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Fish life-history traits are affected after chronic dietary exposure to an environmentally realistic marine mixture of PCBs and PBDEs

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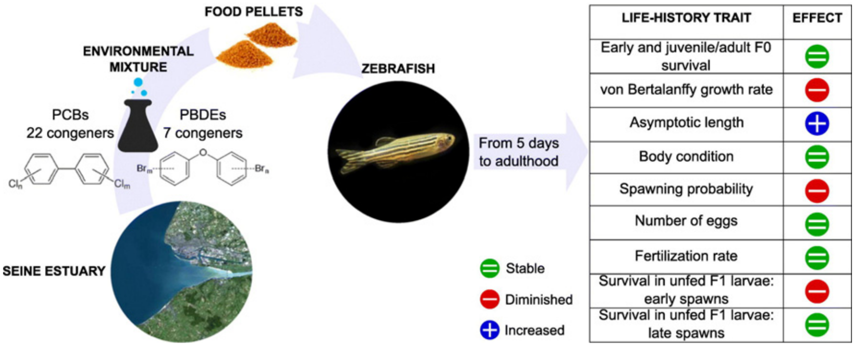
HIGHLIGHTS

- Effects of realistic marine PCB/PBDE mixtures on fish life-history are unknown.
- Zebrafish were chronically exposed to a realistic marine PCB/PBDE mixture via diet.
- Exposed fish grew to larger sizes but their spawning probability was delayed.
- Larval survival of offspring from early spawns was decreased under starvation.
- Environmental PCB/PBDE mixture can alter fish population dynamics via life-history.

GRAPHICAL ABSTRACT



LIFE-HISTORY TRAIT	EFFECT
Early and juvenile/adult F0 survival	⊜
von Bertalanffy growth rate	⊖
Asymptotic length	⊕
Body condition	⊜
Spawning probability	⊖
Number of eggs	⊜
Fertilization rate	⊜
Survival in unfed F1 larvae: early spawns	⊖
Survival in unfed F1 larvae: late spawns	⊜

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ABSTRACT

Polychlorinated biphenyls (PCBs) and polybrominated diphenyl ethers (PBDEs) are persistent organic pollutants that have been shown to affect fish life-history traits such as reproductive success, growth and survival. At the individual level, their toxicity and underlying mechanisms of action have been studied through experimental exposure. However, the number of experimental studies approaching marine environmental situations is scarce, i.e., in most cases, individuals are exposed to either single congeners, or single types of molecules, or high concentrations, so that results can hardly be transposed to natural populations. In the present study, we evaluated the effect of chronic dietary exposure to an environmentally realistic marine mixture of PCB and PBDE congeners on zebrafish life-history traits from larval to adult stage. Exposure was conducted through diet from the first meal and throughout the life cycle of the fish. The mixture was composed so as to approach environmentally relevant marine conditions in terms of both congener composition and concentrations. Life-history traits of exposed fish were compared to those of control individuals using several replicate populations in each treatment. We found evidence of slower body growth, but to a larger asymptotic length, and delayed spawning probability in exposed fish. In addition, offspring issued from early spawning events of exposed fish exhibited a lower larval survival under starvation condition. Given their strong dependency on life-history traits, marine fish population

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dynamics and associated fisheries productivity for commercial species could be affected by such individual-level effects of PCBs and PBDEs on somatic growth, spawning probability and larval survival.

1. Introduction

Persistent organic pollutants (POPs) gather a wide number of chemicals which are of great concern because of their persistence, bioaccumulation and toxicity. In addition, given their propensity for long-range transport, they are globally distributed in various environments worldwide including some far from source areas (Bogdal et al., 2013; Corsolini, 2009; Rigét et al., 2016). Among POPs, polychlorinated biphenyls (PCBs) and polybrominated diphenyl ethers (PBDEs) are two families made of 209 congeners differing by the number and position of one to ten substitution by chlorine and bromine, respectively. PCBs have been used since the 1930s for various industrial purposes, such as dielectric fluids in electrical capacitors, transformers and hydraulic systems (United Nations Environment Programme, 1999), while PBDEs have been used since the 1970s as flame retardants in plastics, furniture, upholstery, electrical equipment, electronic devices, textiles and other household products (United Nations Environment Programme, 2012).

PCBs have been progressively banned in various countries since the 1970s whereas PBDEs have been banned or restricted more recently, beginning in the early 2000s. These regulations were endorsed internationally by the Stockholm Convention on POPs (United Nations Environment Programme, 2001). Today, only the commercial production of deca-PBDE is allowed, although with some restrictions in Europe. Although a decrease in their levels has been reported in biota from various locations (Byer et al., 2015; Rigét et al., 2016) and despite these restrictions, PCBs and PBDEs are still present in all environmental compartments worldwide, including aquatic ecosystems. Therefore they still represent a potential environmental concern.

