25
% change (2000–09 vs 2015–19)		-81%	–	–	ND	–	–	ND	–	–	–	–	–
South Atlantic	**2000–2009**	0.007	0.8	47	0.004	0.29	31	0.024	2.18	57	2.5	2.18	47
	2010–2014	0.024	0.94	39	0.035	0.9	39	0.305	1.3	39	10.8	1.3	39
	2015–2019	0.208	0.36	3	0.055	0.94	3	0.294	1.61	3	1.41	1.61	3
% change (2000–09 vs 2015–19)		2871%	–	–	ND	–	–	1125%	–	–	-44%	–	–
Arctic Ocean	**2000–2009**	0.05	0.41	122	0.008	0.56	120	0.011	1.59	122	0.313	1.59	119
	2010–2014	0.043	0.37	65	0.004	0	63	0.021	1.95	82	0.568	1.95	39
	2015–2019	0.054	0.17	31	0.004	0	31	0.025	3.01	31	0.455	3.01	31
% change (2000–09 vs 2015–19)		8%	–	–	ND	–	–	127%	–	–	45%	–	–
North Pacific	**2000–2009**	0.045	0.8	11	0.001	0.92	11	0.004	1.07	11	0.379	1.07	11
	2010–2014	0.032	0.4	28	0.019	0.81	28	0.028	2.48	77	2.63	2.48	28
	2015–2019	–	–	–	–	–	–	–	–	–	–	–	–
% change (2000–09 vs 2015–19)		-29%	–	–	ND	–	–	600%	–	–	594%	–	–
North Atlantic	**2000–2009**	0.08	0.6	141	0.008	0.66	75	0.043	1.8	173	0.581	1.8	141
	2010–2014	0.103	0.73	85	0.043	0.85	85	0.075	1.9	85	0.818	1.9	63
	2015–2019	–	–	–	–	–	–	–	–	–	–	–	–
% change (2000–09 vs 2015–19)		29%	–	–	438%	–	–	74%	–	–	41%	–	–
Southern Ocean/Antarctica seas	**2000–2009**	0.001	0.5	17	0.001	0	17	0.008	1.46	23	ND	1.46	17
	2010–2014	0.001	0	60	0.004	0	32	0.004		56		–	50
	2015–2019	0.041	0.66	35	0.004	0	18	0.01	2.52	35	0.737	2.52	6
% change (2000–09 vs 2015–19)		4000%	–	–	ND	–	–	25%	–	–	–	–	–

4.3.4.2 The North American Great Lakes

The North American Great Lakes have a large number of measurements of PFAS in water and also are one of the few inland regions with enough data to evaluate temporal trends. Thus, they are discussed separately from other inland waters in Canada/USA. PFAS in approximately 300 surface water samples have been reported since 2002 with the majority from offshore non-urban locations. However, comparison of only non-urban sites was problematic because of a high percentage of results that were less than method detection limits (MDLs) (2000–2009=76%, 2010–2014=60% and 2015–2019=51%), especially in Lakes Superior, Huron and Michigan. Median concentrations and MAD/median values for PFOS, PFOA and PFHxS for all sites in the Great Lakes for the combined urban and non-urban sites are provided in **Table 14**. Median concentrations of PFOA, and PFOS, as well as PFOS/PFOA ratio in 2015–2019 were 37 %, 159% and 108% higher, respectively, than in the period 2000–2009 (see **Table 14**).

Sufficient data were available to calculate annual medians of PFOA and PFOS in the Great Lakes, combining results from all 5 lakes, to further assess temporal trends (see **Figure 50**), Significant declines in median concentrations of PFOA (P=0.035) and PFOS (P=0.035) were observed for the period 2004–2017. The declines in the Great Lakes represented environmental half-lives of 1.8 y for PFOA and 1.7 y for PFOS in lake waters (see **Table 9**). These half-lives are much smaller than the estimate of 15 y for PFOA and PFOS in the Great Lakes precipitation based on sampling from 2006 to 2018 (Gewurtz et al. 2019). The decline, based on 12 sampling years differed from the results based on medians calculated for broader time periods (see **Table 14**) and illustrates that results based on individual sampling years, if available, provide a more accurate picture of trends, especially when the dataset includes a lot of non-detect values.

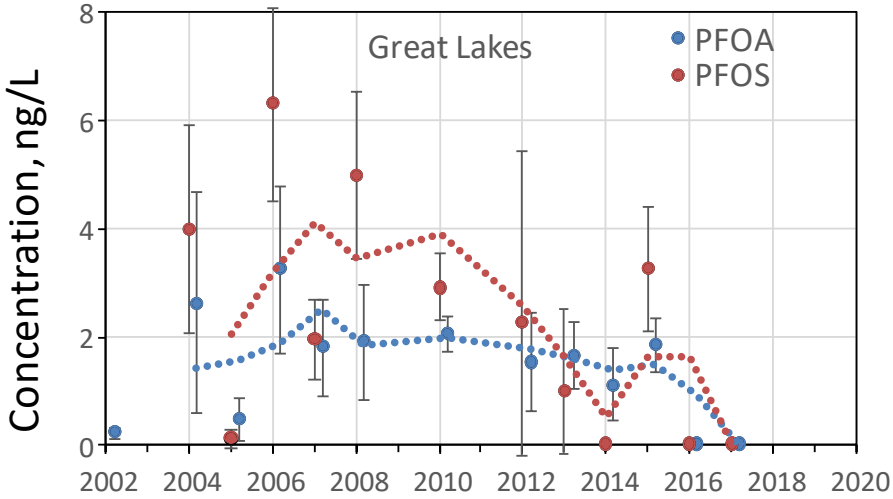


Figure 50. Temporal trends (2002–2019) of PFOA and PFOS annual median concentrations (ng/L) in the North American Great Lakes.
(Data are from all 5 lakes and sampling locations, thus including urban and non-urban influenced locations. Error bars are Median absolute deviations.)

4.3.4.3 Seas and Oceans of Africa, Asia-Pacific, GRULAC, WEOG

Oceanographic cruises in coastal seas and open ocean waters in the Atlantic Ocean and the Arctic Ocean since the early 2000s have resulted in a substantial number of measurements of PFAS which permits assessment of geospatial and temporal trends. Detailed datasets for PFAS are available for 6 seas/oceans: the Baltic, North and Mediterranean Seas, the North and South Atlantic, and the Arctic Ocean (see **Table 14**). There are only limited measurements in the Southern Ocean near Antarctica, and most are near or at detection limits (<0.01 ng/L) which precludes comparison of medians over time.

Detailed measurements have been made for PFAS in the Baltic Sea (Ahrens et al. 2010; Kallenborn et al. 2004; Kirchgeorg et al. 2010), the North Sea (Ahrens et al. 2010; ICES 2020; Theobald et al. 2011) and the Mediterranean Sea (Brumovský et al. 2016; Schmidt et al. 2019; Yamazaki et al. 2019). In general, median concentrations of PFOS, PFOA and PFHxS at combined urban and non-urban influenced sites and non-urban only sites in Europe's coastal seas were similar. Data dispersion was low (medians of MAD/median values for all sites vs non-urban sites of 0.30 and 0.45, respectively) compared to rivers in Western Europe (see **Table 12**; **Table 14**). Lower median concentrations of PFOA were found in combined urban and non-urban samples from 2015–2019 compared to 2000–2009 in the Mediterranean (-100%), the Baltic (-33%) and the North Sea (-38%) (see **Table 14**; **Figure 48**). PFOS concentrations were 14% lower in 2015–2019 than 2000–2009 in the Mediterranean, 5% lower in the Baltic Sea and the North Sea (-92%). PFHxS concentrations were the same or higher in 2015–2019 compared to 2000–2009 in all coastal waters. The uncertainty of the comparison of medians is higher as fewer samples were collected in the period 2015–2019 in the North Sea (n=43) compared to earlier periods (>100). PFOS/PFOA ratios declined in the North Sea and the Baltic from 2000–2009 to 2015–2019 (see **Figure 51**).

From a global perspective, the Baltic and the North Sea had similar median concentrations of PFOA to the East China Sea and the South East China Sea although lower than the Bohai and Yellow Seas (Figure 48 and 51). PFOS concentrations in the European seas were generally higher than the East China Sea and the South East China Sea. PFHxS concentrations in the Baltic and the North Sea were distinctly higher than in the Mediterranean, the East China and the South East China seas (**Figure 48** and **Figure 51**). The result for PFHxS may imply that a distinctive source or formulation of perfluoroalkyl sulfonates was emitted in this region.

The lowest median concentrations of PFOS, PFOA and PFHxS in the 6 seas/oceans for the period 2015–2019 were measured in the Arctic Ocean with median concentrations of 0.054 ng/L, 0.004 ng/L and 0.025 ng/L, respectively (see **Figure 51**). The results for the Arctic Ocean are mainly for the Bering, Chukchi, Beaufort, and Greenland Seas, while the seas and coastal waters north of Russia lack published data. The South Atlantic had highest concentrations of PFAS of all open ocean waters in the period 2015–2019 (see **Figure 48**; **Figure 51**) with medians of 0.21 ng/L for PFOA, 0.055 ng/L for PFOS and 0.29 ng/L for PFHxS. PFOS, PFOA and PFHxS were also relatively higher in the South Atlantic in 2010–2014 compared to other oceans.

Elevated PFOS in the South Atlantic was first observed by Benskin et al. (2012) and confirmed by González-Gaya et al. (2014) who found higher concentrations along the Brazilian coast and also in the open South Atlantic. The use of

sulfluramid (EtFOSA), a PFOS precursor, in Brazil and neighboring countries is the likely source as discussed in the context of inland waters in GRULAC. Use of EtFOSA in Brazil doubled from 2009 to 2014 (Löfstedt Gilljam et al. 2016), which may explain why the South Atlantic has higher PFOS concentrations and PFOS/PFOA ratios than other oceans in 2010-2019 and but similar or lower medians in 2000–2009 (see **Table 14**; **Figure 51**). In general, median concentrations of PFOS, PFOA and PFHxS in the North and South Atlantic were higher in 2010–2014 than in the North Pacific or Indian oceans (see **Table 14**). The presence of lower levels in the North Pacific occurs despite relatively elevated concentrations of PFOA and PFOS in coastal Republic of Korea and Japan (see **Figure 48**). Waters influenced by the Kuroshio Current, which moves East Asian off shore waters northeastward, had very low median concentrations of PFOA and PFOS (0.032 and 0.19 ng/L, respectively) about 2-fold lower than the North Atlantic for 2010–2014 (see **Table 14**).

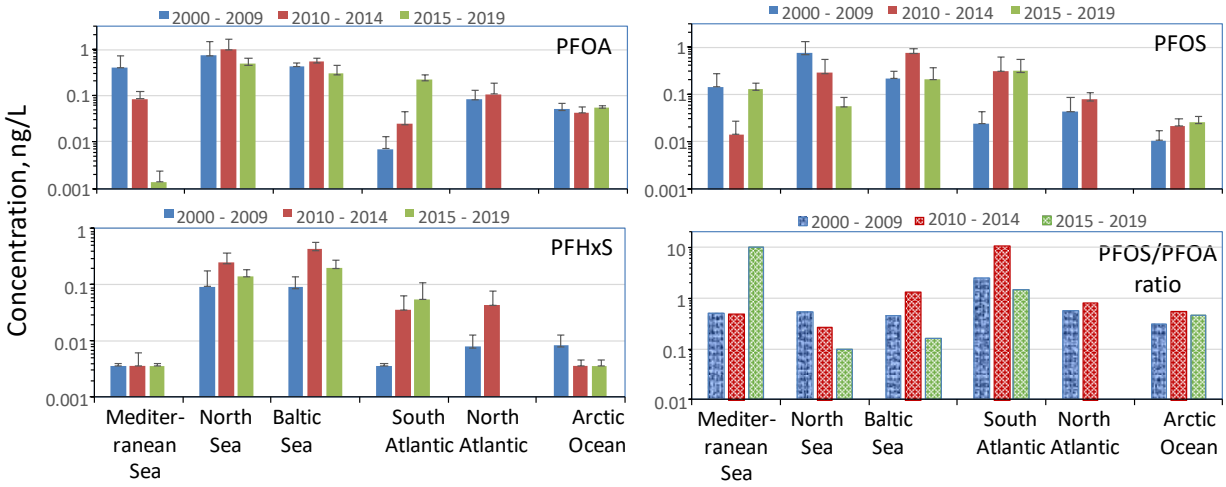


Figure 51. Temporal trend (2000–2009, 2010–2014, 2015–2019) of PFOA, PFOS and PFHxS median concentrations (ng/L) and PFOS/PFOA ratios in coastal seas and ocean waters of WEOG, Africa and GRULAC.
*(Vertical lines are Median absolute deviations. Missing results are due to insufficient data for the time period. Results including sample numbers for each time period are provided in **Table 14**.)*

The North Sea and the Baltic Sea both showed declining median concentrations of PFOA and PFOS (see **Figure 52**), however, these trends were not statistically significant (P>0.05) for the period 2003–2017 (see **Table 9**). Median PFOA and PFOS declined significantly (P=0.035 for both) in the Mediterranean for the period 2012–2018 (see **Table** 9). PFOS declined significantly in the North Atlantic over the period 2007–2014 with a half-life of 17 years (see **Table 9**). No data was available for the open waters of the North Atlantic for 2015–2019. No significant declines in median concentrations of PFOS or PFOA were found for the Arctic Ocean (see **Figure 52**; **Table 9**).

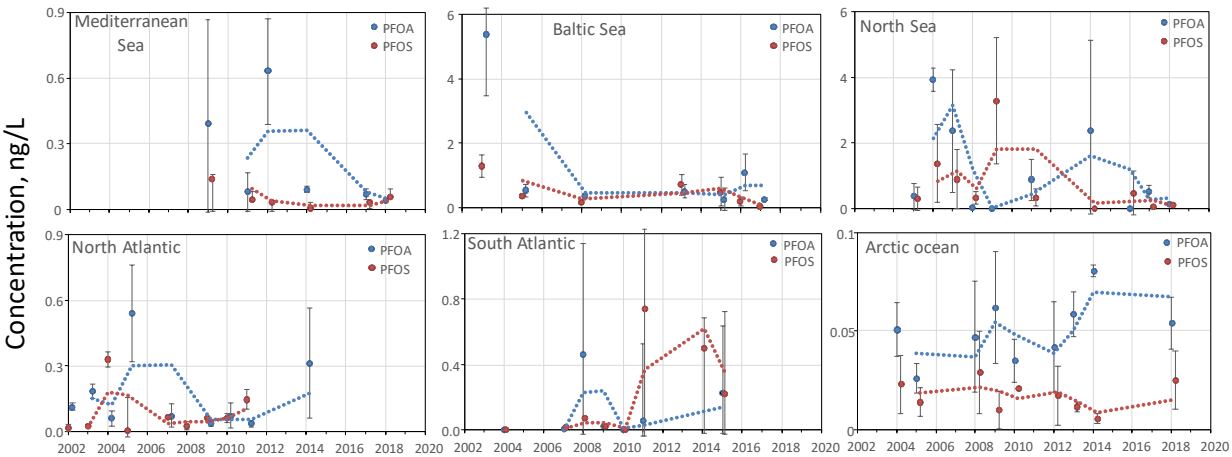


Figure 52. Temporal trends (2002–2019) of PFOA and PFOS median concentrations (ng/L) in 3 coastal seas of Europe, the Great Lakes, and the North and South Atlantic oceans.
(Regions were selected with 5 or more years of data. Error bars are median absolute deviations. Dotted lines are 2-year moving averages.)

4.3.5 Global modelling of PFOS and PFOA in oceans and seas

Global and regional environmental fate and distribution models have been successful in predicting PFOS and PFOA concentrations and temporal trends in coastal and open ocean waters. Modelling has predicted the geospatial variation in concentrations in surface and deep waters of the North Atlantic (Armitage et al. 2009a; Stemmler and Lammel 2010; Zhang et al. 2017) and in latitudinal zones equivalent to the Central North Atlantic and North Pacific Oceans (Armitage et al. 2009b; Wania 2007).This may reflect, in part, the fact that PFOA and PFOS are persistent water soluble compounds and thus good tracers of water masses (Yamashita et al. 2008).

Temporal and spatial trends of PFOS in the North Atlantic Ocean and transport to the Arctic were studied by Zhang et al. (2017) using a 3D ocean general circulation model for the North Atlantic. The model results are presented as a case study in **5. Long-range environmental transport** and are briefly described here in order to compare with observed levels in the North Atlantic.

Inputs of PFOS to the North Atlantic were assumed to be from rivers only because the contribution from atmospheric deposition was thought to be small based on earlier modelling by Armitage et al. (2009b). Zhang et al. utilized the per capita estimates for PFOS emissions developed by Pistocchi and Loos (2009). Zhang et al. (2017) predicted PFOS concentrations of 39 ± 14 pg/L in the North Atlantic in 2010, declining slowly to 35 pg/L by 2020, assuming negligible inputs after 2010. Median concentrations in the North Atlantic were 49 pg/L for 2000–2009, thus similar to modelled results. However, including coastal areas, median PFOS was much higher at 110 pg/L (see **Table 14**). This spatial variability is in agreement with the model which predicted concentrations ranging from 100–500 pg/L in the coastal North Atlantic (Gulf of St Lawrence, North Sea). The assumption of negligible emissions after 2010 appears to have been overly conservative, as measurements suggest increasing PFOS in the Central Atlantic in 2010–2014 compared to 2000–2009 (see **Table 14**).

Stemmler and Lammel (2010) predicted seawater concentrations of PFOA using a global coupled atmosphere-ocean circulation model. Similar to Zhang et al. they noted that knowledge of ocean circulation and its variations was crucial to understanding PFOA's large-scale distribution and fate. Stemmler and Lammel (2010) predicted surface water concentrations of 50 pg/L in the western North Atlantic (Labrador Sea) in agreement with measurements by Yamashita et al. (2005). However, their emissions scenario was based only on fluoropolymer manufacturing sources (to air and water) in the USA, Japan, Belgium and Italy, rather than on riverine inputs, and thus not reflecting extensive measurements of PFOA for rivers in Europe, North America, as well as in East Asia.

Armitage et al. (2009b) modelled PFOS concentrations in the global oceans using the CliMoChem model which divided the global environment into a series of latitudinal bands spanning 18° of latitude. Model inputs included estimated emissions of volatile precursors (FOSEs) as well as of PFOS from manufacturing and use. Predicted PFOS concentrations for the central North Atlantic in 2010 were about 60 pg/L declining to 45 pg/L by 2020. This range of concentrations is similar to observed medians for the Central Atlantic. Temporal trends of PFOA were modelled with BETR Global, a multimedia environmental fate model that describes the global environment as 288 regions based on a 15°×15° grid, and thus higher spatial resolution than the CliMoChem model (Armitage et al. 2009a).

Estimated PFOA for 2005 ranged from about 60 to 250 pg/L in the central North Atlantic and higher concentrations (250–500 pg/L) near the US East Coast, the North Sea and the Mediterranean Sea. These estimates were 2-fold higher than median concentrations of PFOA in the coastal North Atlantic but in good agreement with the median for the Mediterranean for the period 2000–2009 (see **Table 14**). Wania (2007) modelled the time course of PFOA in the Arctic Ocean using the Globo-POP model which, like CliMoChem, includes five latitudinal bands, consisting of four atmospheric layers, terrestrial surfaces, and the surface ocean as a single, unstratified layer of 200 m depth. Assuming a scenario of direct emission of PFOA into the oceans beginning in the 1970s, using data from Prevedouros et al. (2006) as the main entry pathway, the Globo-POP model predicted maximum northward fluxes in 2007 followed by a 50% decline by mid-century. Predicted concentrations of PFOA increased from 50 to 70 pg/L between 2000 and 2005 for north flowing waters which is within the range observed in the North Atlantic for 2000–2009 (see **Table 14**).

4.3.6 Conclusions and recommendations

4.3.6.1 What are prevailing concentrations of PFOS, PFOA and PFHxS in inland waters globally and in neighboring seas, as well as in oceans?

Median concentrations of PFOS in inland waters for the period 2014–2019 were generally in the range of 0.1 to 3 ng/L based on data for inland waters of 45 countries. Medians above this range were observed in the Morava River (Czech Republic), the Rhine River (Germany/Netherlands), Rivers in southwestern Nigeria, Taihu Lake in China, Argentina (Rio del Plata at Buenos Aires), and the São Vicente channel in Brazil. A similar pattern was evident for PFOA with medians also in the range of 0.1 to 3 ng/L except for higher values in the River Sosiani in Kenya and the Ganges River in Bangladesh. These higher median concentrations are likely due to the influence of urban wastewater and surface runoff.

PFOS concentrations exceeded the European Union (European Commission 2013) environmental quality standard (EQS) for inland surface waters of 0.65 ng/L in 21 of 45 countries for samples from 2015–2019 and also in earlier time periods. The highest frequency of exceedances was along the Danube where medians for sample sites in 7 of 8 countries exceeded the EQS value. The EQS was derived for protection of top predators and humans via the consumption of contaminated prey. Valsecchi et al. (2017) derived an unofficial EQS of 100 ng/L for PFOA. Median concentrations of PFOA did not exceed this value in any of the 45 country sites. However, some individual PFOA results in Western European rivers exceeded 100 ng/L.

PFOS/PFOA ratios, an indicator of legacy sources, were highest in WEOG countries with 7 of 12 having ratios >1. These ratios were also elevated in GRULAC where all sampling locations had ratios >1, and at 5 of 8 locations along the Danube, and in the Rhine River. In contrast only two sampling sites in Africa (Senegal coastal water and southwestern Nigeria rivers) had PFOS/PFOA ratios >1. Similarly of 7 Asia-Pacific countries, only the Solomon Islands site had ratios >1. The higher PFOS/PFOA in WEOG likely a legacy of the wide historical production and use of PFOS in this region as documented by Wang et al. (2017). For GRULAC countries, the elevated PFOS/PFOA may be an indicator of EtFOSA in Brazil and neighboring countries.

Coastal waters integrate inputs from multiple sources i.e., rivers and atmospheric deposition, and thus may be a better indicator of regional levels and trends. Median PFOS concentrations ranged from 0.05 ng/L (North Sea) to 0.29 ng/L (Bohai and Yellow Seas) in 2015–2019. PFOS concentrations exceeded the European Union saltwater EQS guideline for PFOS of 0.13 ng/L in 5 of 6 coastal seas and in the South Atlantic Ocean and coastal estuarine waters of the sampling sites in Argentina, Jamaica and Mexico (see **Table 14**). All seas had median PFOA concentrations well below the proposed saltwater EQS guideline of 20 ng/L (Valsecchi et al. 2017).

4.3.6.2 Are concentrations of PFOS, PFOA and PFHxS declining as a result of national and international chemical management controls?

