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Rapid communication

Do fish growth rates correlate with PCB body burdens?

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Growth rates of fish in a polluted ecosystem do not correlate negatively with PCB concentrations.

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ABSTRACT

We evaluated whether growth rates of six fish species correlated with PCB concentrations in a moderately-to-heavily polluted freshwater ecosystem. Using a large dataset ($n = 984$ individuals), and after accounting for growth effects related to fish age, habitat, sex, and lipids, growth correlated significantly, but *positively* with lipid-corrected PCB concentrations for 4 of 6 species. Remaining species showed no correlations between growth and PCBs. Comparisons with regional, lentic growth averages for four species confirmed growth was on par and in three of four cases higher than regional averages in the PCB-polluted ecosystem. We conclude that for these species, at the range of concentrations examined, these PCBs do not exert negative impacts on growth. Rather, factors often cited as influential to growth were also driving growth trends in this study. Future studies that evaluate whether pollution affects growth must account for major growth drivers prior to attributing growth differentials to pollution alone.

1. Introduction

Growth rates are fundamental life-history traits of organisms (Stearns, 1976; West et al., 2001). Variations in growth help differentiate the evolutionary success of individuals, and populations (Phillips, 2009) and play vital roles in ecosystem function, e.g., production (Waters, 1977). Factors such as nutrients, temperature, food availability, competition, predation, and hydrology are traditionally thought to leverage growth rates (Levin et al., 1977; Rypel and Bayne, 2009). Increasingly, human activities, including certain types of pollution, are being linked to growth processes (Migliore et al., 2010; Shigihara et al., 2009; Ward et al., 2010). However, pollution-driven growth impacts are not always straightforward, especially when pollutant concentrations are non-acute, as is often the case in natural ecosystems (Kefford and Nugegoda, 2005). Furthermore, potential growth effects arising from pollution are frequently examined without accounting for other major correlates of growth (e.g., McGourty et al., 2009).

Polychlorinated biphenyls (PCBs) are a set of artificial chemicals manufactured during the majority of the 20th century primarily as an industrial coolant. During the 1970s, widespread concern arose over rising PCBs in food webs, especially in human-consumed fishes, eventually leading to bans in many countries on PCB manufacturing (Kimbrough, 1995). PCBs are lipophilic, and biomagnify in food chains, resulting in high concentrations in organisms at the top of food chains or in organisms that feed near point sources (Rypel et al., 2007). PCBs are also known carcinogens, and consumption of contaminated fish is the primary route of human exposure (Kimbrough, 1995). Over the last 30 years, many studies have understandably focused on tracking and predicting PCB trends in organisms (e.g., Harrad et al., 1994; Olsson and Reutergardh, 1986; Pereira et al., 2009), and elucidating myriad reproductive impacts (Olsson et al., 1999; Reiser et al., 2004; Vos et al., 2000). However, in this study we ask a different and somewhat understudied yet critical question: does PCB contamination affect growth? Whereas growth integrates physiological processes over a lifespan, this variable may be indicative of longer-term effects of PCBs.

2. Materials and methods

2.1. Study ecosystem and brief pollution history

PCBs were produced by the Monsanto Chemical Company at their plant in Anniston, Alabama from ~1930 to 1971. Wastes containing PCBs were released and leeched from Monsanto facilities into Snow Creek leading to chemical flows into Choccolocco Creek – the largest tributary to Logan Martin Reservoir (Fig. 1). Logan Martin Reservoir is a shallow (mean depth 5.5 m), eutrophic, 6179 ha impoundment of the Coosa River. After manufacturing of PCBs at the Anniston facility ceased in the late 1970s, PCBs in fishes began to decline at slow rates. Further descriptions of this site can be found in Rypel et al. (2007).

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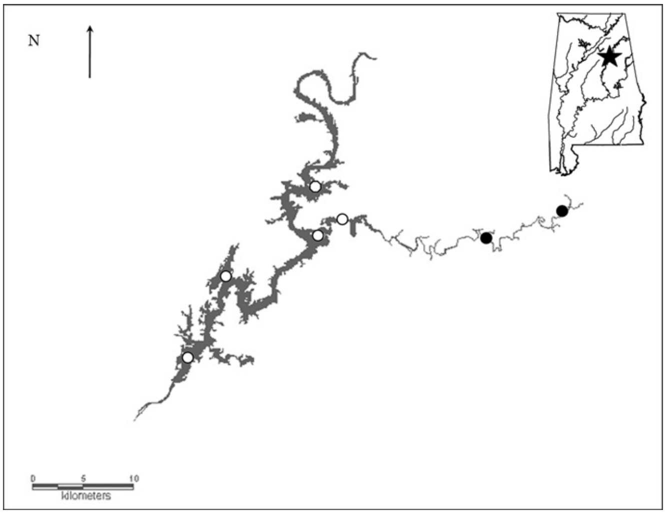

Fig. 1. Sampling sites in Logan Martin Reservoir and Choccolocco Creek. Black circles indicate "lotic habitats" and open circles indicate "lentic habitats".