PCBs and PBDEs are found in the marine environment as complex mixtures of numerous congeners. Due to their long-term persistence and elevated lipophilicity (Mizukawa et al., 2009), they are significantly bioaccumulated and biomagnified through trophic transfer, in most biotic compartments of marine ecosystems (e.g. mollusks, fish, seals; Couderc et al., 2015; Johansson et al., 2006; Letcher et al., 2009). Such bioaccumulation could be a threat for animal communities and their population dynamics through the scaling up of their individual-level effects to the population level (Vasseur and Cossu-Leguille, 2006). Notably, some scientists suspected that chemicals have contributed to the decline of some wild marine fish populations (Hamilton et al., 2015) and it has been suggested that the productivity of some marine fish stocks could be altered due to recruitment impairment caused by nursery habitat degradation in relation to pollutant accumulation (Gilliers et al., 2006; Riou et al., 2001; Rochette et al., 2010). Given the strong dependency of population dynamics on life-history (De Roos et al., 2003; Stearns, 1992), potential individual-level effects of PCBs and PBDEs on fish life-history traits could indeed affect fish population recruitment and dynamics and associated fisheries productivity for commercial species (Vasseur and Cossu-Leguille, 2006).

It is difficult, however, to ascertain the relationship between the presence of one class of chemical and its effects on biota from field observations, because of the accumulation of multiple potential stresses, including many families of chemicals, in natural environments (Baillon et al., 2016). In contrast, the experimental approach allows controlling for potential confounding effects and establishing such links without ambiguity. The effects and the underlying mechanisms of action of PCBs and PBDEs at the individual level have thus been intensively studied through experimental exposure, notably in fish. These studies have demonstrated an alteration of behavior, growth, reproductive, hepatic, and renal functions as well as of the immune and the endocrine systems in fish (Berg et al., 2011; Daouk et al., 2011; Han et al., 2011, 2013; Lyche et al., 2010, 2011; Muirhead et al., 2006; Péan et al., 2013; Yu et al., 2015 and references therein). In particular, several studies have demonstrated that exposure of fish to either PCB or PBDE congener mixtures can affect fish life-history traits such as reproductive success, growth and survival. For example, it has been reported that long-term dietary exposure of zebrafish to a PCB mixture led to a decrease in the number of eggs per spawn and in their fertilization rate (Daouk et al., 2011). Furthermore, dietary exposure of fathead minnows to a single PBDE congener (BDE-47) was shown to reduce cumulative egg production (Muirhead et al., 2006), and McCarthy et al. (2003) showed that Atlantic croaker larvae originating from parents exposed to PCBs technical mixture (Aroclor 1254) through diet were characterized by diminished growth. In addition to their effects on reproductive success and growth, these compounds have been shown to increase fish early-life-stage mortality. Indeed, it has been reported by Foekema et al. (2014) that exposure of common sole eggs to a mixture of POPs (including PCBs and PBDEs) via the water caused acute mortality in larvae after hatching. However, although experimental studies provide valuable information on the potential effects of PCBs and PBDEs, few have focused on environmental situations (see Berg et al., 2011; Lyche et al., 2010, 2011 for experiments mimicking freshwater lake environmental situations). In most cases, the exposure conditions are indeed quite different from environmental situations because of the use of either single congeners, or single types of molecules (i.e., PCBs, or PBDEs, or PAHs), or high concentrations and results can thus hardly be transposed to natural populations. How fish life-history traits may be affected by lifelong exposure to mixtures of both PCB and PBDE congeners that are realistic for the environment therefore remains largely unknown. More precisely, questions about the effects of environmentally realistic mixtures on growth, reproduction and survival and their consequences on individual fitness and population dynamics are still pending.

In this study, we used the zebrafish model to explore the life-history effects associated with long-term dietary exposure to a mixture of PCBs and PBDEs. Due to their lipophilicity, these compounds are mostly found associated to organic matter and not in the water, so that dietary exposure is considered the major route of exposure to PCBs and PBDEs for vertebrates (Muir et al., 2003; Nyman et al., 2002). The selected congeners were chosen to approach environmentally representative conditions for marine ecosystems in terms of both concentrations and compositions. For PCBs, the mixture corresponded to the profile and concentrations found in mussels from an estuary highly-impacted by industrial and urban activities, the Seine estuary in France (Abarnou et al., 2000), which is a nursery area for many flatfish species (Riou et al., 2001). Benthic invertebrates such as mussels are indeed an important food source for many exploited fish species, notably flatfish and demersal fish. As PBDEs profiles in living organisms depend upon their metabolism (Christensen et al., 2002; Ma et al., 2013; Stapleton et al., 2004; Voorspoels et al., 2003), the mixture for this type of molecules was not defined based on specific measurements, but corresponded to a mixture at environmental concentration of the most representative congeners in marine biota and the main congener in marine sediments that were identified for priority action by OSPAR (OSPAR Commission, 2009, 2013).

These PCBs and PBDEs mixtures representative of environment situations were used for identifying life-history effects potentially transposable to wild marine fish populations with possible consequences for their population dynamics and productivity. Effects on early survival,