Significant declines of PFOS were found in inland waters of several countries/regions. Based on annual medians, PFOS declined in lakes in Japan, in the Elbe and Rhine Rivers in Europe, and in the Great Lakes. The declines were generally observed over 8 to 12-year time periods and reflected much higher levels in the mid-2000s compared to the period 2015–2019. PFOS concentrations also declined significantly in the North Atlantic and in the Mediterranean, but surprisingly not in the North Sea where inflows from the Elbe and the Rhine are important sources. Declines of PFOS were also observed in the Bohai and Yellow Seas and in the South East China Sea. Median PFOA concentrations showed fewer declines overall, although large differences from the mid-2000s to 2019 were seen at most sites in the Danube, as well as in the Elbe and the Rhine. Significant declines in PFOA concentrations were also seen in the Mediterranean and the Great Lakes.

The assessment of temporal trends is challenging due to the variation in detection limits among studies. For example, MDLs varied widely in studies on the Great Lakes ranging from 0.001 to 0.8 ng/L despite using essentially the same analytical methodology. A major uncertainty in assessing trends in median concentrations was the variation in MDLs among studies. The selection of a very small ng/L value for all MDLs may have biased some of the medians low where the number of samples was limited. On the other hand, omitting results entirely or replacing them with a fractional value of a high MDL could lead to overestimates of prevailing concentrations. In this regard, the UNEP/GEF GMP II project in 22 countries was a major exception providing comparable, low MDLs (<0.025 ng/L) for PFOS, PFOA and PFHxS for all samples at all locations.

Three time periods were utilized to summarize the available data to overcome issues of limited data for certain years and areas in the UN regions. They corresponded to the period prior to PFOS being added to the Stockholm Convention (2000–2009), the period (2010–2014) corresponding to the first GMP assessment of PFOS in waters, and the 5-year period of the second GMP.[40] Sufficient data were available for these periods to assess temporal trends of PFOS, PFOA and PFHxS in coastal seas, open oceans and inland waters to qualitatively examine temporal trends in surface waters on a large geographic scale. Annual and biannual sampling of surface waters by the Ministry of Environment of Japan provides an excellent model of long-term water monitoring for PFAS at a national level. The ongoing sampling of selected reaches of the Danube River is another example that enabled assessment of trends within a river basin. The 2-year sampling program by the UNEP/GEF GMP II project, with sampling at the same sites and on a 3-month schedule. provided excellent short-term temporal trends. However, for other locations, the assessment had to rely on repeated sampling and analyses by various agencies and institutes to calculate median concentrations. Annual medians provided a more complete picture of temporal trends compared to medians calculated for 5 to 10-year periods. Calculation of medians from studies with different sampling sites and timing of collection, as well as different MDLs, introduces considerable uncertainty which is difficult to quantify. This is particularly the case for annual medians due to smaller sample sizes than those for multiple years.

[40] UNEP/POPS/COP/8/INF/38, http://chm.pops.int/tabid/525.

4.3.6.3 Knowledge gaps

This assessment has demonstrated that there are sufficient data in Western European rivers, US/Canada inland waters including the Great Lakes, the Danube River Basin, and Japan (rivers, lakes, coastal) to assess geospatial trends in inland waters. A major data gap is for China, for which limited data for PFOS is available in the GMP Data Warehouse. However, the peer reviewed scientific literature includes more than 100 articles published in the past 10 years on PFAS in inland and coastal aquatic environments of China. Those data were not tabulated or reviewed for this assessment. Even more limited data were available for other Asia-Pacific countries, Africa and GRULAC. However, the UNEP/GEF GMP II project which included PFAS measurements in surface waters of 22 countries provided important data on prevailing concentrations in rivers and near shore coastal waters.

The available data for PFAS in coastal seas and oceans provided good geospatial data for 7 coastal seas (3 in Western Europe and 4 for East Asia), the North and South Atlantic and the Arctic Ocean. The limited data for the Pacific and Indian Oceans and the Southern Ocean is insufficient to describe geospatial trends given the huge areas of these oceans.

A major knowledge gap is measurement of PFOS and PFOA precursors, both neutrals (MeFOSA, EtFOSA, MeFOSE, EtFOSE, fluorotelomer alcohols, fluorotelomer mono- and di-substituted phosphate esters) as well as anionic and amphoteric chemicals. Recent studies have suggested they are widespread in inland surface waters (D'Agostino and Mabury 2017; Xiao 2017). Total extractable organic fluorine (EOF), total adsorbable fluorine, and total oxidizable precursor assays have been used to assess additional PFAS sources in surface waters (McDonough et al. 2019) including seawaters (Joerss 2020; Miyake et al. 2007). Broad application of these assays would help to determine whether there are significant sources of unidentified PFAS precursors and previously unmeasured PFAS in seawater (Miyake et al. 2007; Taniyasu et al. 2015).

4.3.6.4 Recommendations

The recommendations related to the monitoring of PFOS, PFOA and PFHxS in water are as follows:

- As noted in the regional monitoring report for Africa (UNEP 2021a), continuation of water monitoring at established sites will be critical to allow establishment of concentration trends in the future evaluations;
- Future GMP assessments of PFAS in water should consider using the successful study design of the UNEP/GEF GMP II project (Baabish et al. 2021). The multiple sampling times at the same site and use of the same analytical laboratory yielded an excellent set of results;
- The UNEP/GEF GMP project should be repeated prior to the next global assessment, ideally in a larger number of sites, but at a minimum at the same sites as those used in 2017–2019;
- Careful design of future sampling programmes is needed as PFAS levels in river water are influenced by wastewater and surface runoff in urban areas. Multiple sampling points, preferably at sites that are well characterized in terms of flow and proximity to sources are needed;
- Establishing a global campaign for inland freshwater and coastal seawater sampling involving all UNEP regions conducted prior to each GMP assessment would provide a more robust set of data than the current mix of national data and published scientific articles;
- Lower detection limits would help with future assessments of temporal trends in all locations but especially in open oceans, coastal seas and lake waters. Detection limits in the range of 1–5 pg/L for PFOS, PFOA and PFHxS have been demonstrated by several monitoring programmes and should be universally adopted;
- Efforts should be made for more widespread measurement of precursors of PFOS, PFOA and PFHxS in waters with “total” methods (e.g., total oxidizable precursor (TOP) or total extractable organic fluorine) as well as by targeting specific known precursor compounds;
- Integrated analysis of data including other media, such as air, sediments and biota, with global models will improve understanding of fate of PFAS in the global environment and estimation of future PFAS trends particularly in top predators and humans in remote areas, thus further supporting the effectiveness evaluation.

4.4 Other media

Key messages:

A significant volume of high-quality data on POPs in non-core-media such as snow, ice, sediment, soil and biota (invertebrates, fish, birds, mammals) monitored over several decades are available in some areas such as the Great Lakes, the Arctic, the Baltic, Japan and could be studied along with climate change variables over the same period.

The overall picture seemed to be consistent and indicated that levels of the initial POPs remained relatively low, dominated by secondary sources and unchanged since the second GMP report in 2015.[41] Although less documented, newly listed POPs (e.g., PBDEs, PFOS, SCCPs, HCBD, HBCD, PCNs) showed at best slowing increases. The levels were relatively low compared to the initial POPs (PCB, HCHs, DDT) a decade ago, but the growing presence of other POPs was of concern.

Environmental specimen banks including biological samples and analytical extracts from sampling media have shown to be helpful and cost effective to establish temporal trends and screen potential new chemicals of concern.

Regular and comprehensive efforts to compile and report comparable regional and global data on POPs monitoring should be prioritized as such data can provide best empirical base to improve knowledge about POPs pathways and the changes in space and time of the risk posed by POPs to humans and the environment.

Multimedia ecosystem modelling is central to interpreting biological data and can help design effective monitoring strategies.

All regions noted the urgent need to enhance stable funding for long-term monitoring and technical capacity. Priority action would be needed in Africa, Asia-Pacific, EE and GRULAC.

4.4.1 Introduction

At its third meeting in 2007, the Conference of the Parties to the Stockholm Convention decided that the core media for the GMP for POPs would be air and human tissues (milk and blood); the reasoning behind this choice still stands. POPs in air (and in water for selected POPs) will capture information on the status of emission and LRET of POPs, and POPs in human tissues will indicate human exposure to POPs. This is key information for assessing the effectiveness of the Convention. The choice of core media is based on strategic long-term priorities in the context of a global exercise with limited resources.

Other media such as sediments, soils and biota are considered as non-core media. Spatial and temporal trends of POPs in other media may also be useful for understanding possible sources and pathways of POPs to humans and the environment. POPs levels in sediments, soils and biota could provide us with information on their movements in the environment, i.e., from their sources through food web to humans or top predators in ecosystem. This information could help us improve efficiency and effectiveness of POPs management.

Pesticides and some of the industrial/home-use POPs tend to be emitted through water; thus, water monitoring could be useful for understanding their emission status. Transported POPs through air will deposit on the surface of the earth and contaminate ecosystem and humans. Monitoring of precipitation (rain, ice etc.) particularly in background areas will help us understand the status of transfer of POPs to the receiving environment as well as the effects of climate change on the process. Sediments, ice cores and some of biological samples, such as tree rings, as well as properly archived environmental samples in environmental specimen banks could provide us with temporal trends of POPs pollution by retrospective analysis and help us assessing effectiveness of POPs managements.

Measurements in air and humans provide valuable information that is globally comparable over space and time, only if measurements are shown to follow agreed QA/QC procedures. Good quality measurements in other media are central and indispensable to gauge the importance over time of biogeochemical and commercial pathways of POPs mixtures in the local environment and the consequent exposure routes to humans and ecosystems. During the third phase of the GMP, the Parties participating in the UNEP/GEF GMP II project selected environmental samples of their concern, including other media such as fish and foodstuffs, and conducted their analysis under the QA/QC procedures.

This chapter reports the main findings of the global monitoring of POPs in non-core media reported in the third regional monitoring reports.[42]

[41] UNEP/POPS/COP.8/INF/38, http://chm.pops.int/tabid/525.

[42] UNEP/POPS/COP.10/INF/41, http://chm.pops.int/tabid/525.

4.4.2 Information on other media from regional monitoring reports

4.4.2.1 Africa

Comparable data from other media have been produced through the UNEP/GEF GMP II project. The priority media included soil, sediments, fish, milk, eggs and other food stuff materials. Samples were collected by countries between 2017 and 2019 and analyzed centrally at the laboratories of the project.

MONET-Africa conducted a pilot study of POPs in water in 2013/2014 using a combination of active and passive approaches. Selected analytes including PFAS were measured with a goal of providing background information and guidance for future monitoring efforts.

Participation of more countries is required to increase the data coverage and achieve regional representation. Follow-up studies to delineate key sources and hot spots, and institute mitigation measures to eliminate releases of POPs are needed. Future efforts should include application of the protocols developed in the third phase of the GMP in similar matrices to allow comparison of temporal trends in POPs levels in other media.

Literature studies showed that several research have been conducted in the African region on the contamination of water, soil, sediments and foodstuffs by pesticides with a focus on POP pesticides. Researchers from different institutions either individually or as teams have conducted assessment of POPs in Africa including OCPs, PCB and PBDEs. Limited work exists for PCDD/PCDF, PFOS, SCCPs and PCNs.

According to CropLife International, over 50,000 tonnes of obsolete pesticide waste had been stockpiled across the African continent (CropLife International 2017; Mansour 2009; FAO 1998). Such stock is sometimes comprised of packages of substandard, deteriorated pesticides including POPs. The risks of exposure to POPs from stockpiles are enormous. The management of large amounts of obsolete pesticides and contaminated soil is a major challenge to the region, which could be a secondary source of contamination.

Results from the UNEP/GEF GMP II project

The third regional monitoring report for Africa[43] included a detailed analysis of the current competence and limitation to monitor POPs in the region.

Egypt: Samples from Egypt comprising of baby milk, fish meal and dry soil analyzed for POPs recorded low levels in baby milk with most of the analytes below detection limit. POPs in fish meal ranged from below detection limit to 9.9 ng/g, whereas the POPs levels in agricultural soils were between below detection limit and 1.60 ng/g.

Ethiopia: Sediment samples from Ethiopia registered basic POPs from below detection limit and 47 ng/g for OCPs and below detection limit to 0.1 ng/g for PCB. The major pesticides detected were *p,p'*-DDT, *p,p'*-DDE and HCB.

Kenya: Samples from Kenya included fish, sediments and soil. Dieldrin, *p,p'*-DDE and *p,p'*-DDT were detected in soil and sediments. The levels of pesticides and PCB in fish ranged from below detection limit to 0.03 ng/g. OCPs and PCB levels in sediments ranged from below detection limit to 1.5 ng/g, showing relatively higher levels sediments compared concentrations measured in fish samples. The soil samples recorded the highest OCP levels compared to sediments and fish. However, it should be noted that some of the soil samples might have been collected from impacted sites such as former obsolete pesticide storage site. This could also signify the need for decontamination of the pesticide contaminated sites that are scattered all over the region.

Mauritius: Samples from Mauritius included sediments and fish fillet. POP pesticides in sediments ranged between below detection limit and 14 ng/g. PCB varied from below detection limit to 0.08 ng/g in the same matrix. The concentration of OCPs in fish fillet varied from below detection limit to 0.33 ng/g, whereas PCB concentrations ranged from below detection limit to 0.10 ng/g. The main pesticides detected in the national samples were *p,p'*-DDT, *p,p'*-DDE, *p,p'*-DDD and HCB.

Uganda: Samples from Uganda included fish and sediments. OCPs in fish ranged from below detection limit to 0.19 ng/g, whereas PCB ranged from below detection limit to 0.08 ng/g. OCPs in sediments varied from below detection limit to 0.35 ng/g, and below detection limit to 0.05 ng/g for PCB. The dominant OCPs included *p,p'*-DDT, *p,p'*-DDE, dieldrin, gamma-HCH and HCB.

Zambia: Fish and sediments from Zambia recorded POPs below detection limit to 0.1 ng/g for OCPs and from below detection limit to 0.10 ng/g in the case of PCB in soil. Contamination in sediments ranged from below detection limit to 1.2 ng/g for OCPs and below detection limit to 0.06 ng/g for indicator PCB.

Information from literature

Soil: Soil contamination by POPs has been widely reported in research activities suggesting possible accumulation of POPs in the agricultural soils in Africa. Tue et al. (2016) reported PBDEs in soil from open burning of e-wastes in

[43] UNEP/POPS/COP.10/INF/41, http://chm.pops.int/tabid/525.

Ghana. In addition, contamination of dumpsites by PBDEs from e-waste was also reported by Akortia et al. (2017). In Tanzania, DDT residues ranging from 10.02 to 116 µg/kg dry weight (dw) in soil and 7.5 to 564.2 µg/kg dw in sediments have been reported in Eastern Lake Tanganyika (Mahugija et al. 2017). Other studies by Kihampa and RamMato (2009) reported OCPs in soil in the old obsolete pesticide storage site at Korogwe in Tanzania.

Sediment: Contamination of sediments in Africa by POPs has been reported in several studies. Verhaert et al. (2013) reported PCB contamination in sediments and fish from DR Congo. Further studies by La Guardia et al. (2013) reported PBDEs in sediments from South Africa. Adebayeyo et al. (2011) reported OCPs pollution of water, sediments, Fin and Shell-fish samples from Lagos Lagoon Complex, Nigeria. In Kenya contamination of sediments from Nairobi River was reported by Ndunda et al. (2018). Further study by Orata et al. (2011) reported 'Perfluorinated Compounds contamination and distribution in sediments from Lake Victoria Winum gulf. Pelig-Ba (2011) reported OCPs in sediments and irrigation water from Tono and Vea in the Upper East of Ghana.

Biota and foodstuffs: Fish and foodstuffs contamination by POPs has been reported in several research publications from the region. Adukumi et al. (2010) reported PCB and PCDD/PCDF in fish from Ghana. Afful et al. (2010) reported OCPs concentrations in fish ranging from 0.3 to 71.3 µg/kg. Gbeddy et al. (2012) also reported OCPs in African catfish muscle, Nile tilapia Muscle and gills from the middle Volta basin, while Darko et al. (2008) reported OCPs in fish, sediments and water from Lake Bosomtwi, Ghana. A recent study by Danladi and Akoto, (2021) reported OCPs ranging 7–1.026 µg/kg in fish from Vea Irrigation Reservoir, Ghana. In Uganda, Ssebugere et al. (2013) reported fish contamination by PCB and PCDD/PCDF for samples collected from Lake Victoria.

Orata et al. (2008) reported PFOA and PFOS in Nile Perch and tilapia from Winum gulf of Lake Victoria. In other studies, POP pesticides were reported in Solanum lycopersicum L. and Capsicum annuum L. fruits from a local market survey in Nigeria (Benson et al. 2011). Vaccher et al. (2020) reported PCDD/PCDF, PCB, PBDEs, and PFAS in food stuff comprising of fish, eggs, dairy milk, nuts and seeds from Benin, Cameroon, Mali and Nigeria. A review of POPs studies in Ghana by Bruce-Vanderpuije et al. (2019) included PFAS and DDD in water, PCDD/PCDF and PBDD/PBDF in e-waste soils, and PBDEs in aquatic organisms and dairy products. In Nigeria, Okoya et al. (2013) reported OCPs in sediment-dwelling animals from Mangrove areas of the Calabar River. Owusu-Boateng et al. (2013) reported OCPs in cabbage from farms along River Oyansia, Accra-Ghana.

4.4.2.2 Asia-Pacific

The third regional monitoring report for Asia-Pacific provided significant monitoring data compiled by Japan which has maintained long-term monitoring programmes for POPs in water, sediment, soil and biological samples. The results are not representative of the whole region but are relevant in building a global understanding of the trends in POPs.

Several environmental monitoring programmes for POPs in other media have been established under different laws and objectives. The following monitoring programmes are conducted by the Ministry of Environment: “Chemicals in the environment monitoring programme” under the Act on the evaluation of chemical substances and regulation of their manufacture since 2002 (reorganized from the previous “POPs in biota monitoring programme” since 1978 and “POPs in sediments monitoring programme” since 1985), “Dioxin monitoring programme” under the Act on special measures against dioxins since 1998, “Marine environment monitoring programme” in exclusive economic zones in response to the United Nations Convention on the Law of the Sea since 1998 (reorganized from previous monitoring during 1975–1994). In addition, Japan Coast Gurd has been conducting “Marine pollution survey” under the Law Relating to the Prevention of Marine Pollution and Maritime Disaster by the Hydrographic and Oceanographic Department since 1972. A brief outline of these activities is presented below.

Furthermore, the UNEP/GEF GMP II project has analyzed a list of other matrices for some Asian countries for which the data will be available later.

Water:

The following POPs are measured in river area, lake area, river mouth area and coastal sea area (total c.a. 50 sites) under the “Chemicals in the environment monitoring programme” in Japan: aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, HCB, mirex, toxaphene, PCB, chlordecone, endosulfan, HBB, HBCD, HCHs, PeCB, PBDEs, HCBD, PCA, PCNs, PCP, PFHxS and SCCPs. Of those, aldrin, chlordecone and HBB are not measured regularly due to low abundance or no clear change in recent years.

PCDD/PCDF and dl-PCB have been analyzed in “Dioxin monitoring programme” in public water including water from river, lake, estuary and coastal sea as well as groundwater in Japan throughout the nation (public water: 204 to 2,213 sites; groundwater: 188 to 1,479 sites). From FY2013 to FY2017, the number of monitoring sites for public water and groundwater ranged from 1,442 to 1,537 and from 498 to 556, respectively.

The concentrations of PCB, HCB, *p,p'*-DDT, *o,p'*-DDT, *o,p'*-DDE, cis-chlordane, cis-heptachlor epoxide, alpha-HCH, beta-HCH, gamma-HCH, and pentaBDE in surface water showed statistically significant decrease in a recent decade or two. The average total dioxins (dioxins + furans + dl-PCB) in public water and ground water decreased to

half of their previous values in 1998 and are rather stable in recent years. Dioxins in public water were between 0.17 and 0.19 pg-TEQ/L (2013 to 2017), and 0.39 pg-TEQ/L in 1998. Dioxins in ground water were between 0.042 to 0.055 pg-TEQ/L (during 2008 to 2017) except for 2013 when the average was 0.26 pg-TEQ/L. It was 0.19 pg-TEQ/L in 1998 (I-TEF 1988 was used for 1998, while WHO-TEF (2006) after 2008).

Sediment:

POPs in the bottom sediment are continuously monitored throughout the nation in Japan since FY2002. The following POPs are measured under the "Chemicals in the environment monitoring programme": aldrin, chlordane, chlordecone, DDT, dieldrin, endosulfan, endrin, heptachlor, HBB, HBCD, HCB, HCBD, HCHs, mirex, PCB, PBDEs, PeCB, PCA, PCNs, PCP, PFOA, PFOS, PFHxS, SCCPs and toxaphene. Some of the POPs such as chlordecone are not measured regularly due to low abundance or no clear change in recent years.

Chlordane, DDT, endosulfan, HBCD, HCHs, PCB, PBDEs, PCDD/PCDF, dl-PCB, PFOA and PFOS in sediment from marine environment surrounding Japan is monitored under the "Marine environment monitoring". In addition, Japan Coast Guard has been measuring PCB in the bottom sediment in inner bay since 1974 under the "Marine pollution survey".

The concentrations of PCB, HCB, aldrin, dieldrin, cis-chlordane, oxychlordane, cis-nonachlor, trans-nonachlor, heptachlor, cis-heptachlor epoxide, alpha-HCH, gamma-HCH, delta-HCH, and heptaBDE in sediment showed statistically significant decrease in a recent decade or two. PCB levels in surface sediments in various sampling sites in major bays and oceans in Japan were reported from 2006 to 2018. Although not treated statistically, the data generally showed stable or slight decreasing trends in many places.

Under the "Dioxin monitoring programme", PCDD/PCDF and dl-PCB in bottom sediment have been analyzed throughout the nation (205 to 1,836 sites) since 1998 (for 2013 to 2017, number of monitoring sites ranged from 1,197 to 1,247). The average dioxin concentrations in bottom sediments were between 6.4 to 7.1 pg-TEQ/g dry during 2013 to 2017, and 6.8 to 7.1 pg-TEQ/g during 2008 to 2012 and it seems to decrease to some extent from its value in 1998 but remained stable in the last decade. It was 8.3 pg-TEQ/g in 1998 (I-TEF 1988 was used for 1998, while WHO-TEF (2006) after 2008).