2.2. Fish sampling and PCBs analysis

Fish were sampled at seven stations (Fig. 1), October–November, 2001 and 2002. Six fish species were examined: striped bass (*Morone saxatilis*), channel catfish (*Ictalurus punctatus*), largemouth bass (*Micropterus salmoides*), spotted bass (*Micropterus punctulatus*), black crappie (*Pomoxis nigromaculatus*) and freshwater drum (*Aplodinotus grunniens*). Fish were wrapped in aluminum foil, placed in airtight plastic bags and positioned under ice in coolers for transfer to an Auburn University laboratory. Each fish received a unique number identifier, and the sex, total weight (g) and total length (mm) were recorded. All fish were skinned, filleted, packaged as above, and stored in −20 °C freezers. Frozen, skinned fillets were shipped to Severn Trent Labs, Savannah, Georgia, USA for percent lipid estimation and total PCB residue analysis by gas chromatography.

For PCB analysis, 10 g tissue samples were first extracted by sonication in methylene chloride. Solvent volumes were then reduced by evaporation under a nitrogen stream and extracted lipid and lipophilic pollutants solvent exchanged to hexane. Non-target (high molecular weight) compounds were removed from extracts by gel permeation chromatography. Purified extracts were then analyzed with a gas chromatograph fitted with dual fused-silica capillary columns and dual electron capture detectors and quantification performed using internal standards calibration. Preliminary examination of PCB congeners indicated that Aroclors 1254 and 1260 were present in fish tissues (consistent with the known point-source) and that little degradation of PCBs had taken place (DR Bayne, unpublished data).

Otolith sagittae were used to determine the age (y) of each fish by counting annual growth lines under a dissecting microscope. Ages were determined blindly (i. e., with no knowledge of the sample) by two experienced readers and discrepancies in ages between readers settled with an age determination by a third reader. To place fish growth in the polluted ecosystem in a regional context, we collected regional (Alabama), lentic growth averages for largemouth bass, spotted bass, and black crappie from the Alabama Department of Conservation (ADCNR) and from the literature for freshwater drum from lentic waterbodies (Rypel et al., 2006) for comparison to our Logan Martin Reservoir data. ADCNR regional growth averages were generated from fish sampled during summer months (i.e., at a similar time of year as our growth and PCB data), over the complete ranges of lengths and weights for each population, and using blind age estimates generated from otolith sagittae by ADCNR personnel. Regional growth averages for largemouth bass, spotted bass, and black crappie were based on growth data from a total of 17, 11, and 14 reservoir ecosystems, respectively, and utilized >1000 individual fish in all three cases (http://www.outdooralabama.com/fishing/freshwater/where/reservoirs/). For freshwater drum, regional growth averages were based on growth data from four Alabama reservoirs and a total of 146 individual fish (Rypel et al., 2006).

2.3. Statistical analyses

PCB and % lipid data were natural log (ln) and arcsin square-root transformed, respectively, to meet assumptions of normality prior to all analyses. Whereas lipids and PCBs are collinear, PCB data were normalized for lipid by using residuals of regressions of PCBs on percent lipid data for each species.

Analyses of covariance (ANCOVAs) were used to evaluate which variables correlated with growth for these species. In the models, length was the dependent variable, gender and hydrologic habitat (whether the hydrology of the habitat of capture was lentic or lotic) were categorical variables, and log(age), arcsin square root(lipids), and lipid normalized PCBs were covariates. ANCOVAs were also used to compare growth of fishes (i.e., length-at-age regression lines) from Logan Martin Reservoir to Alabama growth averages. Effects and models were considered significant when $\alpha < 0.05$.

