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Assessment of Polychlorinated Biphenyls (PCBs) and Dioxins in Seafood: Implications for Aquatic Environment and Management

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Polychlorinated biphenyls (PCBs) are a class of synthetic organic chemicals composed of chlorine, carbon, and hydrogen.Historically used in a wide variety of industrial *Emission of dioxins in the atmosphere* applications, including electrical equipment, insulation materials, and lubricants.. PCBs were banned in many countries starting in the 1970s due to their harmful environmental and health effects. Despite this, their persistent nature means they continue to exist in the environment.Dioxins are persistent organic pollutants (POPs), meaning they do not easily break down in the environment. People are exposed to dioxins primarily by eating contaminated food, but also by breathing polluted air. Dioxins are highly toxic. They can cause reproductive and developmental problems, damage the immune system, disrupt the endocrine system, and cause cancer.Both PCBs and dioxins are considered persistent organic pollutants (POPs), which accumulate in fatty tissues and become more concentrated as they move up the food chain. Their persistence and ability to bioaccumulation make them particularly concerning for seafood consumers, as these chemicals reach higher concentrations in large, fatty fish.

Pathways of Contamination in Seafood:

1. **Industrial Discharges:** Industries that historically used PCBs or produced dioxins release these pollutants into waterways either directly through improper waste disposal or indirectly through contaminated runoff. Even though PCBs are no longer manufactured, historical pollution continues to leach from old equipment and contaminated sites.
2. **Atmospheric Deposition:**Dioxins, in particular, can be carried long distances through the atmosphere before settling in water bodies. Industrial combustion, especially in waste incinerators and factories, releases dioxins into the air, where they can travel globally before entering aquatic ecosystems.
3. **Runoff from Landfills and Agricultural Sites:** As rainwater runs off landfills or polluted agricultural areas, it picks up PCBs and dioxins, washing them into rivers and lakes, which then flow into oceans. Contamination can also stem from the use of certain pesticides, which may contain dioxin byproducts.

Health Risks of Consuming Contaminated Seafood:

Consuming seafood contaminated with PCBs and dioxins can have serious health consequences, especially with prolonged exposure. These pollutants are classified as carcinogens and are known to disrupt multiple biological systems.

Cancer Risks: Long-term exposure to PCBs and dioxins is associated with an increased risk of several types of cancer, particularly liver and lung cancer. These compounds interfere with cellular processes and can cause DNA damage, leading to the development of malignant tumors.

Hormonal and Endocrine Disruption:PCBs and dioxins can mimic or block hormones in the body, interfering with the endocrine system. This can lead to a variety of issues, including thyroid problems, insulin resistance, and disruptions in reproductive health.

Immune System Suppression: Exposure to these pollutants has been linked to a weakened immune system, making the body more susceptible to infections and diseases. Both PCBs and dioxins can alter immune function by interfering with the normal production of immune cells.

Reproductive and Developmental Issues: Pregnant women are particularly vulnerable to the harmful effects of PCBs and dioxins. These chemicals can cross the placenta, affecting fetal development and increasing the risk of birth defects, low birth weight, and developmental delays in children. Infants who are breastfed may also be exposed to these contaminants through breast milk.

Studies show that even low levels of dioxins and PCBs can lead to long-term health issues. Vulnerable populations, such as pregnant women, children, and individuals who consume large amounts of seafood, are at a higher risk of exposure.

Detection of PCBs and dioxins in seafood

Detection of PCBs (polychlorinated biphenyls) and dioxins in seafood involves screening assays for rapid assessment and confirmatory instrumental techniques for precise quantification at trace levels (ppt range). Immunological, chemical/biochemical, and molecular assays serve as cost-effective screening tools, while high-resolution gas chromatography/high-resolution mass spectrometry (HRGC/HRMS), often using GC 6890 systems, provides definitive analysis after sample cleanup.

Immunological Assays: Immunological assays, such as enzyme-linked immunosorbent assay (ELISA), rely on antigen-antibody interactions to detect dioxin-like compounds. They offer high sensitivity (down to 1-10 pg/g), rapid results (hours), and portability for field screening of seafood extracts, but may suffer from cross-reactivity with structurally similar PCBs, requiring confirmation. These assays are ideal for high-throughput monitoring in regulatory programs, with kits targeting AhR-binding congeners.

Chemical and Biochemical Assays: Chemical assays use colorimetric or fluorescent reactions (e.g., CALUX or DR-CALUX cell-based bioassays) to measure aryl hydrocarbon receptor (AhR) activation by dioxins/PCBs, providing toxicity equivalents (TEQ) in 24-48 hours. Biochemical

variants employ luciferase reporter genes in cell lines like DR-EcoScreen for enhanced sensitivity (<0.1 pg BEQ/g), correlating well (r^2>0.9) with HRMS results in fish/seafood. They excel in detecting bioavailable fractions but need matrix-matched standards.

Molecular Assays: Molecular assays, including PCR-based quantification of CYP1A1 gene induction or qPCR for AhR pathway biomarkers, assess dioxin exposure at the genetic level in seafood tissues. These detect transcriptional responses to low ng/kg levels, offering specificity for dioxin-like activity without chemical identification, though they require RNA extraction and are less quantitative for individual congeners. They complement chemical methods for ecological risk assessment.

High-Resolution GC/HRMS (GC 6890): The Agilent GC 6890, paired with high-resolution mass spectrometers (e.g., DFS or Orbitrap), is the gold standard for dioxin/PCB speciation in seafood, resolving 17 toxic PCDD/Fs and 12 dl-PCBs via HRGC/HRMS (R>10,000). Sample prep involves saponification, acid cleanup, and column chromatography (silica/alumina), followed by separation on DB-5ms columns with EI ionization for accurate mass confirmation. It achieves EU limits (e.g., 4 pg TEQ/g for fish) with recoveries >70%, replacing older magnetic sector systems in routine labs.

Regulatory Guidelines and Safe Consumption:

The European Food Safety Authority (EFSA) has set a tolerable weekly intake (TWI) of 2 picograms per kilogram of body weight for dioxins and dioxin-like PCBs (PCBs). The FDA's tolerance for polychlorinated biphenyls (PCBs) in fish is 2 parts per million (ppm). The FDA also sets a tolerance of 0.2–3.0 ppm for PCBs in all foods, and 10 ppm for PCBs in paper food packaging.The European Union (EU) has set the maximum level of dioxins and dioxin-like PCBs in fish liver and fish liver products at 20 picograms per gram of wet weight.

Product category	Dioxins (pg WHO-PCDD/F-TEQ/g ww)	Dioxins & dl-PCBs (pg WHO-PCB-TEQ/g ww)
Muscle meat of most fish/fishery products	3.5	6.5
Wild-caught freshwater fish	3.5	6.5
Wild-caught eel	3.5	10
Fish liver and products (except marine oils)	-	20
Marine oils (values per g fat)	1.75	6

Standard limits of dioxins and PCBs as per guidelines

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4. Environmental Protection Agency (EPA) - The U.S. EPA provides extensive information on the sources, environmental persistence, and health effects of PCBs and dioxins. It also outlines the risk management framework for reducing exposure. - EPA guidelines for PCBs and dioxins: https://www.epa.gov