Soil:

Japan is continuously monitoring PCDD/PCDF and dl-PCB in the soil throughout the nation (286 to 3,735 sites) since 1998. The average dioxin concentrations in soils also seem to decrease to some extent from its value in 1998 but are stable in the last decade. They were between 2.3 to 3.6 pg-TEQ/g during 2013 to 2017, and 2.5 to 3.4 pg TEQ/g between 2008 to 2012, while it was 6.5 pg-TEQ/g in 1998 (I-TEF 1988 was used for 1998, while WHO-TEF (2006) after 2008).

Biota:

POPs concentrations in fish, shellfish, and birds are monitoring throughout the nation in Japan. Concentrations of following POPs are measured under the "Chemicals in the environment monitoring programme": aldrin, chlordane, chlordecone, DDT, dieldrin, endosulfan, endrin, heptachlor, HBB, HBCD, HCB, HCBD, HCHs, mirex, PCB, PBDEs, PeCB, PCA, PCNs, PCP, PFOA, PFOS, PFHxS, SCCPs and toxaphene. Chlordecone is not measured regularly due to low abundance or no clear change in recent years. In addition, concentrations of PCB, PCDD/PCDF, and dl-PCB in marine biota (mussels, benthic sharks, squids, cods and crustaceans) have been reported since 1998.

The concentrations of PCB (bivalves), *p,p'*-DDT (fishes), *p,p'*-DDD (bivalves), *o,p'*-DDT and *o,p'*-DDE (bivalves and fishes), *o,p'*-DDD (bivalves), alpha-HCH (bivalves), gamma-HCH (bivalves and fishes), delta-HCH (fishes), tetraBDE (bivalves), alpha-HBCD (bivalves and fishes) and gamma-HBCD (bivalves) showed statistically significant decrease in a recent decade or two. PCB and dioxins levels in mussels, sharks, squids, cods and crustaceans sampled along the lines from bays to open ocean have been analyzed during the last two decades.

Foodstuffs:

The dioxin concentrations in foodstuffs, livestock products and marine products in Japan are reported in surveys conducted by the Ministry of Environment and the Ministry of Agriculture, Forestry and Fisheries, Japan. In addition, survey on daily intake of dioxins is conducted with grants from the Ministry of Health, Labor and Welfare, Japan.

The concentrations of both PCDD/PCDF and dl-PCB in foodstuffs showed steady decrease. The median dioxins levels of duplicated foods of survey participants in recent three years were nearly one third (0.0071–0.0074 pg-TEQ/g: 2014–2016) of those in the early 2000's (0.021–0.028 pg-TEQ/g; 2002–2004). The trend was similar to the decreasing trend of dioxins in blood of participants, and also similar to the Japanese study on dioxin levels in breast milk. Another study on dioxins in foodstuffs by market-basket analysis showed a similar decreasing trend during 2002–2017. On the other hand, the trend of dioxin levels in livestock and marine products was not clear due to large year to year variations.

4.4.2.3 Eastern Europe

Monitoring activities related to other media including soil, sediments and biota exist in some countries in the EE region. However, the EE ROG decided not to use the information generated from non-core media activities in the regional monitoring report as the sources were too variable, measurement was episodic, and the information generated reflected a national or local situation rather than a regional perspective.

With support of the network of reference laboratories, research centres and related organizations for monitoring of emerging environmental substances (NORMAN),[44] the EE ROG was able to review data related to other POPs under the Joint Danube Survey in several sites across Danube. Results on other POPs are presented in Chapter 32 of the Joint Danube Survey scientific report. Some water sampling sites covered not only PFOS and PFOA but also other POPs (OCPs, PCB, DDT, HCB, PeCB, endosulfan, HCHs, and some PBDEs). The Joint Danube Survey also looked at other matrices such as sediments and mussels and their contamination by PCB and DDT. More detailed information is provided in the scientific reports of each Danube survey.

The HELCOM Balthazar Project (2011) targeted contamination of the Neva River and Bay of Finland. In 2014 and 2016, DDT pollution was assessed in Lake Baikal. In 2018 and 2019, DDT, HCB, HCHs, PCP (analyzed as PCA) and toxaphene (Parlar 50) were assessed in Karelia and White Sea.

A research cruise EMBLAS in 2016 focused on the contamination of the Black Sea by DDT, HCB, PeCB and BDEs. Subsequent cruises EMBLAS II and EMBLAS Plus took place with the same target chemicals. The GMP Data Warehouse currently contains data from EMBLAS in 2016.

4.4.2.4 Latin America and the Caribbean

For collecting available information on core matrices and other media, questionnaires were sent to focal points in 32 GRULAC countries. Data coming from monitoring programmes were obtained mainly from the UNEP/GEF GMP II project, GAPS and LAPAN air monitoring networks, UNEP/WHO Human milk survey and MONET-Aqua.

Various countries of the region reported in their NIPs the presence of POPs in media other than the core media. Antigua and Barbuda reported sampling information relevant to soil and sediment; Mexico reported POPs monitoring in human adipose tissue; Brazil reported several studies on POPs in human tissues; Colombia reported POPs monitoring in costal water; Barbados reported in its NIP, the routine monitoring of groundwater; several other countries reported studies in different biotic samples like eggs, fish, bivalves and foodstuffs, among others. None of them, however, reported trends over time.

Evidence of concentrations of POPs in several species of non-migratory endemic wildlife (birds, marine mammals, mussels, and others) as well as soils and mosses are found in scientific literature. Monitoring in other media was also mentioned in the NIPs. Only Colombia reported the existence of a formal monitoring program of POPs in costal water and sediment.

A regional agreement between countries is required to define if levels in other media could be used as regional indicator or sentinels (Eco markers) of local or regional POPs contamination or as supplemental indicators for temporal trend evaluation within an interregional monitoring program for future evaluation.

4.4.2.5 Western Europe and Others

The monitoring work in other media across the WEOG region has been steadily growing since the second phase of the GMP. Vast collections of high-quality data are available; however, the diversity of monitoring efforts makes it difficult to compile those scattered data for statistical analyses, modelling and large-scale comparison. Regular, consistent and rigorous large-scale data compilations would greatly facilitate and enhance the ability to determine trends, LRET and enable ecosystem modeling. To achieve this goal, the archiving of data and samples, QA/QC and data flow between data providers and users should be considered a priority.

Current results seem to indicate that POPs regulated in source regions decades ago have significantly decreased but are still present at low levels that have not changed since the second GMP report in 2015,[45] and some are still of concern in some regions. PCB continues to be present in some regions and species, with levels exceeding thresholds for effects, which is of concern. Some of the new POPs with extensive exemptions for continued use show increasing levels (e.g., HBCD, HCBD, PFOS and PCNs in some areas).

Efforts should be made to make use of the vast body of information that is available for POPs in other media (including wet deposition, water and soils), in collaboration with modelers, to develop a better understanding of the fate of POPs in the multi-media environment under different conditions.

[44] https://www.norman-network.net/.

[45] UNEP/POPS/COP/8/INF/38, http://chm.pops.int/tabid/525.

Following the same logic that was used in the first (2009) and the second (2015) GMP reports,[46] the information relating to data concerning POPs monitored in other media is based on a brief overview of the published outcomes from several well-established long-term monitoring programmes (AMAP, NCP, Great Lakes, HELCOM, OSPAR, MEDPOL) and published data from Antarctica. The data reported cover the initial POPs, PBDEs, PFOS, endosulfan, HBCD, PCNs, SCCPs and PCDD/PCDF.

These programmes have well established QA/QC procedures and publish regular updates on the results in the regions of interest. The uninterrupted work of these monitoring programmes since the early 1990s has yielded an extraordinary corpus of knowledge concerning the presence and pathways of POPs in abiotic and biotic environments. To a large extent the collections of consistent monitoring data reported by the programmes and briefly summarized here have been deposited in recent years in publicly accessible repositories[47] opening up and enabling a vast new field of research for environmental scientists in years to come.

The continued existence of these long-term programmes and data collections is indispensable to improve accuracy of assessments and the effectiveness of policies. AMAP has contributed to the current GMP report an extensive study on trends in POPs monitored in biota.

There is currently no comprehensive reporting on POPs in other media from the Antarctic region, and information provided in this report is based on a literature review. As the Scientific Committee on Antarctic Research programme in Input pathways of Persistent Organic Pollutants to Antarctica (SCAR ImPACT) is aiming for establishing an Antarctic Monitoring and Assessment Programme, the situation on reporting and data availability is hopefully improved by the next GMP report. Further engagement of the Antarctic Treaty and the Scientific Committee of Antarctic Research (SCAR) would be very beneficial in future evaluations.

It has become apparent in recent years that a good understanding of ecosystem process and structure is central to interpret long-term changes in POPs concentrations in organisms operating at different trophic levels (see e.g., Hebert et al. 2000; Braune et al. 2014; AMAP 2021). The fast changes in the last few decades of macroscopic covariables such as ice cover surface, air and sea water temperature, salinity and the resulting change in species ranges and abundances has an impact on POPs' pathways, partitioning in the environment, degradation rates, transfer in the food web, and in particular in POPs levels in top predators.

In this context, the interpretation of POPs monitoring data benefits from ecosystem modelling of changing POPs' pathways and shows the need and benefits of coherent long-term and integrated monitoring strategies in abiotic media, marine, freshwater and terrestrial macroscopic and microbial ecosystems (Thompson et al. 2017). Research and interpretation of monitoring data on POPs must be interpreted considering climate changes on ecosystems structure and function in the Arctic (AMAP 2021).

Finally, the interest and value of environmental specimen banks and dated sediments should be emphasized to build the contour of the POPs landscape in ecosystems over the past century.

The work of WEOG ROG on the media has been based on several long-term motoring programmes and strategic partners to the GMP. For non-core media, the ROGs can only rely on published data compilations by the programmes, consequently the following 2 groups were considered:

(a) Regions with monitoring programmes reporting data systematically available for GMP:

- (i) Arctic: Arctic Monitoring and Assessment Programme (AMAP);
- (ii) North Atlantic: Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR);
- (iii) North America Great Lakes: Canada-United States Great Lakes Water Quality Agreement (GLWQA);
- (iv) Baltic: Helsinki Commission/The Baltic Marine Environment Protection Commission (HELCOM);

(b) Regions with monitoring results, but no systematic report available for the GMP:

- (i) USA: National Oceanic and Atmospheric Administration (NOAA), Environment Protection Agency (EPA);
- (ii) Mediterranean: Mediterranean Assessment Programme (MAP);
- (iii) European Union: Water Framework Directive/Marine Strategy Framework Directive (WFD/MSFD);
- (iv) Antarctica.

[46] http://chm.pops.int/tabid/525.

[47] For example, www.amap.no; www.helcom.fi.

4.4.3 Summary

An overall view of the general temporal trends for the individual POPs across the different programmes is summarized in **Table 15**. Although monitoring information from the Mediterranean and Antarctica is not reported to the GMP, some information could be extracted from available reports.

Table 15. Summary of temporal trends of POPs concentrations in other media measured by AMAP, OSPAR, HELCOM, Great Lakes, Japan and Antarctica

(The colours represent the temporal trends for each monitring programmes: Red: increase; Green: decrease; Blue: no changes in trend (statistically decided); Yellow: non-linear changes that are neither increase nor decrease; Grey: cannot be statistically decided. ○: substances regulated earlier with low levels and no change in the last years. Δ: newly listed POPs. Note that Japanese national monitoring includes trend data for bivalves, fish, water and sediments (see Table 5.2.3-1, Table 5.2.4-1, Table 5.2.4-2 of the third regional monitoring report for Asia-Pacific).

	Northern Hemisphere						Southern Hemisphere
	AMAP (1975-2000)	AMAP (2001-2014)	OSPAR (1995-2014)	HELCOM (1978-2018)	Great Lakes (1970-2017)	Japan (fishes) (2002-2018)	Antarctica (NA)
Aldrin	o	o	o	o	o	o	o
α-HCH							
β-HCH							
Chlordane	1					o	
Chlordecone	o	o	o	o	o		o
DDT		1				o	
Dieldrin						o	
Endosulfan	o	o	o	o	o		o
Endrin	o	o	o	o	o	o	o
γ-HCH						o	
Heptachlor						o	
HBB	Δ	Δ	Δ	Δ	Δ	Δ	Δ
HBCD					3	Δ	
Hexa-, hepta-BDE			2	2	3	o	
HCB							
Mirex			o	o	o	-	o
PeCBz							
PFOS					3	Δ	
PCB						o	
PCDD							
PCDF							
Tetra-, penta-BDE					4	o	
Toxaphene		5				-	
HCBD							
PCP	Δ	Δ	Δ	Δ	Δ	Δ	Δ
PCN						o	
DecaBDE						Δ	
SCCP	Δ	Δ	Δ	Δ	Δ	Δ	Δ
Dicofol	Δ	Δ	Δ	Δ	Δ		Δ
PFOA						Δ	
PFHxS	Δ	Δ	Δ	Δ	Δ	Δ	Δ

Note: 1. One local source (whale processing site) causes an increasing trend in some species; 2. BDE-153 and BDE-154 only. 3. Increasing in some lakes, decreasing in other lakes; 4. Overall decreasing, increasing in whole fish in Lake Erie and in sediments in Lake Superior; 5. Parlar 26 decreases annually by 5.9%, parlar 50 increases annually by 0.8%.

Across the regions, alpha- beta- and gamma-HCH, DDT, PCB, tetra- to heptaBDE showed decreasing trends, and/or decreasing/no change. No substances showed increasing trends across all regions; however, in the Great Lakes, HCB, HCBD, PCNs and decaBDE in general showed increasing trends, as well as DDT in Antarctica, and HCB in the Baltic region. Dieldrin and toxaphene were reported by both AMAP and GLWQA, showing decreasing levels or nonlinear trends. PFOS was reported across several regions, with contrasting trends: increasing in the Arctic and the Great Lakes and decreasing in the Baltic region and the North Atlantic.

Some compounds were only reported from one region, thus no general assessment across the regions could be made, such as for those only reported from the Arctic: chlordane (decreasing), heptachlor (no linear trend), mirex

(decreasing/no linear trend), PeCB (decreasing/no linear trend); and for those only reported from the Great Lakes: PCDD (decreasing), PCDF (decreasing), HCBD (increasing), PCNs (increasing) and PFOA (no linear trend).

For several substances, there was no new trend data reported since the second GMP report in 2015.[48] There was less data on new POPs (e.g., PCP, dicofol, SCCPs, HBB, PFHxS), likely due to challenging analytical chemistry and lack of comparable methods. Some of the initial POPS were no longer measured and reported due to low levels and no change over time (e.g., aldrin, chlordecone, endosulfan, mirex, endrin).

Below is a summary of the substances with reported data, complementary to **Table 15**, with some selected examples. Further details can be found in the reports from the specific regional programmes.

HCHs were in general decreasing in all reported media and regions; however, still the levels were of concern in some species such as in cetaceans from the Mediterranean region.

DDT was in general decreasing in all reported media and regions; however, the levels were increasing in Antarctic biota. The pattern of DDT was changing, with an increasing ratio of the metabolite DDE compared to its precursor DDT, which could be an indication of lack of new “fresh” DDT. In some areas like the Great Lakes, the average levels were well below the target threshold of 1.0 µg/g ww across the basin.

Dieldrin was in general decreasing or levelling off in all reported media and regions; however, it was still one of the most abundant organochlorines in waters of the Great lakes, second to alpha-HCH.

HCB was in general decreasing or no trends in most reported media and regions; however, still the levels were of concern in some species such as in cetaceans from the Mediterranean region. Some HCB temporal trends were increasing, such as in Great Lakes water and a few OSPAR trends for the North Atlantic.

Mirex levels were generally decreasing or showing low levels with no change. Mirex would no longer be reported for some of the programmes, such as the Great Lakes.

PCB were in general decreasing, or no annual trend was reported across media and regions. Most congeners had low and acceptable levels, whereas PCB-118 was close to or exceeded the EAC in three out of five assessment areas in the North-Atlantic (OSPAR). PCB concentrations exceeded the threshold in some areas of the Baltic Sea (EC: 75 µg/kg WW with 5% lipid normalization). ΣPCB was still above the target of 0.1 µg/g ww in whole fish in some fish species in some of the Great Lakes. Dioxin-like PCB levels in Mediterranean sperm-whales were the highest for this species worldwide. PCB in Arctic top predators were still high and associated with negative effects.

PBDEs were in general decreasing or showing a non-linear trend across regions for the tetra- to hepta- homologues. DecaBDE, which was sparsely reported and only available as a separate congener for two regions, where the Great Lakes showed increasing trends, and Antarctica decreasing trends. In Great Lakes sediments, total PBDEs, and in particular the deca-substituted BDE-209 were increasing across all the five Great Lakes, with doubling times ranging from 4 years to 74 years. Although levels were declining in the Baltic region, ΣPBDE in all areas monitored in fish failed the threshold (EQS: 0.0085 µg/kg WW with 5% lipid normalization). The PBDEs levels were still of concern in some species such as in cetaceans from the Mediterranean region, in particular prevalent high levels of BDE-209.

Toxaphene was only reported in the Arctic and in the Great Lakes. In both the Arctic and the Great lakes, the levels were decreasing with a linear or non-linear trend, or no significant temporal trend. In the Great Lakes, current levels of toxaphene in fish for consumption was less of a concern for public health than other dominant chemicals such as PCB and mercury, and thus would no longer be reported.

Hexabromocyclododecane (HBCD) trends post-2000 were decreasing across the regions that report data. In the Arctic and in the Baltic the levels were increasing pre-2000. HBCD concentrations in Baltic fish were below the threshold value in all areas (EQS: 167 µg/kg ww with 5% lipid normalization).

Hexachlorobutadiene (HCBD) was only reported from the Great Lakes, where there was an increasing trend in the water in most lakes.

PFOS was generally decreasing or showing a non-linear trend across regions. In Great Lakes whole fish, the declining trends observed at most locations were statistically significant only in the Lake Ontario (since 2002), Lake Huron and Lake Michigan. Although the trends were decreasing, the levels were still high in the North Atlantic, and in edible portions of some Great Lake fish. Average concentrations of PFOS in whole fish were generally above the FEQ guideline of 4.6 ng/g ww in all the five Great Lakes. However, concentrations of PFOS in common fish species did not result in advisories that would be more restrictive than the consumption guidelines already set for PCB. There was a gradient toward increasing PFAS contamination from the upper Great Lakes (Superior and Huron) to the lower Great Lakes (Erie and Ontario) for both tributary and open-lake sediments. There were significant PFAS levels in cetaceans in the Mediterranean.

[48] UNEP/POPS/COP/8/INF/38, http://chm.pops.int/tabid/525.

PCNs were only reported from the Great Lakes, where there was an increasing trend in the water in most lakes.

PCDD and PCDF were surprisingly only reported from the Great Lakes, where there was a decreasing trend.

4.4.4 Main findings

All regions reported the existence of POPs monitoring data in other media. In most cases the information was dispersed in the scientific literature and was difficult to compare. Only WEOG, EE and Japan had extensive long-term collections for some media (rain, surface water, soil, biota). In the regional monitoring reports, only WEOG and Japan described long-term trend data. The regional monitoring report for Africa contributed a wealth of information that to some extent could be taken as baselines.

The overall picture seemed to be consistent and indicated that levels of the initial POPs remained relatively low, dominated by secondary sources and unchanged since the second GMP report.[49] Although less documented, new POPs (e.g., PBDEs, PFOS, SCCPs, HCBD, HBCD, PCNs) showed slowing increases. The levels were relatively low compared to the initial POPs (PCB, DDT) a decade ago, but the growing presence of other POPs was of concern.

The volume, geographical and ecological coverage of good quality POPs monitoring data in other media has significantly increased in the past decade. Many challenges remain including the need to enhance technical capacity and stable infrastructures to produce long-term coherent monitoring efforts in many regions of the world.

Environmental specimen banks including biological samples and analytical extracts from sampling media have shown to be helpful and cost effective to establish temporal trends and screen potential new chemicals of concern.

Regular and comprehensive efforts to compile and report comparable regional and global data on POPs monitoring should be prioritized as such data can provide best empirical base to improve knowledge about POPs pathways and the changes in space and time of the risk posed by POPs to humans and the environment.

As the monitoring programmes progress, the data richness increases. The thorough statistical analyses of temporal trends, i.e., in regions with dense monitoring collections such as the Arctic, the Great Lakes, North Atlantic and Baltic Sea, combined with power analysis on how to best design the study in terms of numbers of samples needed to detect a given change, has greatly improved our understanding. This understanding is given a retrospective statistical model, analyzing the temporal trend in measured data.

Mechanistic models to help understand temporal trends

When addressing temporal trends of POPs in biota, not only changes in emissions come to play, but also changes in sources and exposure during different life stages, as well as species- and individual differences in elimination. By combining contaminant observations with mechanistic understanding of the processes involved in the contaminant distribution and enrichment of various media, **mechanistic models** can help us quantify and compare the different processes that are involved. In these models, the processes involved are chosen and defined by mathematical solutions, and the chemical-, environment-, and ecosystem is described by scaling the parameters defined in the processes such as octanol-water partitioning coefficients, temperature, species characteristics, dietary relations. When properly explaining observed data, the models can identify which are the most sensitive parameters affecting the contaminant levels, and to model prospective temporal trends given defined settings, i.e., effect of reduced emission.

Examples of mechanistic models used to understand contaminant behavior is the combination of a global multimedia model (BETR Global, MacLeod et al. 2001), with a human exposure model (ACC-HUMAN, Czub and McLachlan 2004) to predict spatial PCB-153 concentration in human milk (McLachlan et al. 2018). This resulted in high correlation between modelled and measured concentrations, with identification of global regions with over or under-predictions where understanding is needed.

Similar approaches are used to understand the human exposure to contaminants in the Arctic, including contributors and drivers of the observed temporal trends, as reviewed by Wania et al. (2017). Here, the development of mechanistic models to understand Arctic environmental distribution, food web accumulation and human exposure and accumulation is summarized (Wania et al. 2017). They identified how changes in diet from tradition to market affect and reduce the temporal trends, thereby confounding the observed temporal trends by reduced emissions (Quinn et al. 2012). The human exposure models have been used to understand that PCB levels increase with age observed in cross-sectional monitoring studies, as a “ghost of the past” rather than increased levels with age *per se*, as the individual has experienced past high exposure that remains in the body (Quinn and Wania, 2012). In fact, time since peak exposure best explains the relationship between body burden and age, and interpretation of body burden vs age relationships will differ between monitoring studies of repeated measures of an individual (longitudinal–concentration trends in individuals) and sampling a cross-section of the population over time (Ritter et al. 2009; Quinn and Wania, 2012; Nøst et al. 2016).

[49] UNEP/POPS/COP.8/INF/38, http://chm.pops.int/tabid/525.

Data availability, consistency and comparability

Only WEOG and Japan reported long-term trends of POPS in other media (see **Table 15**). Other regions reported the existence of some dispersed data that were informative but difficult to compare and did not include trends over time.