3. Results and discussion

We analyzed 984 individual fish for PCBs and growth. Significant growth models were produced for all species (Table 1). For 4 of 6 species, sex significantly affected growth. For all species for which data were available, hydrologic habitat significantly affected growth. Lipid content correlated significantly with growth for 5 of 6 species. Lipid-normalized PCBs correlated with growth of 4 of 6 species, and in all these cases, the correlation was positive. Comparisons of Logan Martin fish growth with regional averages revealed that growth was significantly higher for largemouth bass, spotted bass, and black crappie in Logan Martin Reservoir (Fig. 2A–C, ANCOVA P's = 0.001, 0.001, 0.001, respectively). For freshwater drum, growth did not differ with Alabama lentic averages (ANCOVA, $P = 0.34$).

The frequent depiction of pollution as being harmful to organism growth may not always be an accurate generalization. While in acute cases, high concentrations of PCBs can affect growth (particularly as juveniles, Desaulniers et al., 1999), at more moderate concentrations found in many natural populations, this same trend may not hold. In fact in this study, positive relationships were found between growth and PCB concentrations even after co-linearities between lipids and PCBs were removed, supporting results of laboratory studies showing a growth promotion effect for certain PCBs (Bengtsson, 1979, 1980). However, other laboratory and a few field studies have found negative, sub-lethal effects of PCBs on growth at similar concentrations as those found in this study (Adams et al., 1989; Knezovich et al., 1987; McCarthy et al., 2003).

Several possibilities could help explain a lack of correlation between growth and PCBs for two species and a positive correlation for four species. (1) For species that showed no correlation between growth and PCBs, it can be inferred, that at these concentrations,

Table 1
Results of ANCOVAs evaluating fish growth in Logan Martin Reservoir. Significant effects are indicated in bold. For categorical variables, categories with effects that were significantly higher are indicated in parentheses. For covariates, correlation directions with growth are indicated in parentheses.

Species	N	PCB range (mg kg^{-1})	Model R^2	Model P	Categorical variables		Covariates		
					Sex	Habitat[a]	Age	Lipids[b]	PCBs (lipid normalized)[c]
Largemouth bass	183	0.03.0–4.22	0.72	**<0.0001**	**0.006 (F)**	**0.001 (Lentic)**	**<0.0001**	**0.001 (+)**	0.52 (−)
Spotted bass	195	0.03–5.12	0.81	**<0.0001**	**0.002 (F)**	**<0.0001 (Lentic)**	**<0.0001**	**0.001 (+)**	**0.004 (+)**
Striped bass	91	0.21–8.00	0.65	**<0.0001**	0.14	N/A	**<0.0001**	0.49 (+)	**0.001 (+)**
Black crappie	111	0.04–3.50	0.63	**<0.0001**	0.85	N/A	**<0.0001**	**<0.0001 (+)**	**0.01 (+)**
Channel catfish	270	0.03–20.60	0.80	**<0.0001**	**<0.0001 (M)**	**<0.0001 (Lotic)**	**<0.0001**	**<0.0001 (+)**	**0.001 (+)**
Freshwater drum	134	0.02–33.90	0.71	**<0.0001**	**0.005 (F)**	**<0.0001 (Lotic)**	**<0.0001**	**<0.0001 (+)**	0.57 (+)

[a] Striped bass and black crappie were not collected in sufficient numbers in lotic habitat to use habitat as a covariate.
[b] % lipid data were arcsin square-root transformed.
[c] Data were normalized using residuals from a regression of ln(PCBs) to arcsin square-root(lipids).