During the third phase of the GMP, UNEP/GEF initiated several valuable efforts to obtain comparable monitoring data of POPs in other media (water, sediment, fish) in Africa, Asia-Pacific and GRULAC, some preliminary results were briefly reported above. It is important that these efforts are consolidated and expanded in the future.

Facilitating data flow and accessible compilations of POPs monitoring data with reliable QA/QC is central to the GMP. A growing number of digital infrastructures such as EBAS/NILU, ICES, GEOSS and the GMP Data Warehouse have developed IT tools to deal with data. Their cooperation and joint work will be indispensable.

4.4.5 Conclusions and recommendations

Conclusions	Recommendations
Long-term stable monitoring of biotic and abiotic media, sharing environmental sample collections, analytical methods and curated data are central to evaluating the effect of measures taken and to enhancing understanding of the changing structure of ecosystems and POPs pathways leading to exposure. Despite the relative abundance of monitoring data, the statistical power to identify significant trends over time is limited, and efforts should be made in monitoring design and advanced data analysis to enhance accuracy of estimated temporal trends.	Facilitate cooperation and capacity to maintain long-term monitoring plans/programmes and environmental specimen banks integrating multiple media, robust QA/QC and reporting in a coherent transparent service to enhance accuracy of estimates of changes over time.
Current results indicate that POPs regulated in source regions decades ago have significantly decreased but are still present at low levels that have not changed since the second GMP report[50] and are still of concern in some regions. New POPs with ample exemptions for use (e.g., PBDEs, HBCD, HCBD, PFOS, PFOA, SCCPs), showed increasing levels of concern.	Report evidence of the success of past regulations in decreasing exposure to POPs to consolidate the need of further work with chronic low levels of initial POPs (e.g., PCB, HCB) and the growing threat of partially regulated POPs (e.g., PFOS, PFOA, PBDEs, HCBD, SCCPs) and chemicals with POPs characteristics sometimes used as alternative.
The complex ecotoxicology of mixtures and the rapidly increasing quantities released to the environment of new substances with POPs characteristics are a challenge and an opportunity to transform monitoring strategies. Integrated assessments should not bury primary data under indicators but develop tools to look at primary QA/QC controlled empirical data provided in public repositories by a diversity of fields, from meteorology to molecular biology. Machine learning, statistical and process modelling tools can enhance process understanding and operational capacity.	Integrate POPs monitoring work and resulting data of abiotic media and macroscopic organisms with climate data and molecular biology and toxicology in curated and accessible repositories.
Local, indigenous knowledge about ecosystem process and structure has been of great value for scientists in developing understanding of POPs pathways and exposure routes. Science should provide local agents with meaningful and operational tools to deal with contaminants and POPs.	Establish and maintain conditions that facilitate common understandings and cooperation between local agents and scientists to develop effective strategies in public health and environmental policy on POPs.

5. Long-range environmental transport

Key messages:

Integrated assessment of POPs involves using models as a platform to quantitatively link emissions of POPs to the levels and trends observed in the environment. It is the most effective way to quantify the extent of LRET of POPs and forecast the effectiveness of emission reductions. A variety of modeling tools are available to support integrated assessment of emissions, transport in the environment, and levels and trends of POPs observed at monitoring stations.

[50] UNEP/POPS/COP/8/INF/38, http://chm.pops.int/tabid/525.

Experience with modeling existing POPs has beneficial synergies with identification and risk profiling of candidate POPs. Priorities for improving POP modeling capabilities include better descriptions of air/condensed phase partitioning and reducing uncertainties in emissions and degradation rates of POPs in air, water and soil with targeted laboratory and field studies.

Analysis of airflow back-trajectories and monitoring data on the initial POPs and newly listed POPs in Africa suggests that elevated air concentrations, measured at some of the MONET sites are primarily due to sustained local emissions. At the same time, low concentrations, observed at mountainous site Mt. Kenya, represent the continental background levels, largely affected by LRET of POPs from distant sources.

Air monitoring data in the Asia-Pacific region and analysis of back trajectories provided some interesting trends and transport related information. In particular, decreasing trends of DDT and increasing trends of HCBD were observed at monitoring sites of East Asian Monitoring Programme, which supports the view that these changes were affected by LRET, rather than the local emission effects (though national monitoring may also be affected by the local effects).

Potential sources and LRET pathways of POP pollution in the GRULAC region were analyzed using HYSPLIT-NOAA model for three monitoring sites located in Barbados, Jamaica and Uruguay throughout 2018. Back trajectories indicated potential effect of marine emissions and emissions from small vessels for the site in Barbados, emissions from nearby sources of Haiti, the Dominican Republic, Puerto Rico and the Caribbean islands for the site in Jamaica, and LRET from the sources in Brazil, Paraguay, Argentina, and Chile for the site in Uruguay.

LRET of POP pollution in the EE region was assessed by application of multi-compartment modelling for HCB, PCB and PCDD/PCDF. Predicted levels of pollution and emissions of all studied POPs have decreased significantly between 1990 and 2018 (i.e., HCB by 90%, PCB by up to 80%, PCDD/PCDF by 40–75%). Model simulations indicate changes of spatial distributions within the region and changes of significance of imports from lower latitudes. Significant contribution of secondary emission sources (re-volatilization from soils, vegetation and surface waters) to the pollution has been noted.

The direct influence of climate change on levels and trends of POPs in the global environment on the timescale of decades is likely to be much smaller than the influence of reductions in primary emissions that can be achieved through policy action. However, indirect effects of climate change on chemical cycling, including changes in food web structure, are not yet fully understood, and are not described in these model scenarios.

5.1 Assessment of long-range atmospheric transport

In the following sections, the information on long-range atmospheric transport is summarized from the regional monitoring reports for Africa, Asia-Pacific, Eastern Europe and GRULAC. Monitoring networks are in place in all regions, but spatial coverage and resolution are imperfect, and in most regions, there are severe gaps in temporal coverage of the stations. The needs for strengthening monitoring capacity, regional programmes and networks are highlighted in **2. Challenges to implementation**.

5.1.1 Africa

Temporal trends in ambient air and long-range transport of POPs to sites of the MONET-Africa network across the continent were studied for the year 2018 (HYSPLIT-NOAA model; White et al. 2021). The density heat map from back trajectory analysis of POPs in ambient air for MONET-Africa sites in Congo, Ghana, Ethiopia, Kenya, Mali, Mauritius, Morocco, Nigeria, and Sudan is shown in **Figure 53**.

The Mt. Kenya and Reduit, Mauritius, sites recorded the lowest POPs concentrations. Year-round, the Mt. Kenya site mainly received long-range transported air from either the northeast or southeast along the coast of East Africa and across the Indian Ocean. Advection to the Mauritius site, Reduit, was year-round dominated by air masses from the Southern Ocean and no major land masses.

From the modeled air mass origin distributions, Bamako and Khartoum covered the largest geographic areas of continental Africa and are likely influenced by multiple sources, both domestic and regional, including significant impact by Saharan dust. Brazzaville recorded the highest atmospheric levels of most POPs, with minimal changes as well as temporal trends indicating significant active local emissions.

In West Africa, e-waste recycling in Accra- Agbogbloshie is one of the most significant point sources of POPs and its emissions are expected to be primarily carried northeast across the rest of Accra year-round, but also affects POPs levels some 200 km away, Abetefi site, at least from November to January. Declining (or insignificant) trends during 2008–2018 (or shorter periods) prevail for OCPs, DDT, endosulfan and HCHs at all sites. Few other trends of OCPs were not consistently downward, in the case of dieldrin, even increasing at one site, i.e., Asela, Ethiopia. PCB trends were found decreasing too, but slower than OCPs. For PBDEs and PCDD/PCDF no trends were found at the sites, except for the Mauritius site (increasing PCDD/PCDF and decreasing PBDEs; White et al. (2021).

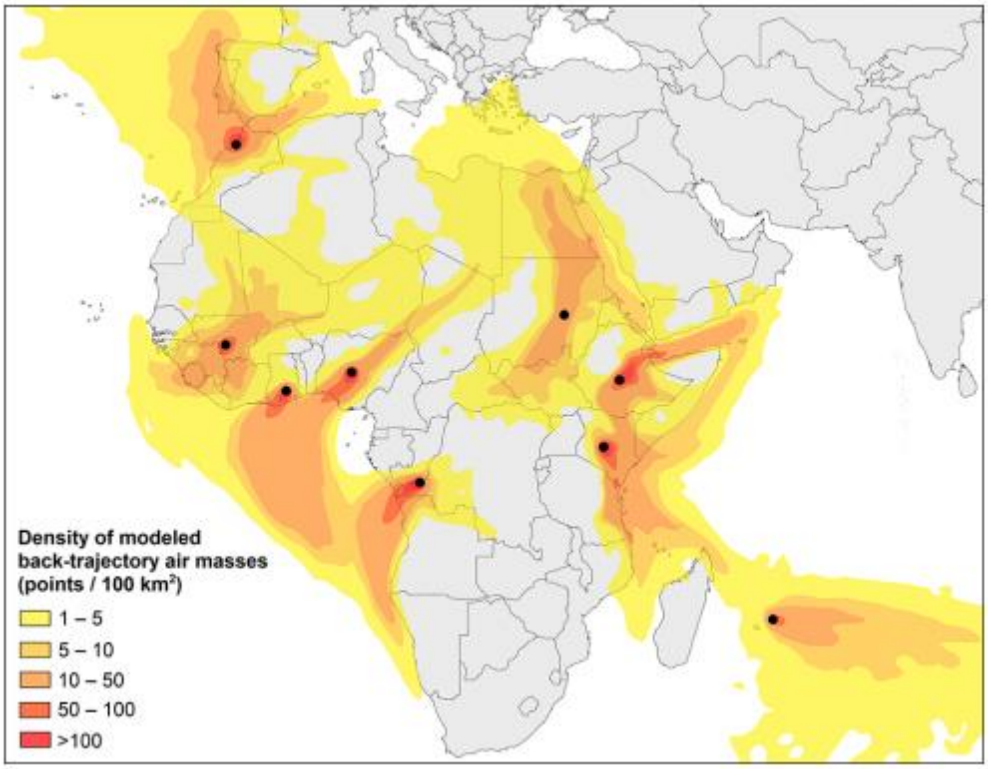


Figure 53. Density heat map from back trajectory analysis of POPs in ambient air for MONET-Africa sites. *(Source: White et al. 2021.)*

Modelled back trajectories for most of the monitoring sites in coastal countries indicated the likely effect of local emission sources on the pollution levels (e.g., emissions from Agbogbloshie, the largest e-waste recycling site in Africa) rather than LRET from other countries.

Monitoring sites in continental Africa are likely influenced by multiple sources, including local emissions, and transboundary transport of emissions. The lowest concentrations, measured at the high mountains site Mt. Kenya, reflect the continental background pollution.

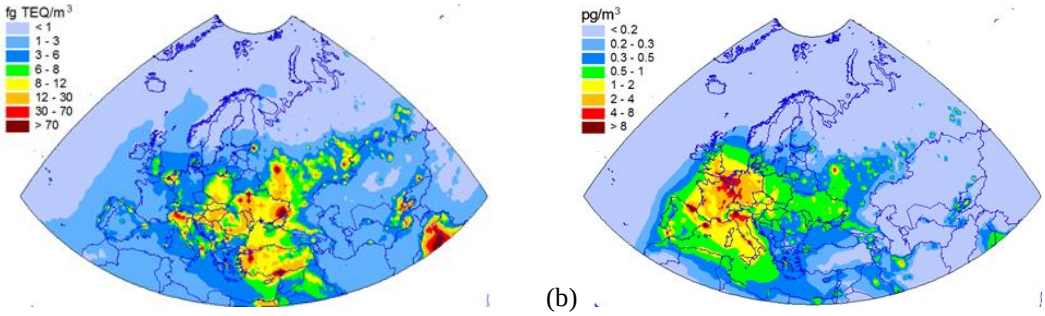
5.2.2 Asia-Pacific

Long-range atmospheric transport of POPs in Asia-Pacific is driven by Trade wind (east to west) around equatorial region and Westerlies in middle latitude area with seasonal effect of Asian Monsoon between the continent and the oceans. Only some trends observed in the monitoring data in Asia-Pacific region were studied due to the insufficient number of long-term regional monitoring programmes or studies on POPs. Nevertheless, the back trajectory results of air monitoring data in the POPsEA project provided some interesting trends and transport related information.

Decreasing trends of DDT and commercial pentabromodipheyl ether (c-pentaBDE), as well as the increasing trends of HCBD were observed. In the case of HCBD, similar levels of its drastic increases were observed not only in Hedo, Okinawa, but also in Fukue, Nagasaki and in the Japanese national monitoring program within a same period in 2017. Similarly, a clear decreasing trend of DDT, particularly *p,p'*-DDT and *o,p'*-DDT, were observed in Hedo, Okinawa and Gosan, Jeju as well as in measurements taken in the Japanese national monitoring program. These observations support the view that the temporal trends in HCBD and DDT are the result of LRET, rather than the local effects. Particularly, HCBD is volatile and has one of the highest characteristic travel distances (CTD) among all POPs, and comparison of the observed data with other regions may provide us with more insight into the potential sources and their global transport.

5.2.3 Eastern Europe

LRET in the EE region was assessed by modelling for HCB, PCB and PCDD/PCDF (see **Figure 54**) (MSC-E reports). Pollution levels and emissions of all studied POPs decreased significantly between 1990 and 2018 (i.e., HCB by 90%, PCB by up to 80%, PCDD/PCDF by 40–75%). Model simulations indicate changing distributions within the region and of significance of imports from lower latitudes. Besides, more significant contribution of secondary emission sources (re-volatilization from soils, vegetation and surface waters) to the pollution was noted.



(a) (b)

Figure 54. Spatial distribution of modelled annual mean concentrations of PCDD/PCDF (a) and PCB-153 (b) for 2018.

5.2.4 Latin America and the Caribbean

In order to detect changes in concentrations with some reliability, the temporal and spatial resolutions must be taken into consideration to properly design a regional monitoring programme, and measurements must be sustained in the selected sites. Of the 93 monitoring sites in GRULAC, 57% operated for just one year. The inconsistency of monitoring sites, lack of regular participation by countries and data variability were major obstacles for trend analysis.

The evaluation of short-range transport in the region was carried out through the search for scientific articles and the application of back trajectory analysis and the HYSPLIT-NOAA model in three sites of the region that presented maximum median values of the region in air and human milk matrices. Most of the identified scientific articles mainly referred to other parts of the world, which could reflect the little attention the GRULAC region has received on this issue. Local back trajectory studies were conducted in Mexico in the early 2000s and more recently in Colombia and the Caribbean. It was not possible to apply the HYSPLIT-NOAA model to more sites in the region due to the lack of financial resources.

Evaluation of LRET in the GRULAC region for 2018 was carried in Barbados, Jamaica, and Uruguay applying the HYSPLIT-NOAA model. Back trajectories for the site in Barbados indicated predominant east-west wind direction from the equatorial mid-Atlantic with potential pollutant emissions due to the areas closest to the monitoring site, including marine emissions and emissions from small vessels. However, it is considered important to analyze long-range back trajectories in order to evaluate possible contributions of pollution transport from the African continent.

Analysis of back trajectories for the site in Jamaica showed potential effect of emissions in the areas close to the monitoring site including Haiti, the Dominican Republic, Puerto Rico and the Caribbean islands of Montserrat, Guadeloupe and Dominica among others.

In case of the monitoring site in Uruguay about 70% of trajectories indicated atmospheric transport from north-east direction crossing southern parts of Brazil and Paraguay, while for the rest 30% the transport from south-west direction was estimated with potential influence of emission sources in Argentina and Chile.

Furthermore, satellite images of the fires reported during 2018 were reviewed. It seemed that there was an important contribution from these events that may have generated and/or mobilized some POPs. It is highly recommended to review these contributions in more detail to identify the types of burning (vegetation or waste, among others) that took place in the region.

More research is needed to assess the risks of exposure to POPs through atmospheric transport in the region's boundaries. The absence of continuous and sustainable monitoring programmes and subsequent atmospheric modeling capacity were the limiting factors for establishing temporal and spatial trends that are statistically significant.

5.2 Long-range environmental transport modeling

5.2.1 Introduction

Measurements of POPs at locations far from sources provide direct empirical evidence of LRET at regional, continental, hemispheric and global scales. A complete assessment of LRET of POPs can only be achieved by integrating information and understanding about (i) the location, rate and temporal trend of emissions; (ii) measured levels at different locations; and (iii) rates of transport through the environment in the atmosphere, oceans, rivers and migratory species. Mass balance chemical fate models provide a platform for synthesizing information about emissions, transport processes, and measured concentrations by quantitatively describing processes that control the fate of chemicals in the environment (MacLeod et al. 2010; Hung et al. 2013).

In recent years, international working groups have reviewed POP modelling activities and made recommendations for research priorities. For example, the Working Party on Exposure Assessment under the Organisation for Economic

Co-operation and Development (OECD) is currently undertaking review of its tool "Pov and LRTP Screening Tool"[51] which has greatly contributed to assessing persistence and long-range transport potential of organic chemicals at a screening level. Others include the 2010 Assessment Report of the Task Force on Hemispheric Transport of Air Pollutants (UNECE 2010; Gusev et al. 2012), formed under the Convention on Long-range Transboundary Air Pollution (LRTAP) in 2010; the Saltsjöbaden V workshop (Grennfelt et al. 2013); the workshop on Next Generation Air Quality Monitoring (Hung et al. 2013); and the outcomes of the ArcRisk EU FP7 Collaborative Project (Carlsson et al. 2018). These working groups have generally agreed that degradation rates of POPs are a driving source of uncertainty in model scenarios, and that improving emission inventories is among the most important research priorities for applying models to understand the LRET, levels, and trends of POPs in the environment and in human milk and blood.

Models link the concentrations of POPs in the environment to emissions that have occurred at specific locations and times and provide a conceptual basis for understanding the levels and trends that are observed at monitoring stations. A conceptual structure of a global scale chemical fate and transport model that links the location, level and trend of POP emissions to measured concentrations is shown in **Figure 55**. Models thus provide a basis to assess how reductions in the emissions of POPs are reflected in reductions in levels in the environment. Environmental fate models linked to bioaccumulation models can extend the assessment to link emissions to POPs levels and trends in wildlife and in the bodies of humans (Cowan-Ellsberry et al. 2009; McLachlan 2018).

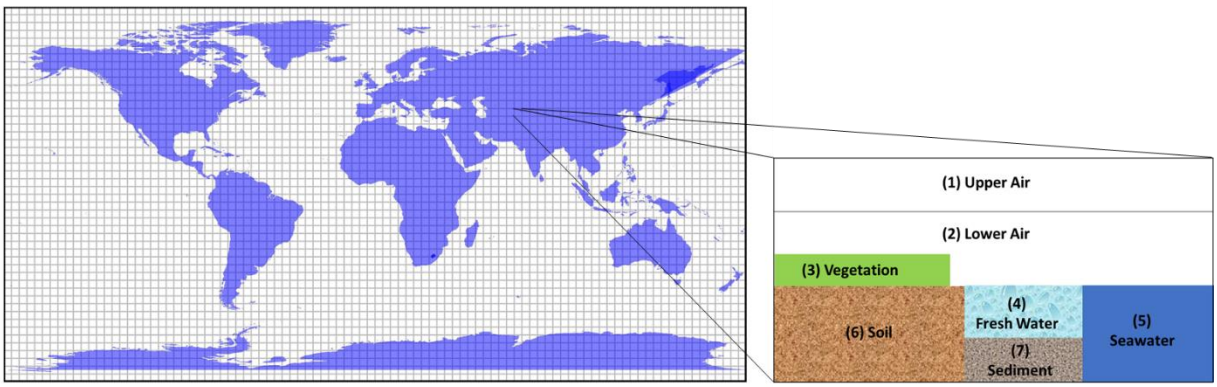


Figure 55. Conceptual structure of a global scale chemical fate and transport model that links the location, level and trend of POP emissions to measured concentrations.
(The BETR Global model (MacLeod et al. 2011) describes the global environment on a grid with variable spatial resolution. Within each grid cell chemical emissions and fate processes that distribute POPs between air, water, soil, sediment and vegetation are modelled, and grid cells are connected by flowing air and water.)

Models can also be applied to isolate the effect of emission reductions from other factors that may affect levels and trends of POPs observed at monitoring stations, such as variability in local conditions and long-term changes in climate (UNEP/AMAP 2011; Carlsson et al. 2018). Models are particularly useful when they support the formation of testable hypotheses that guide research (MacLeod et al. 2020).

The first two global effectiveness evaluation reports under the Stockholm Convention described POPs modeling studies that mostly focused on relatively well-studied POPs including PCB and HCHs and illustrated capabilities to link emission inventories to levels and trends. The role for models in identifying and composing risk profiles of new POPs and to screen for the most relevant transport pathways was illustrated in the second report.

In the regional monitoring report for WEOG, four recent case studies of applying the integrated approach of emission estimation, process-based modelling, and model evaluation against measurement data were summarized. These case studies have been selected to illustrate recent advances in integrated assessment modeling, specifically: (i) linking emissions to human body burdens of POPs at the global scale, (ii) conducting integrated assessment of POP candidates, (iii) estimating emissions of POPs and POP candidates from monitoring data, and (iv) modeling global emissions, fate and transport of PFOS in the ocean.

Considered together, these four case studies demonstrate that cross-disciplinary collaboration with an integrated approach that brings together information from models, emission estimates and environmental monitoring provides a quantitative, global-scale accounting of POPs or POP candidates. Applying and iteratively improving POP assessments using the integrated approach has the potential to play a much more prominent role in implementation and effectiveness evaluation of the Stockholm Convention, and in the design and execution of the GMP, for example

[51] https://www.oecd.org/chemicalsafety/risk-assessment/oecdpovandlrtpscreeningtool.htm.

by supporting development and critical evaluation of emission inventories, and by identifying priority research areas that target critical uncertainties within the emissions-fate and transport-environmental concentration chain.

5.2.2 Case studies of the integrated approach to understanding long-range environmental transport of POPs

5.2.2.1 Predicting global scale exposure of humans to PCB-153 from historical emissions

Most integrated approach studies of POPs have focused on understanding emission-to-concentration relationships for POPs in air, which is a core medium for monitoring, and in some cases also water, which is a core medium only for PFOS. The other core media for monitoring POPs for the effectiveness evaluation under the Stockholm Convention are human milk and blood. The database of measured levels of POPs in human milk maintained under the UNEP/WHO Human Milk Survey is a valuable resource in this regard. This database was employed together with the global POP fate and transport model BETR Global (MacLeod et al. 2011) and the human exposure model ACC-HUMAN (Czub and McLachlan 2004) to assess current capabilities for emission-to-human exposure modeling of a prototypical traditional POP, PCB-153. The concentration of PCB-153 in human milk for 56 countries around the world was modelled based on a global historical emissions scenario and compared to observations in the database.

Historical primary emissions of PCB-153 beginning in 1930 were obtained from Breivik et al. (2007 and 2016). This emission inventory considers emissions occurring throughout the entire lifecycle of PCB-containing products (including production), as well as emissions from the export and import of e-waste (see Breivik et al. 2016 for further details). The BETR Global model at a grid cell size of 3.75°×3.75° (lat/long) was used to simulate the global fate and transport of PCB-153, with transport process of chemical associated with particles from soil compartments to freshwater compartments removed because the parameterizations within the model were found to not apply to arid environments.

ACC-HUMAN (Czub and McLachlan 2004) predicts the concentration of chemicals in foodstuffs (namely fish, beef, and dairy products) from concentrations in environmental media (namely air, water, and soil). Human exposure to the chemicals is further modelled using ingestion scenarios, ultimately leading to estimates of chemical concentrations in human tissues. A range of uptake and elimination processes by organisms throughout the food web, such as ingestion of food and soil, inhalation, gill or root uptake, fecal egestion, childbirth, and nursing are considered. The lifetime exposure of representative individual humans was modeled based on variable concentrations in food and environmental media arising from the spatial and temporal trends in emissions.

Country-specific environmental concentrations of PCB-153 were derived by taking population-weighted averages of the overlying 3.75° grid cells of BETR Global. Concentrations of PCB-153 in human milk for first-time mothers were then modelled, using a model woman who was “born” 20-30 years before the year that breast milk measurements were made (the year of “birth” was selected based on the average age of primiparae mothers in the country of interest). Country-specific dietary patterns and animal lipid ingestion rates were employed using WHO Global Environment Modelling System cluster diets (UN 2017) and food balance sheets from the Food and Agriculture Organization of the United Nations (FAO 2017). All meat, dairy, and freshwater fish consumed in a country were assumed to be produced in that country, except marine fish which were assumed to be internationally sourced and thus had chemical concentrations that were driven by modeled PCB-153 concentrations in BETR Global grid cells corresponding to regions with the highest global fish harvesting (UBC 2014).

Modelled human milk concentrations were compared to measurements from the UNEP/WHO Human Milk Survey (van den Berg et al. 2017; Hulek et al. 2014). This monitoring program under the Stockholm Convention measures country-specific PCB-153 human milk concentrations from first time mothers employing pooled milk samples from either 10 donors (until the year 2003) or 50 donors (after the year 2003) per country. The data employed covered the years 2000 to 2014 from 56 countries.

Measured and modelled concentrations of PCB-153 in human milk were strongly correlated when considering both log-transformed absolute values and rank orders of concentrations in different countries (**Figure 56**, r=0.76 for Pearson illustrated in the left panel, rs=0.74 for Spearman illustrated in the right panel, $p < 0.0001$). The root mean square difference between the measured and modelled values was 0.65 log units (i.e., a factor of 4.5). Despite this overall good agreement, two particular clusters of bias were identified in the modelling results that showed a clear geographic pattern. The seven countries of West Africa (blue squares in **Figure 56**) were characterized by strong underprediction of PCB-153 concentrations in human milk, while concentrations in Hungary and Bulgaria (red triangles in **Figure 56**) were strongly overpredicted (see also **Figure 57**).

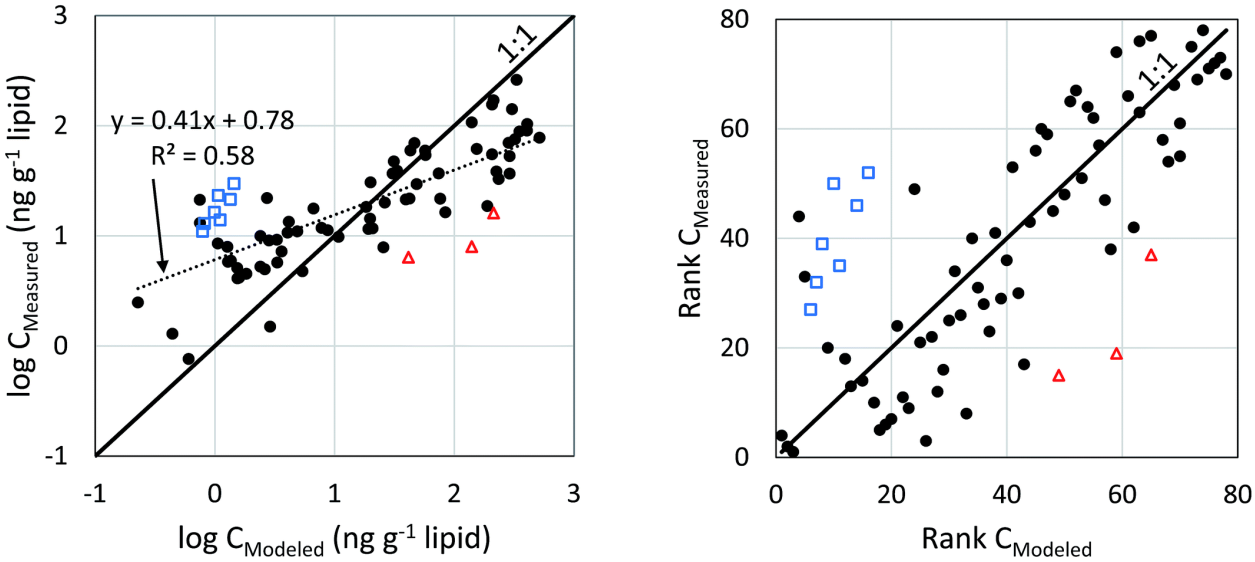


Figure 56. Comparison of measured and modelled concentrations of PCB-153 in human milk for 78 milk samples from 56 countries collected under the UNEP/WHO Human Milk Survey (modelling data as described in McLachlan et al. 2018).
(Left panel: Comparison between measured and modelled lipid-normalized values of the logarithm of PCB-153 concentrations. Right panel: Comparison between the measured and modelled rank order of the concentrations in the 78 samples. The blue squares represent samples from 7 countries in West Africa, and the red triangles represent data from Hungary (2001 and 2006) and Bulgaria (2014). Figures 3 and 4 of McLachlan et al. 2018.)

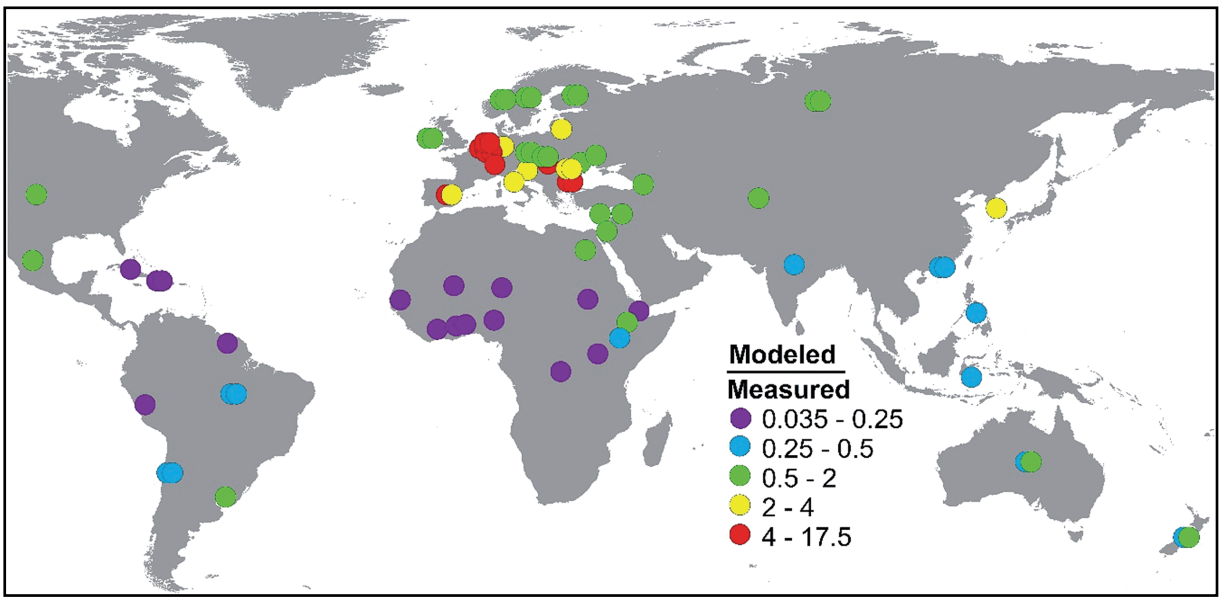


Figure 57. Quotient of the modelled/measured lipid normalized concentrations of PCB-153 in human milk in different countries.
(*Measurement data collected under the UNEP/WHO Human Milk Survey; modelling data as described in McLachlan et al. 2018. Figure 5 of McLachlan et al. 2018.)*

The overprediction in Hungary and Bulgaria is an indication that the model may be predicting stronger gradients in concentrations across Europe than are measured (see **Figure 57**). One possible explanation for this is the large amount of intra-European trade in agricultural goods that is not reflected in the modelling assumption that meat, dairy, and freshwater fish are sourced and consumed in the same country. A sensitivity analysis using European-wide averages did not improve the predictions for these outlying countries. Given the historically high emissions of PCB-153 in central Europe, strong gradients in PCB-153 would be expected, and this analysis highlights the need to use detailed and highly resolved data on food sourcing for regions with this characteristic.

In contrast to the overprediction of PCB-153 concentrations in human milk in European countries, underprediction of concentrations was seen for the seven West African countries (see **Figure 57**). One possible explanation is the under-estimation of recent emissions of PCB-153 in this region due to e-waste burning. A sensitivity analysis using a 'worst-case' scenario of the amount of e-waste that is burned in e-waste importing countries of 20% (compared to the default scenario of 5%) from the Breivik et al. (2016) emission inventory was conducted, and still resulted in underpredictions by a factor of roughly 10 or more of PCB-153 concentrations in milk. This indicates that other factors may be influencing the modelling framework's ability to capture the high levels of PCB contamination, such as contamination in imported food, processes occurring at a spatial scale finer than 3.75°×3.75° or unrepresentativeness of the sampled population in regions with large spatial gradients in PCB concentrations.

In order to directly link POP emissions to toxic effects, one must understand the transfer from emissions to concentrations in vulnerable organisms, and in the case of human health outcomes to concentrations in particular people or groups of people. Modelling national averages and evaluating against the UNEP/WHO human milk database does not capture instances where specialized local or regional diets strongly influence the exposure potential to PCB. Undeman et al. (2018) investigated the interplay of proximity to emission sources, sourcing of food, and food web structure on human exposure to PCB-153 employing a modelling framework similar to that used in the global case study by McLachlan et al. described above. They found that a diet composed of aquatic mammalian carnivores, particularly in Canadian Inuit communities, far outweighed the remoteness from PCB sources in determining exposure. PCB-153 concentrations for these Inuit communities were 6-8 times higher than a reference population in northeastern Europe that did not eat aquatic mammalian carnivores, despite having air and seawater concentrations that were 60 and 20 times lower, respectively. Such specialized diets are not explicitly considered in the approach taken by McLachlan et al. (2018) which (for the most part) considered exposure to PCB for a representative population of each country.

This case study highlights the need for collecting detailed food sourcing data for regions with large gradients in environmental POP concentrations, as well as for better understanding of the environmental levels and exposure routes of POPs in Sub-Saharan African countries. Recent publications by Huang et al. (2020) and Moeckel et al. (2020) indicate that work on investigating exposure pathways for POPs in Sub-Saharan Africa is an area of active research.

5.2.2.2 Global emission inventory, long-range environmental transport, and environmental distribution of dicofol

Dicofol is an organochlorine acaricide (USEPA, 1998; POPRC, 2013) that was a popular substitute for DDT due to the two chemicals' functional and structural similarity. Findings regarding dicofol's potential to harm wildlife and humans (Clark et al. 1990; Wiemeyer et al. 2001; Kojima et al. 2004; Reynolds et al. 2005; Hoekstra et al. 2006; Lesenger et al. 1991) led to the imposition of national and multinational restrictions (e.g., Weem, 2010; OSPAR 2002), and to international regulation under Annex A of the Stockholm Convention in 2019 (POPRC 2013; Decision SC-9/11). To support scientific assessment of dicofol's LRET, Li et al. (**Figure 58**; see Li et al. 2015 for additional details) developed an inventory of global dicofol usage between 2000 and 2012 and used these estimates to conduct an investigation of the ability of dicofol to be transported from release regions in the lower and mid-latitudes to the Arctic and the subsequent fate characteristics of the chemical in the Arctic.

Depending on data availability, geographically resolved estimates of dicofol usage were compiled using national reporting statistics, data on cultivated areas and dicofol application rates, and other regional or continental usage data, coupled with geographic constraints based on dicofol-treated crops and agricultural intensities. Global usage data was generated for the years 2000-2012 and allocated to a 1°×1° latitude/longitude grid (**Figure 58** and Li et al. 2015 for additional details). A total of 28.2 kilo tonnes (kt) of dicofol active ingredient were estimated to have been used globally between 2000 and 2012, with 77% of this in Asia specifically contributing 69% of the total. Likely due to voluntary restriction and phase-outs at national and regional levels, as well as a decrease in its market share, annual global dicofol usage declined by a factor of 4.6 from 3.4 kt in 2000 to 0.73 kt in 2012. Areas of high dicofol emissions were identified in the low and mid-latitudes of the northern hemisphere and include central and eastern parts of China, India, countries on the Mediterranean coast, and California and Florida in the U.S.

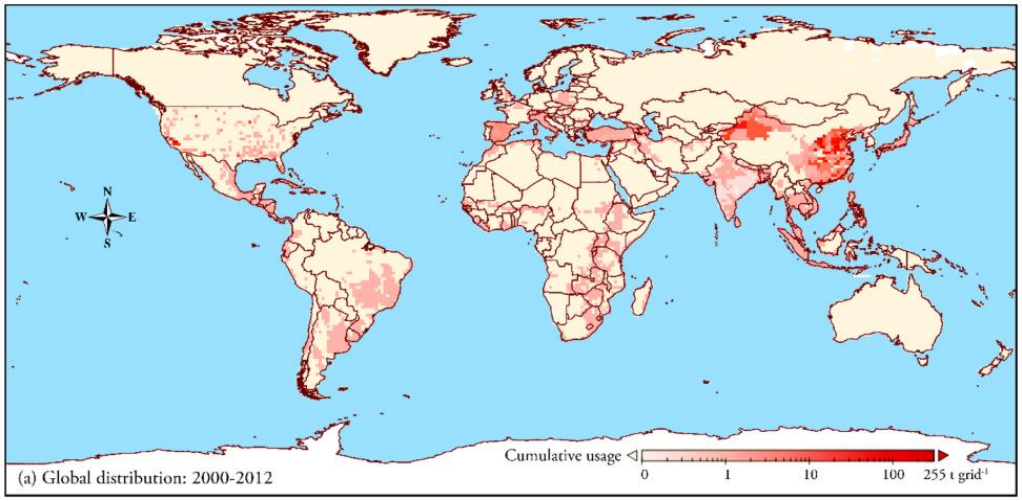


Figure 58. Estimated cumulative dicofol usage from 2000 to 2012 based on the emissions inventory compiled by Li et al. 2015.
(Grid spacing is 1°×1° latitude/longitude. From Figure 2 of Li et al. 2015.)

The gridded dicofol emission estimates were used to drive the BETR Global model at a 15°×15° latitude/longitude grid spacing (MacLeod et al. 2011) to evaluate the spatio-temporal dynamics of the global transport and environmental distribution of dicofol between 2000 and 2012. The simulations indicated that dicofol can be transported northward, driven by atmospheric and oceanic advection, from its low- and mid-latitude source regions (see **Figure 59**). While the bulk of dicofol present in the atmosphere was distributed in low and mid-latitudes (panel b), mirroring the geographic distribution of global emissions, seawater concentrations of dicofol were highest in the Northern Hemisphere oceans north of 45° latitude (panel c). In some regions of the Arctic such as Alaska, Siberia, and northern Canada, modelled dicofol concentrations in soil were even comparable to those in tropical regions treated with dicofol (panel d). The excess contamination in northern oceans and soils relative to that in the atmosphere predicted by the BETR Global simulations suggests that dicofol has the potential to be enriched in the surface media of the Arctic.

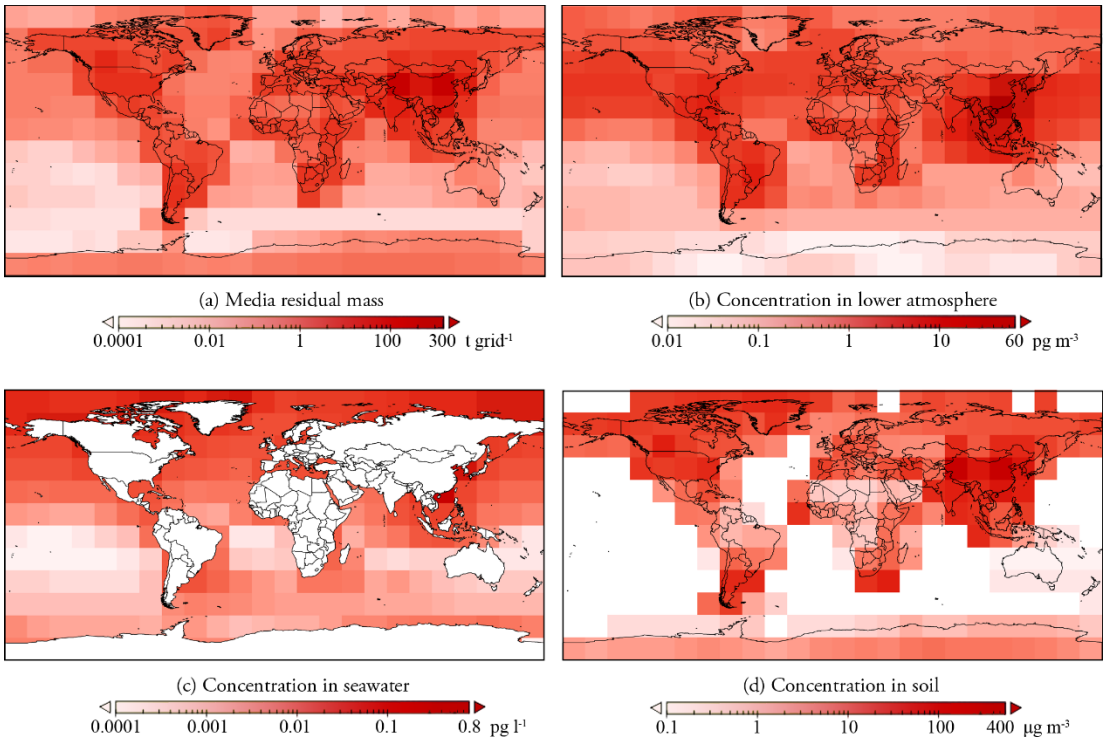


Figure 59. BETR Global modelling results of dicofol environmental distribution at the end of 2012 showing (a) total environmental burden, (b) lower atmosphere concentrations, (c) seawater concentrations, and (d) soil concentrations.
(Grid spacing is 15°×15° latitude/longitude. Figure 3 of Li et al. 2015.)

To assess the extent of the enrichment of dicofol in the Arctic surface media relative to the initial POPs and candidate POPs, the authors further modelled the global fate and transport of dicofol using version 1.1 of the Globo-POP model (courtesy of F. Wania from the University of Toronto at Scarborough; see Wania and Mackay, 1995 and 2000). Globo-POP describes the global environment as 10 latitudinal climate regions. Results from this modelling indicated that with constant, continuous emissions of dicofol for a decade, 0.06% of the cumulative global dicofol emissions would be found in the Arctic surface media at the end of the tenth year (referred to as the absolute Arctic Contamination Potential (eACP)), and that 3.70% of the dicofol inventory in the global environment would be present in Arctic surface media at this time (referred to as the relative Arctic Contamination Potential (mACP)). Compared with 10 selected initial and candidate POPs, dicofol has a moderate efficiency for LRET given that it has an eACP value higher than three initial POPs (heptachlor, aldrin, and hexabromocyclododecane) and has the strongest efficiency for accumulation in Arctic surfaces with an mACP value higher than all compared chemicals (see Li et al. 2015 for details).

Source region concentrations of dicofol were found to decrease more rapidly with concomitant decreases in emissions compared to environmental concentrations of dicofol in remote regions. For instance, despite a decline of a factor 4.6 in global dicofol emissions from 2000 to 2012, soil and sediment concentrations in the Arctic only declined by factors of 3.9 and 3.5, respectively. This slower decline in surface media concentrations implies that once deposited on Arctic surfaces, dicofol has the potential to pose a long-lasting effect on the health of the ecosystem. The results of this modelling study also indicate that under the GMP, monitoring atmospheric concentrations of dicofol in source regions would closely reflect the effectiveness of the Stockholm Convention in reducing or curbing the emissions of POPs. However, monitoring concentrations in surface media and biota in remote areas would provide a potentially different, but more complete, picture of the effectiveness of the Convention's implementation.

5.2.2.3 Global gridded emissions and long-range environmental transport of tris-(1-chloro-2-propyl) phosphate (TCPP)

An expert working group recently noted that progress towards elimination of POPs is reflected in temporal trends in air, human milk and blood, but that it would be best assessed by tracking trends in emissions directly (Hung et al. 2013.

Emission inventories for POPs are often compiled using a 'bottom-up' approach of collecting chemical production, usage, and emission factor data which is then extrapolated over space and time. An alternative is for modelers to tackle the problem of uncertain or lacking emission inventories more directly within the integrated approach by considering the problem "in reverse", i.e., by using monitoring data and models as a basis to propose scenarios that fill gaps in knowledge about the location, rate, and trend of emissions in a 'top-down' approach. The 'top-down' approach recognizes emissions as the most poorly constrained part of the integrated approach and makes predicting emissions, rather than environmental levels, the focus of modelling efforts. Emission scenarios that provide good agreement with monitoring data and available 'bottom-up' emission information provide a basis for formulating testable hypotheses that can be evaluated in further research work, which may include more focused work on 'bottom-up' estimates.

Tris-(1-chloro-2-propyl) phosphate (TCPP, CAS No. 13674-84-5) is an organophosphate flame retardant (OPE) widely used in industrial products (van der Veen and de Boer, 2012). TCPP is not a Stockholm Convention POP, however it has been suggested as a POP candidate[52] and has been measured in remote regions globally (Sühring et al. 2016; Li et al. 2017; Castro-Jimenez et al. 2016; Salamova et al. 2014). TCPP is used as a replacement for flame retardants that have been more heavily regulated, including polybrominated diphenyl ethers (PBDEs) that have been banned under the Stockholm Convention (Marklund et al. 2005; Möller et al. 2012; Green et al. 2008). Estimates of the usage and emissions of TCPP to the environment are few and are poorly constrained (REF possibly their citations 15 and 19 as the only known emissions estimates). In addition, there are high uncertainties regarding physicochemical properties of TCPP, particularly degradation rates in air and water.[53] Traditional 'bottom-up' emissions inventories of chemicals require knowledge of a chemical's production, usage, and emission factors from various use categories (e.g., Breivik et al. 2007), knowledge which is not currently available at the global scale for TCPP. Inspired by previous modeling studies that aimed to estimate emissions at local and regional scales (Rodgers et al. 2018; Bogdal et al. 2014 A and B; Gasic et al. 2009; MacLeod et al. 2007; Buser et al. 2013; Schenker et al. 2009), a modified 'top-down' approach was taken by Li (2019) to estimate global emissions of TCPP to air and water.

Measurements of TCPP in air (219 measurements from between 2006 and 2016) along with measurements in seawater (111 measurements from between 2010 and 2017) were compiled from literature sources (see Li 2019, for details). Measurement data from rural and remote areas, rather than urban areas, was selected as appropriate for comparison to the modeled concentrations. Measurements collected from the literature were averaged within BETR Global model

[52] https://tema.miljodirektoratet.no/old/klif/publikasjoner/2871/ta2871.pdf.

[53] https://www.miljodirektoratet.no/globalassets/publikasjoner/klif2/publikasjoner/2871/ta2871.pdf.

grid cells, resulting in measurements in air for 130 grid cells and in water for 23 grid cells that could be used in the integrated assessment.

To simulate the fate of TCPP in the environment, the BETR Global model was employed with monthly time step and 3.75°×3.75° (lat/long) grid spacing (MacLeod et al. 2011; McLachlan et al. 2018). Scenarios using three potential gas phase atmospheric half-lives of TCPP were employed (12, 60, and 300 hours) to investigate the plausibility of the range of half-lives proposed by Li et al. (2017), and an analogous range of potential half-lives in water was also investigated (1440, 7200, and 36000 hours), with the value of 1440 hours being based on an estimate from EPI Suite 4.0 (see USEPA, 2017 for latest version). As a first step, unit emissions of TCPP to air were distributed globally to land-based emission grid cells proportional to artificial nighttime light intensities using the 2010 Defense Meteorological Satellite Program/Operational Linescan System (DMSP/OLS) dimensionless nighttime light index (NGDC), as a proxy for intensity of industrialization (MacLeod et al. 2011; von Waldow et al. 2010; Huang et al. 2015; Jiang et al. 2017; Göktas et al. 2016). A range of scenarios for emissions to water were explored, including zero emissions to water and emissions to water equal to one-half and one times emissions to air. In total, 27 modelling scenarios were investigated employing all unique combinations of emission parameters and the degradation rates in air and water. The model was run assuming constant emissions to a state in which concentrations of TCPP during consecutive simulated years were repeated. Thus, the assessment provides an estimate of the average emission rate of TCPP during the period when measurements were made, i.e., 2006 to 2016.

The results of the unit emissions modelling simulations across the 27 scenarios were compared to the measurement data to derive scenario-specific global emissions scaling factors that provide the best agreement between measured and modelled concentrations in each scenario. The single scenario that was judged to provide the best agreement between model predictions and measurements was that with half-life in air, half-life in water, and emissions to water being 60h, 7,200h, and Ew=0.5EA (respectively), with total global emissions being 39.5 kt/y. It was not possible to improve model performance by adjusting the relative emission rates of TCPP independently in seven (sub) continents indicated in **Figure 61**, meaning that the initial spatial allocation of TCPP emissions according to intensity of nighttime light intensities could not be refined. **Figure 60** displays the regression between log10 values of observed and modelled concentrations of TCPP in air and water using the preferred modelling parameters, while **Figure 61** shows the globally gridded emissions to air under this preferred scenario.

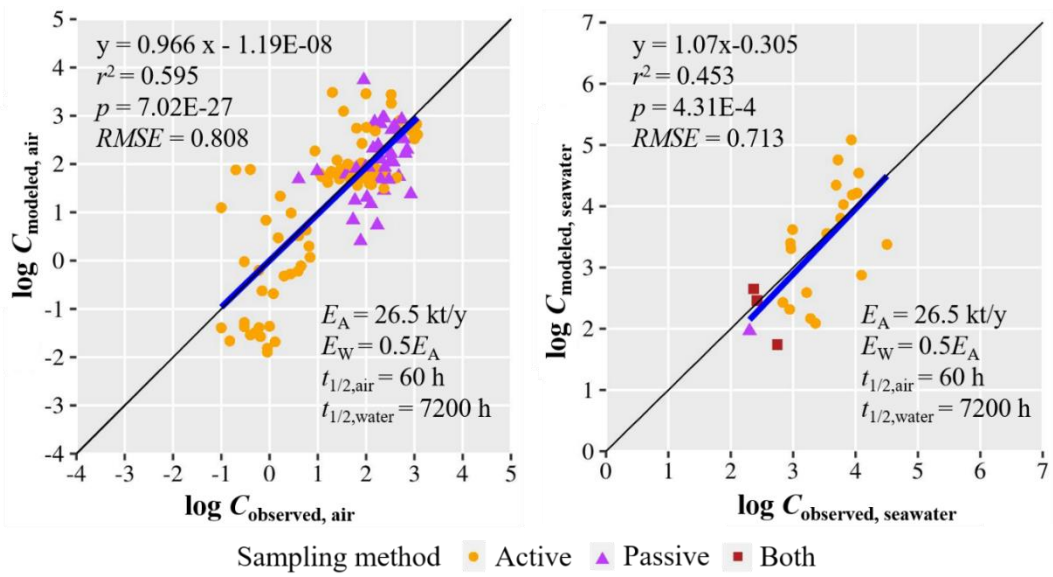


Figure 60. Comparison of the base-10 logarithm of modelled and observed concentrations of TCPP in global air (left panel) and seawater (right panel) based on the measurements and modelling described in Li 2019.
(Modelling is based on the scenario with global TCPP emissions to air of 26.3 kt/y, global emissions to water of 13.2 kt/y, and half-lives for degradation of TCPP of 60 hours in air and 7200 hours in water. Black line indicates the 1:1 comparison line; blue line indicates the regression line. Figure 1 of Li 2019.)

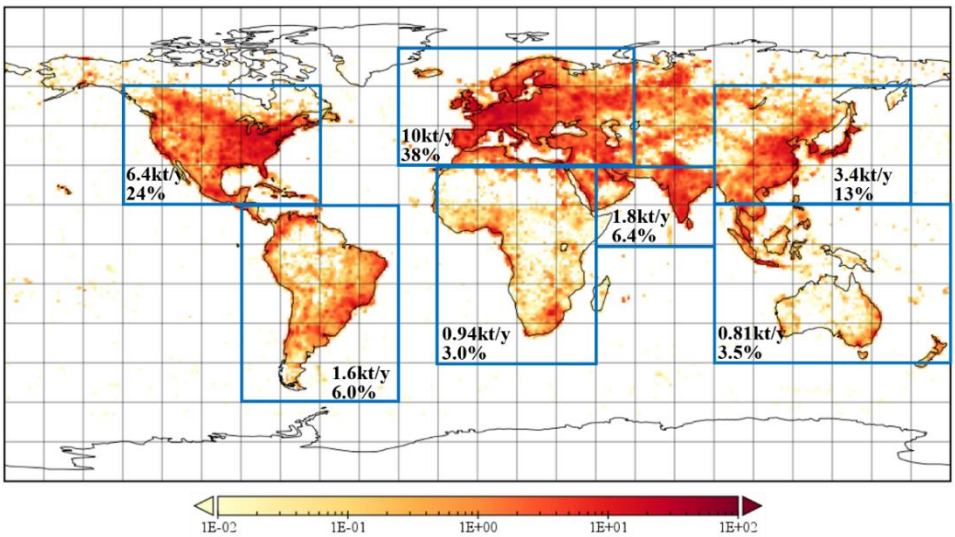


Figure 61. Global gridded inventory of TCPP emissions to air inferred from the integrated 'top-down' modelling approach described in Li 2019 under the preferred scenario for TCPP emissions to air (i.e., 26.5 kt/y) and environmental degradation half-lives (i.e., 60 hours in air and 7200 hours in water).
(Annual emission rates for different (sub) continents (blue rectangles) are indicated. Grid spacing is 1°×1° latitude/longitude. Figure 2 of Li 2019.)

Globally, the root mean square error (RMSE) of modeled atmospheric concentrations was 0.81 log units. Isolated occurrences of relatively large differences between modelled and measured values are found in several locations such as Barbados (0.03), the Great Lakes region (>20), Czechia (62), and Indonesia/Australia (200–400) (**Figure 62**, top panel). In seawater the RMSE was slightly lower than in air (0.71 log units), but TCPP measurements in seawater do not provide good global coverage, which results in higher uncertainties in the entire assessment than for atmospheric measurements (Error! Reference source not found., lower panel).

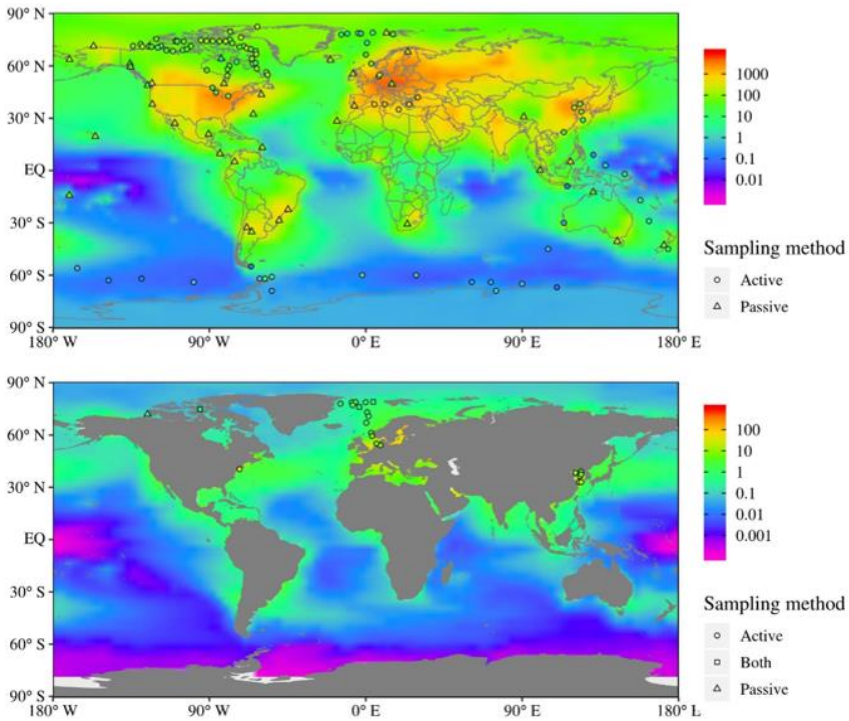


Figure 62. Modelled (color gradient in the background) and observed (colored symbols) concentrations of TCPP in air (pg/m^3; top panel) and seawater (ng/L; bottom panel) under the preferred scenario for TCPP emissions to air and water (i.e., 26.5 kt/y and 13.3 kt/y, respectively) and environmental degradation half-lives (i.e., 60 hours in air and 7200 hours in water).
(Modelled values are annual mean concentrations. Modelling data grid spacing is 3.75°×3.75° latitude/longitude. From Figures 3 and 4 of Li 2019.)

Limitations and sources of potential bias within the integrated assessment conducted by Li (2019) include the lack of interannual variability in TCPP emissions, uncertainty in the measurement data accuracy (both in terms of the absolute value as well as the geographic area covered by these measurements), and assumptions about physico-chemical properties of TCPP that were not reflected in the scenario analysis. While this investigation of TCPP should be considered preliminary, it provides valuable insights about the link between emissions and concentrations in the global environment. Plausible environmental fate parameters have been established for TCPP in air and the 'top-down' emission inventory provided by this assessment serves as a reference point for future studies that could establish temporal and spatial trends.

5.2.2.4 Modelling long-range environmental transport of PFOS in the ocean

PFOS and other perfluoroalkyl acids (PFAAs) are part of a class of industrial chemicals, PFAS, with large historical production volumes (Armitage et al. 2009b; Wang et al. 2014). PFAAs are extremely persistent in the environment and can adversely affect human and ecological health (Sunderland et al. 2019). PFOS (Annex B), PFOA and PFHxS (Annex A) are regulated under the Stockholm Convention. The ocean is recognized as the terminal sink for PFAAs released to the environment, and measurements of PFOS, PFOA and PFHxS in water are reviewed in **5.1** . Zhang et al. (2017) conducted an emissions inventory and modelling case study of PFOS in the North Atlantic Ocean that illustrates application of the integrated approach to a PFAA with diffuse emission sources that provides valuable insights into current emission rates and fills gaps in available measurement data.

Spatially and temporally resolved oceanic discharges of PFOS were estimated from wastewater monitoring data at the river-catchment level in North America for the year 2010 (**Figure 63**, panel A) and from river monitoring in Europe for 2006–2007 (**Figure 63**, panel B). The estimated discharges from these discrete time periods were extrapolated to a range of initial estimates of total time dependent PFOS inputs to the North Atlantic between 1958 and 2010 (**Figure** 63, panel C) based on global historical use and emission inventories (Armitage et al. 2009b; Wang et al. 2014). This initial emissions inventory was mapped onto a 1°×1° latitude/longitude grid to drive an oceanic fate and transport model.

The Massachusetts Institute of Technology general circulation model (MITgcm; http://mitgcm.org), a 3-D ocean circulation model, was used to simulate PFOS transport in the ocean through lateral and vertical oceanic circulation, mixing and particle settling. The model has a horizontal grid size of 1°×1° latitude/longitude and includes 23 vertical levels (see Zhang et al. 2017 for additional details on the model setup). For the years 1958 to 2010, the model was forced with 1°×1° gridded inputs to the North Atlantic Ocean between 20°N and 60°N from rivers and wastewater treatment plants in North America and Europe using the inventory developed here. Between 2010-2038 inputs are assumed to be zero to simulate elimination of PFOS production, use and emissions.

Modeled seawater concentrations are highly correlated with measurements (R^2=0.90, p=0.01) but the model based on the median of the initial release estimation had a mean bias of 75% relative to observations for all regions. Adjusting the emissions produced mean modeled surface water (10 m) concentrations of 39±14 pg/L in 2010 compared to an observed value across all offshore sampling locations of 43±21 pg/L between 2009 and 2011. The adjusted releases represent a refined hypothesis about historical emissions that incorporates both 'top-down' and 'bottom-up' information from the integrated approach. According to these refined estimates, cumulative PFOS inputs to the North Atlantic Ocean were 2.4×10^3 mg. North American coastal releases accounted for 59% of total releases and the remaining 41% was from Europe (see **Figure 63**).

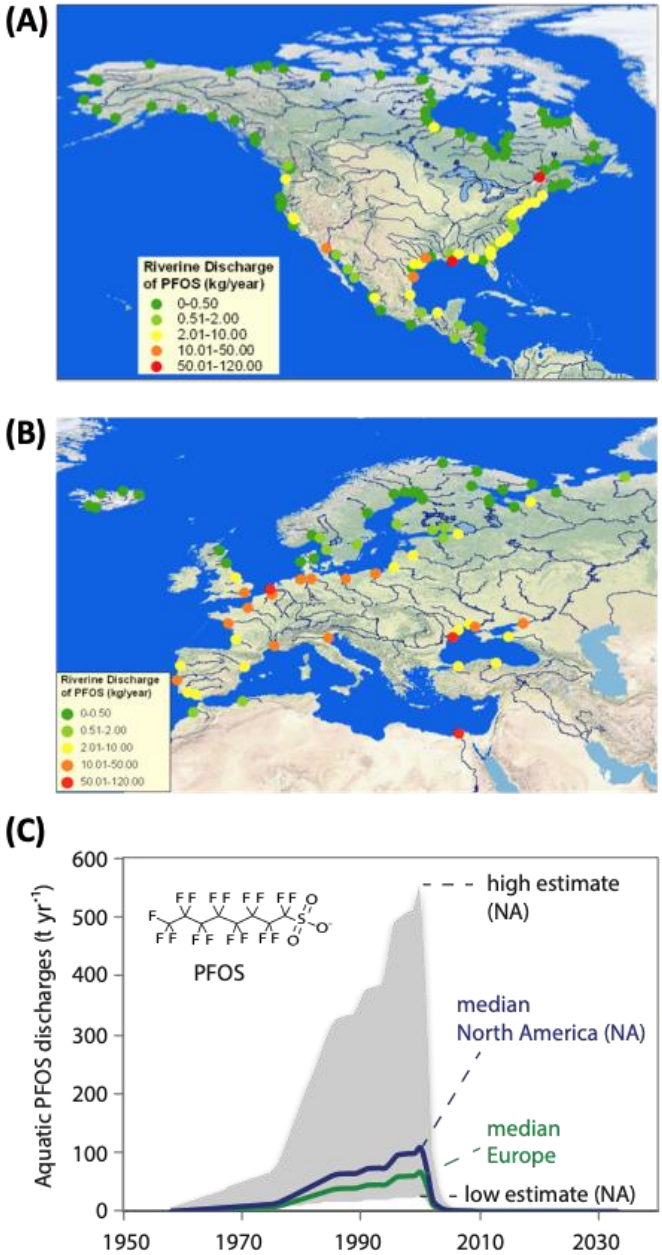


Figure 63. PFOS discharges (kg/y) in 2010 from rivers in North America to the ocean (panel A) and from major rivers in Europe for 2006-2007 (panel B); and continental discharges of PFOS (t/y) to the North Atlantic Ocean (20°N-60°N) from European and North American (i.e., U.S. and Canada) wastewater and rivers from 1958 to 2010 (panel C).
(North American discharges in panel A are based on the approach developed by Zhang et al. (2017), and the European discharges in panel B are based on the catchment population regression developed by Pistocchi and Loos (2009). Solid lines in panel C indicate median discharge estimates while the shaded grey region indicates the 95% confidence interval for North American discharges. Panel C is Figure 1 of Zhang et al. 2017.)

The major surface currents (modeled at 10 m depth) in the Atlantic Ocean result in predominantly eastward and northward transport of coastal PFOS pollution toward the Subarctic (see **Figure 64**). PFOS enriched seawater plumes from the St. Lawrence River, Florida Current, and North Sea are clear features of the modeled concentrations in 1980 and 2000, with concentrations more than an order of magnitude higher than the open North Atlantic. By 2020 these plumes have largely dissipated due to reductions in emissions (see **Figure 64**).

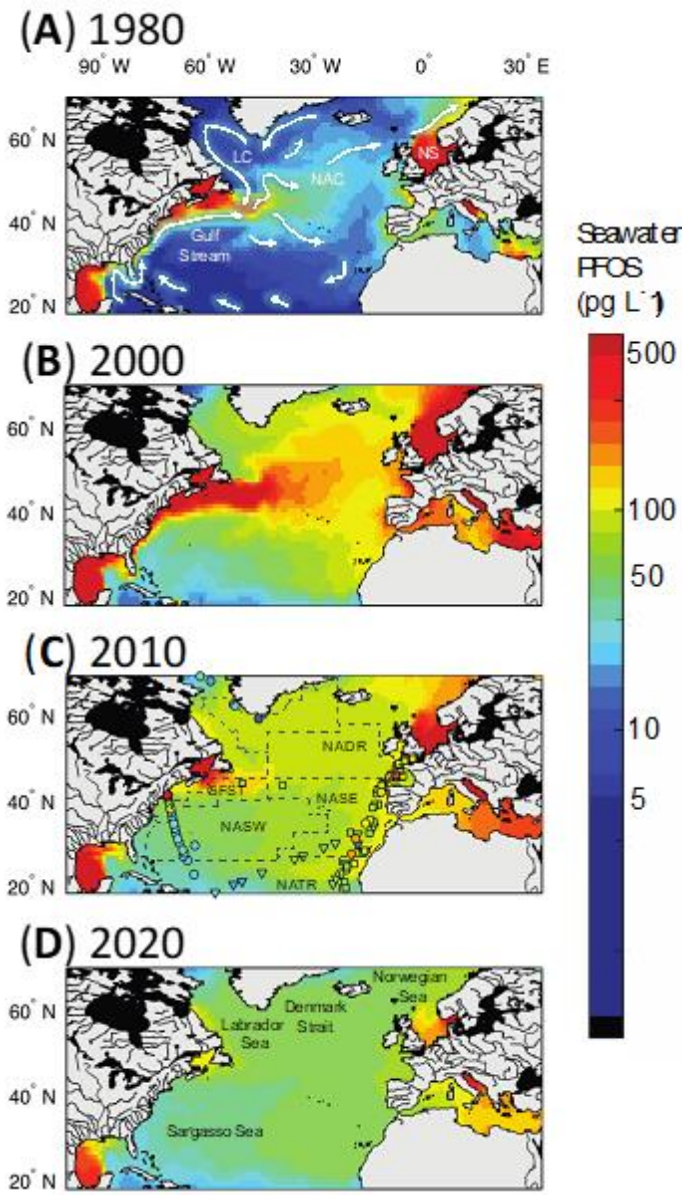


Figure 64. Modelled temporal evolution of surface water (10 m) PFOS concentrations (pg/L) in the North Atlantic Ocean from 1980 to 2020, as described in Zhang et al. 2017.
(Major surface currents are indicated by white arrows in Panel (A). Panel (C) shows modelled surface concentrations for 2010 compared to observations from 2009–2011 obtained from: Ahrens et al. (2009a; 2009b; 2010b); Benskin et al. (2012); Gonzalez-Gaya et al. (2014); Zhao et al. (2012). Current labels: NAC=North Atlantic Current, LC=Labrador Current, NS=North Sea. Longhurst Biogeographical Provinces (Longhurst, 2007). Abbreviations: NADR=North Atlantic Drift Province, GFST=Gulf Stream Province, NASW=North Atlantic Subtropical Province-West, NASE=North Atlantic Subtropical Province-East, NATR=North Atlantic Tropical Gyral Province. From Figures 2 and 4 of Zhang et al. 2017.)

The mass distribution of PFOS shifts from the surface ocean to the deeper ocean over time (see **Figure 65**). Variability in the 95th percentile confidence interval of surface water PFOS concentrations (panel A) is quite large for the first two-thirds of the simulation, indicating large spatial variability across the modelled domain, though this decreases over time. PFOS concentrations peaked in 2001 in the surface layer (shortly after peak emissions around 2000), while the peak in subsurface concentrations lags by 2–3 years (roughly 2005, panel B). Peak PFOS concentrations lag even longer after peak emissions for seawater near the permanent thermocline (panel C), with concentrations not expected to plateau until approximately 2040.

Temporal trends in PFOS in the surface mixed layer (0–10 m) are highly location specific, which is evident in three 5°×5° latitude/longitude regions at different locations in the North Atlantic Ocean (**Figure 65**, panels D, E and F). For the region closest to sources (panel D), large spatial variability exists before PFOS source control in the early 2000s. After source controls are implemented, median seawater concentrations and spatial variability decrease rapidly in this

5°×5° region. For the open ocean (panel E), PFOS concentrations only decrease by one third over five years following source control. In the subarctic region (panel F), PFOS concentrations reach their maximum 8–9 years after source control due to the time lag for transport to this region. After the peak, and after dilution into the whole ocean occurs, concentrations decrease at a slow rate with a half time of over 20 years.

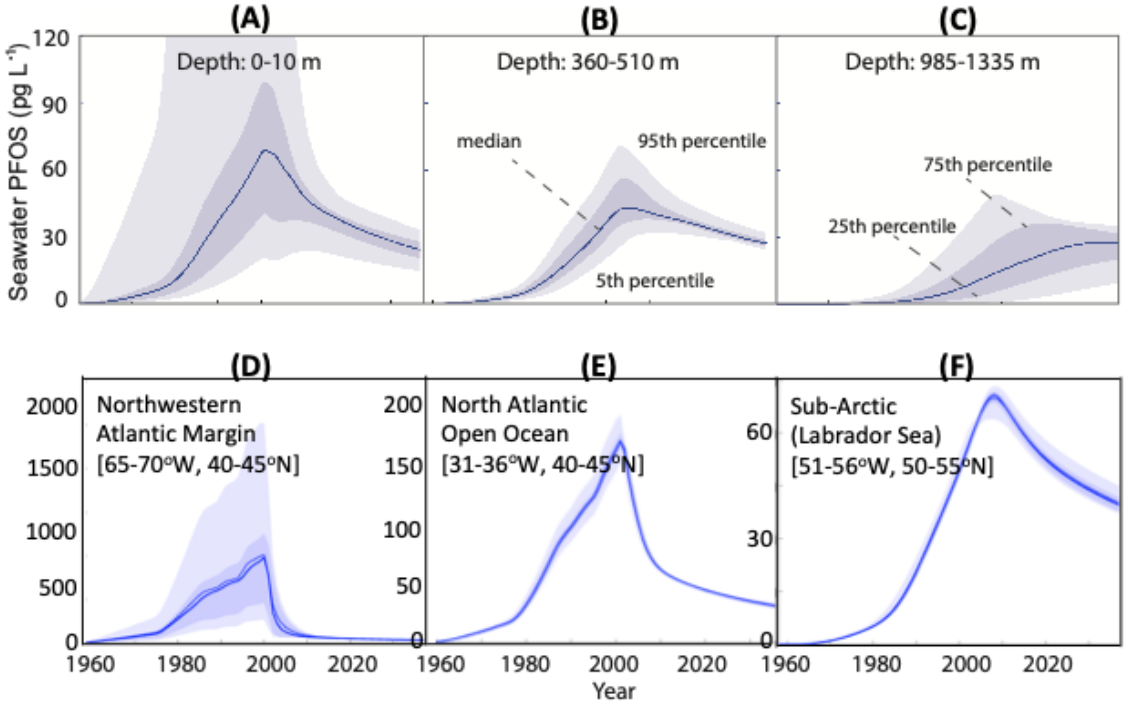


Figure 65. Modelled PFOS concentrations in North Atlantic seawater (20°N–60°N; pg/L) at the surface mixed layer (A), the subsurface (B), near the permanent thermocline (C), and for the surface mixed layer within different 5°×5° latitude/longitude geospatial regions (D–F) based on the updated PFOS release scenario shown in Figure 63.
(Solid lines indicate the basin- or region-wide median concentration, darker shading indicates the 25th and 75th percentile concentrations, and lighter shading indicates the 5th and 95th percentile concentrations. Panels (A–C) are Figure 5 of Zhang et al. 2017.)

Figure 66 shows gross depth specific PFOS flows into and out of the Arctic from the North Atlantic from 1958 to 2038. Most of the flux of PFOS into the Arctic occurred from mid-depth inflow (20–1000 m; 1.1×10^3 mg) relative to that from surface inflow (0–20 m; 60 mg). Entrainment of PFOS into the Atlantic meridional overturning circulation (AMOC) is estimated to have prevented 5.3×10^2 mg PFOS from entering the Arctic (see Zhang et al. 2017 for details). A weakening of the AMOC due to climate change (Fisher et al. 2010; Rahmstorf et al. 2015; Rhein et al. 2015; Yashayaev, 2007) could thus result in an increase in PFOS entering this region.

The modelling conducted by Zhang et al. (2017) illustrates high spatial variability in PFOS ocean concentrations and lag times between elimination of emissions and declining trends in environmental concentrations that vary strongly as a function of geographic location and ocean depth. Long-term seawater monitoring sites for PFAAs have not been established so far, but if they are they should be located within a region where spatial variability is relatively small. Such monitoring sites could be at the ocean margin where PFAA concentrations respond quickly to changes in continental source strength and impact on the marine ecosystems occurs. Monitoring sites located where ocean currents deliver PFAAs to remote regions such as the Arctic would provide valuable information in integrated assessment of LRET. In addition to changes in source strength, the observed temporal trends from long-term monitoring can be influenced by other factors such as climate change. The modeling indicates that the AMOC has prevented substantial amounts (~5.3×10^2 mg) of PFOS from entering the Arctic, and that the flux of other persistent chemicals similar to PFOS into the Arctic may increase with climate change-driven weakening of the AMOC.

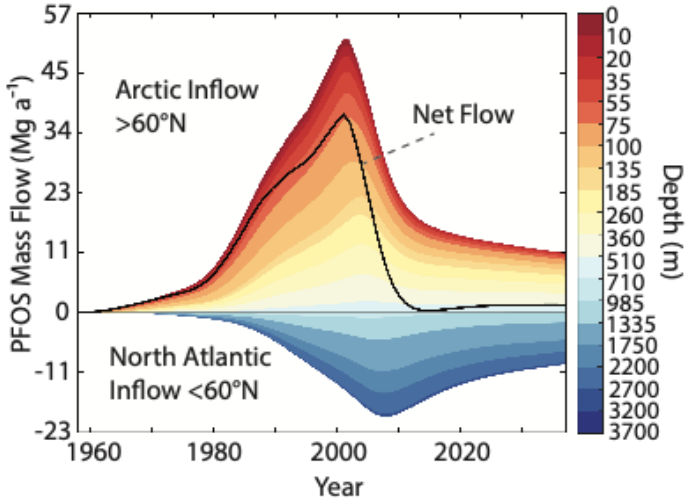


Figure 66. Modelled PFOS circulation above and below 60°N at various seawater depths from the years 1958 to 2038.
(Blue shading indicates deeper waters while red, orange, and yellow shading indicates surface or subsurface waters. Nef flow is indicated by the solid black line, with positive numbers representing flow into the Arctic region (i.e., above 60°N) and negative numbers indicating flow into the North Atlantic (i.e., below 60°N).)

5.3 Main findings

Africa

Back trajectory analysis conducted for MONET monitoring sites in Africa with over 10 years of measurements revealed that POP concentrations observed at urban, suburban, rural, and agricultural sites in coastal countries are largely affected by local emissions, while in the continental areas by a mixture of local sources and transboundary transport from other countries in the region. Additional meteorological data, information on climatological conditions and application of modelling tools are required to establish the contribution of LRET to distribution of POPs in the region. There is a need to build regional capacity for application and interpretation of LRET modelling to predict regional transport of POPs.

Asia-Pacific

Only some countries in the Asia-Pacific region are currently developing their programmes on monitoring and inventories, while others lack capacity for POP monitoring. Back trajectory results of air monitoring data in East Asian Monitoring Programme provided some interesting trends and LRET related information based on measured POP concentrations and back trajectory analysis. In particular, decreasing trends of DDT and c-pentaBDE as well as increasing trends of HCBD were observed at monitoring sites which supported the view that these changes were affected by LRET, rather than the local emission effects (though national monitoring may also be affected by local source such as small-scale industries, traffic and agricultural activities).

Eastern Europe

LRET of POP pollution in the EE region was assessed by application of multi-compartment modelling for HCB, PCB and PCDD/PCDF. Predicted levels of pollution and emissions of all studied POPs have decreased significantly between 1990 and 2018 (i.e., HCB by 90%, PCB by up to 80%, PCDD/PCDF by 40–75%). Model simulations indicated changes of spatial distributions in the region and of significance of imports from lower latitudes. A more significant contribution of secondary emission sources (re-volatilization from soils, vegetation and surface waters) to the pollution was noted.

Latin America and the Caribbean

Potential sources and LRET pathways of POP pollution in the GRULAC region were analyzed applying the HYSPLIT-NOAA model for the three sampling sites in Barbados, Jamaica and Uruguay, revealing influences from nearby sources as well as LRET. More systematic studies should be designed and implemented to assess LRET of POP pollution in the GRULAC region.

Western Europe and Others

The LRET of PFOS presents a new set of challenges relative to other POPs because of its distinct properties and potential for formation in the environment from precursor substances. Clear evidence for LRET in the atmosphere and

deposition of PFOS and/or its precursors to remote waters (and ice cores) can be seen from detectable levels in remote, uninhabited lakes in northern Canada and in Antarctica. LRET in the oceans is also evident from detectable levels of PFOS thousands of kilometers from emission sources in surface and deep ocean waters that can be explained by ocean circulation modeling.

The presence of POPs in regions that are remote from sources, such as the Arctic, is compelling evidence of their LRET. People living in the Arctic and consuming a diet composed of local foods can even have higher exposure to certain POPs than people living in temperate regions.

Long-range environmental transport modelling

Integrated assessment of POPs involves using models as a platform to quantitatively link emissions of POPs to the levels and trends observed in the environment. It is the most effective way to quantify the extent of LRET of POPs and forecast the effectiveness of emission reductions. A variety of modeling tools are available to support integrated assessment of emissions, transport in the environment, and levels and trends of POPs observed at monitoring stations.

Case studies that integrate emission inventories, chemical fate modelling, and monitoring data at the global scale have been carried out for some POPs, including PCB, which have been modelled from source to presence in human milk, HCHs, DDT, dicofol and PFOS. Uncertainties in emission inventories and in the rates of degradation of POPs in air, water, soil and sediments often dominate uncertainties in the description of the global fate and LRET of POPs.

Experience with modeling existing POPs has beneficial synergies with identification and risk profiling of candidate POPs. Priorities for improving POP modeling capabilities include better descriptions of air/condensed phase partitioning and reducing uncertainties in emissions and degradation rates of POPs in air, water and soil with targeted laboratory and field studies.

Climate change and variability could have a direct impact on the semi volatile compounds such as POPs and affect both primary and secondary releases into the atmosphere. Climate change could affect the rate of mobilization of POPs from materials and stockpiles, as well as the use patterns of the primary sources, while for secondary sources the higher temperatures could increase POPs emissions by shifting the partitioning between soil-air and water-air (Lamol et al. 2009). In addition, it is anticipated that climate change may increase incidences of vector borne diseases such as malaria which may influence the use of POPs such as DDT for control of malaria epidemics.

Levels of HCB and PCB at certain monitoring stations in the Arctic have shown increasing temporal trends in recent years, which may be related to local re-volatilization due to a warming environment. Global and regional-scale model scenarios that forecast the impact of climate change on levels of POPs generally find that changes of up to a factor of 2 in air and a factor of 4 in water are possible relative to base-case climate scenarios. However, reductions in emission rates of POPs that are expected to occur simultaneously with climate change can reduce levels by orders of magnitude. Therefore, in the long-term (i.e., decadal time scales) climate change is not expected to obscure or counteract reductions in levels of POPs that are possible due to phase-out of production, use and emissions.

The levels and trends of POPs at remote locations (e.g., in the Arctic) can also be affected by sources from materials used at the monitoring stations and emissions from local communities. Local emissions are expected to increase under climate change due to increased human activities in the North (resource development, shipping, mining, urbanization) and relatively poor waste management systems compared to the South. However, model scenarios that include enhanced emissions of chemicals in the Arctic in response to climate change demonstrate that when considering the Arctic as a whole, local emissions are a minor contributor to Arctic pollution by POPs compared to LRET in all scenarios.

Some integrated assessment studies have used models to isolate the impacts of climate change on concentrations of POPs in the environment from other factors. The direct influence of climate change on levels and trends of POPs in the global environment on the timescale of decades is likely to be much smaller than the influence of reductions in primary emissions that can be achieved through policy action. However, indirect effects of climate change on chemical cycling, including changes in food web structure, are not yet fully understood and are not described in these model scenarios.

Cooperative work to integrate GMP data and other data with numerical models to estimate spatial and temporal trends in POP emissions, and link to human and environmental burdens, would greatly enhance understanding of the effectiveness of actions to protect human health and the environment.

5.4 Conclusions and recommendations

Conclusions	Recommendations
In Africa, monitoring data have revealed POPs contamination of ambient air from remote sites, suggesting potential contribution of LRET. However, additional meteorological data, information on	There is a need for building regional capacity for application and interpretation of LRET modelling results to support policy makers to incorporate the

Conclusions	Recommendations
climatological conditions and modelling tools are required to establish the contribution of LRET to distribution of POPs in the region. The existing data for several sites have been collected over a short period of time.	modelling predictions in national and regional POPs management interventions. Additional monitoring data are required to verify the modelling predictions with the monitoring results.
In the Asia-Pacific region, currently, the monitoring data are available only for East Asia and the Pacific Islands. Monitoring data to enable the assessment of LRET of POPs in the region are lacking in most countries in the region.	There is a need to establish environmental monitoring in the South, West and Central Asia to expand the monitoring network to cover all of the Asia-Pacific region. More detailed assessment of LRET in the Asia-Pacific region, including back trajectory analysis, modelling studies and compilation of the emission source information, is needed to analyze POP trend data and to clarify their LRET and possible source regions.
HCBD is among the POPs with the highest characteristic travel distances in the air. The simultaneous increase of HCBD observed at several sites suggested the occurrence of large-scale emissions and LRET, rather than local emissions. However, measurements of HCBD in air are limited to a narrow area in East Asia.	Additional monitoring data on long-term variations of HCBD concentrations in other locations will be needed to reveal the source and the scale of the increase.
The first analysis of back trajectories in the GRULAC region showed that to understand the transport processes to the monitoring site, it is necessary to have temporally disaggregated data to establish seasonality in order to be able to relate and understand the values of the observed concentrations with possible sources that could contribute to those values. This information will allow evaluating these sources in a second stage and defining local or regional reduction or mitigation actions.	More systematic studies should be designed and implemented to address LRET of pollution in the GRULAC region. Passive air monitoring and active sampling along with modelling could be used to analyze the transport of POPs between source and receptor areas. It is recommended that POPs modeling capabilities and training should be stimulated within the region.
Satellite images of the fires in the GRULAC region reported during 2018, indicated that there was an important contribution from this activity that may have generated and/or mobilized some POPs.	It is recommended to review the contributions of the fires in the GRULAC region in 2018 in detail to identify the type of burning (agricultural, waste, vegetation) that took place in the region.
Uncertainties in emission inventories for POPs can be reduced in a targeted way within an integrated assessment approach by applying models to estimate ranges of plausible emissions that are necessary to account for observed POPs levels.	More effective methods to identify and characterize emissions of POPs are needed to assess the impact of transport of goods and waste, in particular e-waste, all over the world.
Climate-related effects can impact the emissions and cycling of POPs in the environment and have the potential to obscure or modulate trends of POPs that are observed in air and other media. The research project ArcRisk concluded that the influence of climate change on levels and trends of POPs in the global environment on the timescale of decades is likely much smaller than the influence of policies that would reduce emissions.	Shorter-term effects of climate change and climate variability that vary by region and subregion and by chemical should be taken into consideration when interpreting measurements of POPs in environmental media.
Climate change influences food web structure and POP trends in biota, which will subsequently affect exposure to wildlife and humans. Climate variability and climate change affects the environment and ecosystem's structure and function more likely affect POP food web accumulation and toxicity to a larger degree than how climate change affects LRET of POPs.	It is necessary to understand how climate change induced changes in the ecosystems affect the temporal trends of POPs in other media including biota, e.g., through changes in diet, in order to separate ecosystem changes effects of POP temporal trends from changes in POP temporal trends due to global regulation and bans of the POPs through the Stockholm Convention.
Existing models are often not adequate for assessing new compounds (e.g., polar/ionizable POPs) that behave differently in the environment.	Research studies such as studies of partitioning to particles and particle-associated transport and fate are needed for high molecular weight POPs and

Conclusions	Recommendations
	polar/ionizable chemicals that exist in air primarily on the particle-phase.
Emissions of POPs have shifted from mainly industrial, combustion and agricultural sources to a wide range of indoor sources associated with commercial products, where human exposure can be a significant concern. Emissions from the waste sector to water, air, and soil are also relevant for the newly listed POPs, as a result of their commercial uses and waste disposal fate pathways. Monitoring strategies include assessment of these sources and attempts to link emissions of these chemicals to human and environmental burdens.	Monitoring programmes need to be flexible and adaptable to deal with the challenges presented by new POPs.
Improved modeling capabilities within the integrated assessment approach will enable the vast corpus of environmental monitoring data that has been established over the past decades to be leveraged to achieve a more quantitative and predictive understanding of the levels and trends of POPs and POP candidates in the environment. Improved integration between monitoring programmes and modelers may help to identify gaps in information and optimize future study designs and ongoing monitoring efforts.	Enhance modelling capabilities, especially by improving emission inventories and estimates of POP degradability, and by improving understanding of air-surface exchange. This will help to reduce uncertainties about the extent of LRET of POPs and POP candidates, interpret trends appropriately, ascertain the effectiveness of actions that have been undertaken, and forecast impacts of current action or inaction.
Using models to formalize the link between emissions and concentrations of POPs and POP candidates in air, water, soil, wildlife and humans has a wide range of benefits for supporting the development of the GMP and for the effectiveness evaluation of the Stockholm Convention. These benefits include: (i) spurring the development and refinement of emission inventories for POPs and POP candidates; (ii) aiding in the design of monitoring programmes and quality assurance of monitoring data, and (iii) understanding trends in POPs levels in a changing climate.	In order to fully realize the benefits, the following research and monitoring priorities are recommended: • Support the development of global scale modeled ‘integrated assessments’ of emissions, fate and transport processes and environmental levels and trends for all POPs and POP candidates. In order to realize the benefits of these assessments it is recommended to compose a complete case study for each POP and POP candidate that can be updated regularly and refined as new information is produced relevant to emissions, fate and transport properties and environmental levels and trends; • Apply the principles of integrated assessment at local, regional and global levels to improve emission estimates. High uncertainties and missing information in emission inventories is often the dominant source of uncertainty in integrated assessments of POPs. The integrated approach can be applied at local and regional scales and near suspected source areas to infer emission rates of POPs that can then be scaled using emission factors to compare with national estimates and to drive global scale models; • Support the development and improvement of POP modeling capabilities as well as laboratory and field research to understand POP properties. Important research needs to further develop POPs models include improving modeling of gas/particle partitioning in the atmosphere and of air/surface exchange in general. Uncertainties in assessment of individual POPs are often driven by uncertainties in physico-chemical properties and degradation rates in air, water and soil which could be reduced using targeted laboratory and field studies.

III. Evaluation of the global monitoring plan and conclusions and recommendations for the next phase

1. Arrangements

1.1 Media

Ambient air and human milk and blood have been established as suitable core media for evaluating changes in POP concentrations over time on a global scale. Water is a suitable core environmental medium for monitoring of hydrophilic substances such as PFOS and PFOA. For future evaluations, all the regions should continue monitoring and reporting POPs levels in those core media, and at the same sampling sites to the extent possible, as the most appropriate and cost-effective option.

Additional data on POP concentrations in other media are available from existing programmes in various regions. Those data could be used to supplement the assessment of POP concentrations in core media and changes over time, provided that these data have been reviewed by the ROGs.

1.2 Need for updating of the framework for the global monitoring plan for POPs as the Convention evolves

The third phase of the GMP was conducted pursuant to the amended GMP for POPs,[54] the amended implementation plan for the GMP,[55] and the updated guidance on the GMP.[56] Those documents provided an appropriate framework and guidance to perform the required activities. Future phases of the GMP should continue to use those documents as their foundation, taking into consideration the outcomes of the second effectiveness evaluation report.

The GMP guidance provides a useful basis for the POPs monitoring and for harmonized data collection, storage and handling. The GCG encourages the regions to use the guidance and communicate any feedback on the guidance through the ROGs.

The guidance should be continuously updated to cover newly listed POPs and other relevant issues, including further streamlining of its content and maintaining updated information on existing and well-established sampling procedures to further support data harmonization and use.

1.3 Other issues relevant to the implementation of further evaluation

1.3.1 Implementation

The involvement of Parties in the activities of the GMP is important to ensure its successful implementation. Parties should be encouraged to engage actively in the implementation of the GMP and in the effectiveness evaluation, in particular by continuing to monitor the core media and supporting the further development and long-term implementation of the GMP. In order to facilitate communication with the ROGs, Parties should ensure that information and contact details of the Stockholm Convention official contact points and national focal points are updated in a timely manner.

1.3.2 Sustainability of monitoring activities

A rigorous and continuous long-term monitoring programme for POPs in core media (air, human tissues, and water for PFAS) is an absolute necessity to fulfil the scientific basis and requirements of Article 16 of the Convention. With three phases of implementation of the GMP since the entry into force of the Convention, several long-term programmes have reported consistently on the temporal trends for POPs and in some cases have extended their scope to address regional data gaps that have been identified. New programmes have also been implemented to address data gaps and are establishing new baselines for future trends assessment. Monitoring activities that had been initiated and contributed data to the first monitoring reports should continue to be supported, and their sustainability ensured, in particular through partnerships, capacity strengthening and gradual increase of national commitments.

1.3.3 Chemical mixtures

Human health and the environment are impacted by exposure to chemical mixtures, which include a multitude of known and unknown POP-like chemicals, including their transformation products. Future reporting under the GMP would benefit from considering information, where available, regarding levels of all listed POPs and candidate POPs

[54] UNEP/POPS/COP.6/INF/31/Add.1.

[55] UNEP/POPS/COP.6/INF/31/Add.2.

[56] UNEP/POPS/COP.10/INF/42.

in the same samples, as this can enhance understanding of co-occurrences, co-exposure and environmental loads. Similarly, reporting of the concentrations of precursors of the listed PFAS, such as through total methods, could enhance understanding of environmental loads.

1.3.4 Data comparability and QA/QC

Comparability within and across monitoring programmes to evaluate changes in levels over time and the regional and global transport of POPs has been improved. Data from passive air samplers are uniformly expressed on an air concentration basis, allowing for general comparisons across the various monitoring programmes at the global level. While comparability across monitoring programmes is important for comparing concentrations in air spatially and for modelling purposes, intraprogramme comparability is essential for the purpose of comparing air concentrations in time, i.e., deriving temporal trends.

As noted in **2.1 Main findings**, QA/QC practices, along with inter-laboratory exercises and intercalibration studies, are essential for ensuring data comparability. Efforts should continue to be directed at improving comparability within and across programmes, providing for evaluation of changes in levels of POPs over time, enabling regional comparisons and modelling. See also the conclusions and recommendations in **2.2 Conclusions and** recommendations.

1.3.5 Data handling

There is an urgent need to facilitate access and interoperability of existing monitoring databases.

The GMP Data Warehouse was further enhanced to better assist the ROGs and the GCG in preparing the regional and global monitoring reports. The GMP Data Warehouse should continue to be used and enhanced for harmonized data handling in future evaluations, and further explore efficiencies, such as by coordinating and/or linking with existing databases.

See also the conclusions and recommendations in **3.2 Conclusions and** recommendations.

1.3.6 Data analysis and interpretation

As long time-series data are generated over time and become increasingly available, it will be important to start analyzing and describing how these were produced. This type of analysis is important to identify means towards the sustainability of data production and could inform priority setting in the future, as well as future funding mechanisms.

Regarding data interpretation and attribution of observed changes, a number of factors are important to consider, including ecosystem and climate changes. Partnering with modelers to improve interpretation and understanding is important for the following:

(a) Factors influencing temporal trend data (e.g., climate change) and the required frequency of data and reporting for different POPs in the future;

(b) The role of primary versus secondary emissions and how these relate to observed temporal trends in core media, and exposure reduction success in the context of the effectiveness evaluation;

(c) Linking with other available sources of data such as satellites to improve interpretation.

1.3.7 Data flow and use

The compilatory effort by the ROGs provides the basis for improving global understanding of POPs. The GMP and the GMP Data Warehouse offer opportunities for increased use of data by different users, including in training, LRET and ecosystem models, and for emission estimates. The GMP report, which provides a large and careful compilation, is important for understanding global trends over time as it provides a one-stop shop for setting out comparable data collection protocols and a coherent, careful and transparent reporting process that makes data accessible and useable.

1.3.8 Enhanced work to contribute to the effectiveness evaluation

Cooperative work to integrate through the GMP process, the best available data with numerical models to estimate spatial and temporal trends in POP emission rates and link to human and environmental burdens has been shown to enhance understanding of the effectiveness of actions to protect human health and the environment. Future evaluations could consider how best to enhance, consolidate and report on such cooperative work.

2. Challenges to implementation

2.1 Need for further capacity enhancement

2.1.1 Capacity enhancement on a regional basis

For most regions, monitoring activities have been put in place and have produced data for the development of the third monitoring reports. Nevertheless, some regions entirely lack monitoring capacity for some of the newly listed POPs and still face serious challenges in obtaining time-series data, including for the initial 12 POPs. These regions will require further support and assistance in the development of monitoring programmes, keeping in mind sustainability considerations for the GMP, and in continued collaboration with strategic partners.

Laboratory capacity is limited in some regions, in particular to analyze trace levels of POPs in core media and the more analytically complex POPs. Further capacity strengthening is needed to ensure that laboratories in developing regions have the necessary equipment, essential spare parts and consumables, training of laboratory personnel and participation in future interlaboratory assessments, taking into consideration potential synergies with other monitoring efforts under the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal, the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade and the Stockholm Convention, the Minamata Convention on Mercury, the United Nations Framework Convention on Climate Change and the Convention on Biological Diversity. Stockholm Convention regional centres for capacity-building and the transfer of technology are encouraged to help in developing such capacity.

Regional monitoring activities have been put in place during the third phase, in collaboration with strategic partners, with a view to further developing the network of regional laboratories using harmonized protocols for the monitoring of POPs. Strategic partnership arrangements should be continued in future monitoring phases. Furthermore, enhanced cross-regional coordination is needed with respect to analyzing and assessing data on regional and global environmental transport and related climate effects, and considering current international efforts, such as the United Nations Economic Commission for Europe (UNECE) Task Force on Hemispheric Transport of Air Pollution under the Convention on Long-range Transboundary Air Pollution (LRTAP), the AMAP or other appropriate bodies studying global environmental transport of POPs. The GCG recognized the value of developing workplans and engaging with the Task Force on Hemispheric Transport of Air Pollution under the UNECE Convention on LRTAP and other groups to develop global multimedia modelling strategies and tools to complement and inform long-term monitoring strategies and trends interpretation under the GMP.

The UNEP/GEF GMP projects conducted to date have been extremely useful in enabling developing regions to participate in the GMP and the effectiveness evaluation under the Convention. It is important that the capacity that has been built to date remains sustainable. There is a need for further support to continue the work. Other regions that include countries that are eligible for GEF funding should be provided with equal opportunities to participate in such projects. Future UNEP/GEF GMP projects should be informed by the work of the ROGs for the GMP.

Parties should actively seek financial assistance from international funding entities such as GEF and other donors for continued implementation of monitoring activities on POPs, the effectiveness evaluation and related activities.

2.1.2 Capacity enhancement for modelling resources

Modelling is required for the best possible interpretation and full exploitation of environmental monitoring data. The GMP has been relying on external modelling resources under regional conventions such as the Convention on LRTAP and other regional research projects. Some regions (e.g., Africa, Asia-Pacific, GRULAC) have not or only been covered sporadically. In research, large-scale atmospheric and/or multicompartmental chemical fate modelling has been a rare activity which in recent years has not been much supported by funding programmes. Own large-scale modelling capacities would strengthen the effectiveness evaluation under the Stockholm Convention.

2.2 Information from the regional organization groups

2.2.1 Africa

The third regional monitoring report for Africa described in detail the limited availability of comparable data and the dispersion of efforts in academic and governmental efforts that hinder comparability. The report outlined the requirements in technical competence and laboratory infrastructures to address the challenges at hand.

The UNEP/GEF GMP I and II projects were implemented in the region to support capacity enhancement to analyze POPs. The project covered the Democratic Republic of Congo, Ghana, Mali, Nigeria, Senegal, Togo, Egypt, Ethiopia, Kenya, Mauritius, Morocco, Uganda, Tanzania, Tunisia and Zambia. The project focused on gap analysis of the 9 new POPs listed in 2009 and development of detailed guidelines, protocols and manuals, training of participating national and regional laboratories and provision of technical, backstopping by established international laboratories, as well as

strengthening analytical performance in participating countries by provision of consumables and spare parts for sampling and analysis of POPs in key matrices and participation in international inter-laboratory calibration exercise and information dissemination through national, regional workshops and global workshops.

Most countries in the region have elaborated their national implementation plans under the Stockholm Convention and outlined the need to build capacities for POPs analysis to contribute to reporting of environmental levels. It is vital to ensure continuity of established monitoring sites and QA/QC protocols and standards for POPs monitoring to provide comparable data to assess temporal trends and LRET.

The Africa ROG identified the following challenges affecting POPs monitoring in the region that need to be considered in future activities:

(a) Increasing number of new POPs chemicals:

The number of listed POPs has increased from the initial 12 POPs to 30 in the third GMP. As more chemicals are added, new sampling and analytical methodologies as well additional suitable matrices for their monitoring may be required. There is increasing pressure on monitoring activities;

(b) Need for capacity building:

There is a need for capacity building of the regional personnel to participate in the sample collection and analysis of POPs as well as interpretation of the POPs monitoring data and LRET of POPs. POPs monitoring and production of comparable data require continuous training and capacity building for the personnel involved. Addition of the new matrices and new POPs need to be included in the training;

(c) Analytical capacities to analyze POPs at the regional level:

Most of the regional laboratories are in possession of gas chromatography/electron capture detector (GC/ECD) or low-resolution gas chromatography/mass spectrometry (GC/MS) which cannot analyze some of the POPs such as PCDD/PCDF, PBDEs and PFOS. At the moment the region depends on strategic partners to analyze all POPs in the monitoring samples. However, for long-term sustainability, there is a need to build regional capacity for analysis of POPs in core media and other media;

(d) Lack of long-term monitoring programme for POPs in water and other media:

The listing of PFOS, a hydrophilic substance, has seen the addition of water as a core-media. This requires establishment of a harmonized water monitoring programme and protocol to ensure production of comparable data for analysis of temporal trends. Some new POPs have significant influence from emissions from wastes, such as wastewater treatment plants and landfills, to water, air, and contaminated soil that need to be clearly delineated through targeted research to help in the interpretation of the monitoring data;

(e) Communication and information exchange:

The region experienced impediments due to weak internet connection. The online participation in teleconferences and webinars could not be exploited to the maximum due to weak signal encountered;

(f) Comparability of data:

The region faces challenges with comparability of POPs levels in other media such as soil, sediments, fish and biota due to lack of uniform protocol for sampling, analysis and data presentation. The ROG mainly relied on the data for other media from the UNEP/GEF GMP project implemented between 2010–2012 and 2017–2019 since the samples were collected within the same timeframe and analyzed centrally;

(g) Data gaps in some sub-regions:

Whereas major data gaps have been filled in the third phase of GMP, only one country participated in the mothers' milk survey from the southern Africa sub-region. This creates challenges regarding representativeness of the POPs levels in the sub-region that needs to be improved. More countries in the sub-region are encouraged to participate in the future mothers' milk survey to build more representative dataset;

(h) Sample specimen banking and storage of the POPs data:

While huge amount of POPs data have been produced, the addition of new POPs or the need for data verification may require retrospective analysis of the samples to determine the temporal trends. Although WHO provides specimen banking for mothers' milk samples, there is no capacity for centralized specimen banking for air, water and other media. In addition, data storage for other media is required in order to establish temporal trends;

(i) Sustainability of existing programmes:

The goal of the GMP is to provide sufficient data to determine trends in POPs levels in the core media. Long-term sustainability of the initiated monitoring activities remains a priority to the region to allow effectiveness

evaluation. Whereas initial trends have begun to emerge for some of the initial POPs, the existing comparable data for air, mothers' milk and water are not adequate to allow analysis of temporal trends and LRET of POPs. Therefore, resources are required to ensure continuity of the monitoring activities including sampling, analysis and data storage in order to establish trends in POPs levels;

(j) Security and safety:

Political and security challenges at some sites inhibited continuous sampling of air. In some instances, sites experienced temporal discontinuation from data collections which created data gaps.

2.2.2 Asia-Pacific

Most countries in Asia-Pacific have limited facilities for POPs monitoring and inventory. While the POPsEA project, UNEP/GEF GMP II project and UNEP/WHO Human Milk Survey have successfully covered more countries and regions, number of POPs studies were still limited. In addition, specialists meeting the requirements of the knowledge and techniques for POPs analysis are limited in the region. Insufficient quality control and data validation were observed. In order to fill data gaps and cover needs in Asia-Pacific, further financial and technical supports on POPs monitoring should be provided according to Articles 12 and 13 of the Convention, in addition to the continuation and further expansion of existing programmes.

The lack of capacity is identified in most of the countries in the Asia-Pacific region. For example, Fiji recently started the air monitoring with passive sampling method, but the monitoring highly depended on collaboration and knowledge sharing assistance. In addition, Fiji and other Pacific Islands currently have no facility for POPs inventory programmes. There is still a long way to go to achieve an Asia-Pacific Monitoring System to provide timely and reliable data for the GMP and useful tools to support national and regional decisions on this important matter. The difficulties involved in the lack of POPs monitoring capacity for most countries in the region include lack of funds and advanced technology as well as insufficient knowledge and training of technical groups. In particular, more resources are needed for improving the analytical facilities and methods for the determination of POPs. More trained personnel should be employed for the daily operation of the instruments. Capacity building is not only needed for initial POPs, but also for the analysis of newly listed POPs. Most countries in the Asia-Pacific region currently do not have analytical facilities for PFAS.

In order to have a better evaluation of the POPs level in the future, more regional/sub-regional programmes that are similar to the POPsEA project or the UNEP/GEF GMP project in the Pacific Islands should be established. The following areas are the key elements for the capacity building for the development of POPs analysis:

(a) Enhanced human capacity;

(b) Inter-calibration or interlaboratory assessment;

(c) Strengthened skills for sampling and analysis infrastructure

(d) Strengthened existing laboratories for analyzing the core media

(e) Enhanced QA/QC;

(f) Financial assistance to establish long-term, self-sufficient laboratories.

POPs analysis laboratories in the Asia-Pacific region should implement robust and validated methods according to international scientific standards by adopting the suitable analytical method to their circumstances and proving the capabilities with successful participation in international comparison studies. Capacity building has to be set as the highest priority for establishing emerging POPs laboratories and for improving the capacities of existing laboratories in the region. Countries in the region should be encouraged to participate in ongoing programmes to promote the implementation of the Convention such as in the inventory activities. Analytical capacities for the POPs monitoring may be enhanced through existing collaborations and with seeking funds from national and international organizations.

2.2.3 Eastern Europe

Some parts of the EE region are well monitored through existing air monitoring networks pertaining to international monitoring programmes such as EMEP, GAPS and MONET, in particular the western part of the EE region. The monitoring combines active and passive sampling and up to 30 years-long time-series are available for chlorinated POPs and about 15 years-long series exist from passive sampling.

Over the years, at least some POPs data exist for 21 countries out of 25 described in this report (no information is available for Albania, Azerbaijan, Bosnia and Herzegovina, Georgia and a limited information is available for the Russian Federation). Air monitoring also covers the majority of the listed POPs and data are available until 2019.

On the other hand, Central Asian countries have a limited availability of information that only covers several organochlorine POPs (alpha-, beta-, gamma-HCH, HCB, PCB, and DDT in 2008–2010). Restarting such activities would require both policy and technical support for a sustainable solution of POPs data collection in that sub-region.

Data availability for human tissues is even more limited. Information generated through WHO and UNEP/WHO surveys covers only 13 countries out of 25 in the EE region and 11 countries participated in the surveys more than once. Support in participation of non-EU EE countries in the milk surveys needs to be significantly strengthened in particular for South European countries, and for Central Asia and Caucasus countries. On the other hand, the UNEP WHO surveys are a perfectly adequate source of information on POPs levels and useful for the effectiveness evaluation.

Water data are available for some countries in the western part of the region through European Joint Surveys (i.e., Joint Danube Survey). Data gaps exist in southern and eastern part of the region and support will be needed to fill in these gaps in particular in the non-EU part of the region and in the Russian Federation.

In addition, countries in the region perform national POPs monitoring in non-core media (soil, sediment, food, water) that provides additional information on levels of the initial POPs in particular. Information on POPs levels in the eastern part of the region were also complemented by several research projects of a limited time span.

Information related to POPs levels in human blood is not available neither through regional nor through national programmes.

Monitoring data on occurrence of dioxins and furans and brominated and fluorinated chemicals are scarce, in particular due to the lack of analytical capacities in non-EU part of the region and high costs of analyses. Nevertheless, capacity to analyze these chemicals exists in the region, for example in the RECETOX who has state of the art facility and instrumentation as well as trained personnel; however, this capacity needs to be enhanced in the region. Plans for the future include continuing the strategic partnerships for air monitoring with MONET-Europe, GAPS and EMEP, supporting the operation of the second active sampling station in Leova, Moldova, and further supporting the information collection from southern Europe, Central Asia and promoting greater involvement of the Russian Federation institutions into established networks while catering for the national legal requirements and keeping up with the QA/QC programme.

The questionnaire on POPs monitoring capacities has revealed an increase in overall capacities for POPs analyses in the region, but expertise and infrastructures to analyze dioxins/furans, PFOS and PBDEs are limited in southern and eastern part of the region. Nevertheless, partnerships with advanced infrastructures and strategic partners performing monitoring activities have so far allowed us to compensate for the gaps. National efforts are needed to reestablish POPs monitoring in core media as priority for most countries in the region. Technical assistance is needed to increase expert capacities.

To strengthen the evidence and identification of trends, repeated participation of countries in milk survey should be encouraged and, where appropriate, also supported.

The EE ROG proposes the following list as priority issues for the next GMP phase in the EE region:

(a) Establish closer contacts with relevant institutions in the Russian Federation and involve them in ongoing POPs monitoring programmes;

(b) Increase availability of data in relation to human exposure (POPs levels in breast milk) and provide support to participation of South European countries and Caucasus and Central Asian countries in the next rounds of UNEP/WHO surveys;

(c) Ensure availability of human exposure data from general population in the EE region for reference purposes, as some of undertaken human biomonitoring activities focused only on highly exposed populations and existing information on concentrations of POPs in the region may not be fully accurate;

(d) Secure data from existing national biomonitoring programmes, national cohorts or the European projects (such as alignment studies under HBM4EU, EHEN project cluster on human exposome);

(e) Explore additional/newer harmonized POPs monitoring activities in Europe as they have the potential to contribute data for the next GMP phase. These include, for instance, the ERA-Planet project supporting the GOS4POPs initiative of GEO for air data, passive sampling of surface water through the AQUA-GAPS network organized by RECETOX and many others. The EU will further harmonize its approaches to the risk assessment and management of chemicals under the Horizon Europe Partnership (PARC) in 2022–2028. It is expected that relevant chemicals such as PFAS, flame retardants or some other candidate (potential candidate) POPs will also be studied. This will be an important source of information for the following GMP campaign.

2.2.4 Latin America and the Caribbean

The GRULAC region has been collaborating with strategic partners since 2000, delivering data for the last three phases of the GMP. Monitoring capabilities exist in at least nine countries in the region. However, there are significant data gaps in some areas including Central America to establish spatial and temporal trends of POPs in the core media. The inconsistency of site locations in the countries, lack of regular participation and data variability do not allow the analysis of significant trends. Air monitoring programmes in the region are still supported by external financing.

There has been capacity building through programmes and projects, but the challenges remain for the analysis of newly listed POPs. While many countries have made investments to acquire equipment for the initial POPs, advanced technology is required to measure other new POPs, which implies further investments.

There is a need to sustain and expand the existing monitoring networks, which should begin with national efforts to promote regionally managed monitoring programmes. The region needs to create sound scientific monitoring programmes using local resources, as all the existing programmes are supported mainly by external funding which limits their long-term support and sustainability. The commitment of countries to sustain monitoring programmes should be based on their national interest in having public policy management instruments to reduce the risk of exposure to these substances and on their willingness to establish a regional structure able to support monitoring programmes on a long-term basis.

Building capacities and stimulating synergies in areas such as the design and implementation of monitoring programmes, training of experts in the POPs analysis, especially the newly listed POPs, together with aid for improving laboratory facilities as well as modelling, data management, analysis and interpretation would help establishing sustainable monitoring programmes in the region.

The ROG could play a key role in stimulating synergies for the development of national monitoring programmes that could contribute to a regional network; however, provision of financial support should be envisaged from countries of the region.

According to the main monitoring findings, analysis of 13 newly listed POPs were performed for the first time in air and human milk and constitute the baseline for future evaluations; air concentrations from monitoring sites of the initial POPs depended mainly on the particular characteristics of the site as well as the meteorological influences; human milk monitoring showed decreases in most of the parameters and water delivered baseline concentrations of the three target substances.

Future monitoring of human milk should consider the ethical and technical challenges. These studies should also consider actions to better understand the exposure of vulnerable groups as indicators to protect future generations, as stated in the SDGs and the Stockholm Convention.

To build a successful strategy to face the challenges of POPs monitoring, interaction between governments, academic institutions, industry and non-governmental organizations is required, both at the national and regional levels.

The GRULAC region should formalize a coordinating structure to develop a Regional Action Plan (RAP). This would enable countries to evaluate available options and actions necessary to meet the requirements of the GMP under the Stockholm Convention; develop a regional monitoring program with indication of scope, limitations, costs and benefits; and identify requirements for capacity-building and access to external assistance.

2.2.5 Western Europe and Others

The WEOG ROG identified the following key elements to improve implementation of the GMP:

(a) Challenges with POPs listed after 2009:

Certain high molecular weight POPs including polar/ionizable chemicals (e.g., PFOS) exist in air primarily on the particle-phase. To improve understanding of regional and global transport of particle-associated POPs, improve the performance of fate models and help to interpret temporal trend information from monitoring programmes, better information is needed on gas-particle partitioning properties of POPs, as well as studies of particle-associated transport and fate;

(b) Chemical mixtures:

Human health and the environment are impacted by exposure to chemical mixtures which includes a multitude of known and unknown POP-like chemicals, including their transformation products. Research in this area is advancing rapidly due to increased accessibility of high-resolution analytical equipment (e.g., GC/MS/MS, LC/MS/MS). Future reporting under the GMP would benefit from including information, where available, regarding levels of all listed POPs and potentially candidate POPs in the same samples, as this can enhance understanding about co-occurrences and thus about co-exposure and environmental loads. Similarly,

reporting of the concentrations of precursors for listed PFAS, such as through total methods, also enhances understanding about environmental loads;

(c) Efficiencies for monitoring programmes:

In order to deal with analysis pressures for new POPs, monitoring programmes may need to adjust their protocols and resources to better align with new priorities. Possible strategies include reduced frequency of analysis of the initial POPs (e.g., PCB, OCPs), optimized analytical methods, and partnerships among laboratories to address specialized analytical needs. It is not necessary for every laboratory to be an expert for every class of POP. In addition, many programmes are incorporating the latest advances in the field of science such as high resolution and non-targeted analysis (and associated data archiving for future reference). Future reporting may be able to draw on data generated through these advances;

(d) Sample archiving or sample banks:

Investing resources to ensure the integrity and sustainability of sample banks will provide a highly cost-effective tool for understanding the effectiveness of regulatory and policy intervention, as they enable retrospective analysis on current and future POPs as well as for screening studies on candidate POPs. Environmental specimen banks and natural archives have proven to be to elucidate baselines and changes over time of recently listed POPs and chemicals of emerging concern;

(e) Enhanced coordination:

Enhanced coordination with the POPs Review Committee could be beneficial to advance in the understanding of the nature and intensity of LRET, and timely identification and screening of emerging chemicals of concern. Several global initiatives and multilateral environmental agreements with common objectives (e.g., Basel, Rotterdam and Stockholm conventions, Minamata Convention, Convention on Biodiversity, Framework Convention on Climate Change) could benefit of more active interfaces between their monitoring and modeling efforts that have worked to some extent in parallel in recent decades.

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Chapter II, 1 and 2: Data availability, consistency and comparability

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