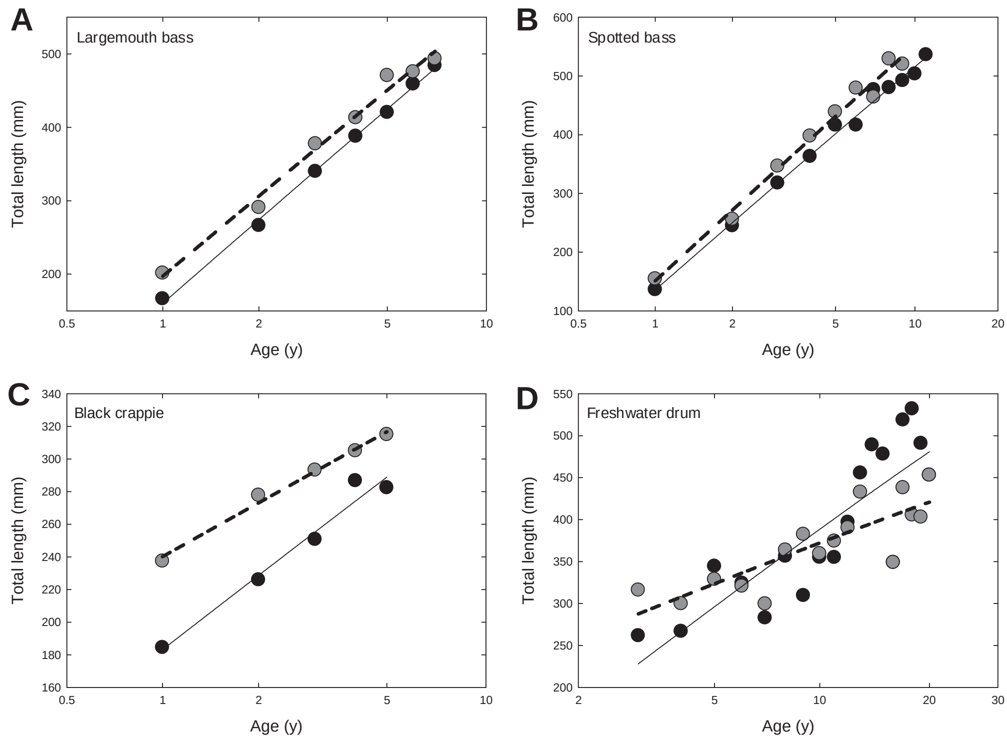

Fig. 2. Growth of four fish species in PCB-contaminated Logan Martin Reservoir (grey circles, dashed line) compared with growth averages for Alabama (black circles, solid line). Note logarithmic *x*-axes.

PCBs likely do not affect growth. (2) Alternatively, if lipids can reflect current PCB concentrations of fishes (e.g., a fatter fish tends to have more PCBs), then conversely, PCBs may reflect past lipid content. For example, a fish with high PCB concentrations, but only average lipid content, could represent a fish that once had high lipid reserves and rigorous growth. (3) Interestingly, and as stated previously, positive effects of PCBs on fish growth have been shown in laboratory studies – an effect that was hypothesized as being linked to hormonal/thyroid dysfunction via PCBs (Bengtsson, 1979, 1980). More research is needed on potential growth promotion effects of PCBs to explore possible physiological mechanisms and origins for such an effect.

"Growth biodilution" is defined as how biomass-specific concentrations of pollutants diminish as cells divide causing lower concentrations in faster growing individuals (Pickhardt et al., 2002). While this term has gained a central place in ecotoxicology, the phenomenon has been observed primarily with Mercury (Hg) (Jardine et al., 2009; Rypel, 2010a). PCBs behave entirely differently than Hg, both physiologically and biogeochemically, and these differences seem to extend to growth biodilution. No evidence for growth biodilution was found in this study. In fact, there may even be an opposite effect of "growth concentration" occurring with PCBs, perhaps because of their lipophilic behavior or through dysfunction of hormonal systems. Again, further research is needed in this area.

Fish growth was fast in the PCB-polluted ecosystem. Growth was significantly faster for three of four species in the polluted ecosystem relative to regional growth averages. For freshwater drum, growth did not differ, and was reduced at advanced ages relative to regional averages. However, this pattern conformed to a previously reported ecological pattern – reservoirs with high hydrologic retention times produce slower growing drum (Rypel et al., 2006). Infact, Logan Martin Reservoir supports a championship-grade black bass fishery. The Bassmaster Classic Tournament (one of the world's most prestigious angling tournaments), has taken place at Logan Martin Reservoir three times, all of which were during the 1990s, a period when PCB concentrations in fishes were ~3 times higher than they were during this study (Mitchell, 2006).

Organism growth is a complex physiological and ecological process, but one that has been studied extensively in the past. Concern over the potential influence of pollutants on growth is legitimate, but such questions must be thoroughly examined before ascribing cause and effect. Life-history, physiology, habitat, and ecosystem structure and function are traditionally raised as factors that drive growth variations at large spatial scales (Levin et al., 1977; Phillips, 2009; Rypel, 2010b). For example, sex-specific rates of fish growth often vary between habitats or ecosystems as a function of differences in the diversity and abundance of key prey items, e.g., riverine versus lacustrine prey items (Rypel, 2010b; Rypel and Bayne, 2009). This study produced results concordant with this conventional paradigm. The majority of growth variations were explained by habitat, sex, and lipids. Furthermore, PCB concentrations often correlated *positively* with growth. Yet in the literature, it is often assumed that because growth differs between two habitats or ecosystems, one of which is polluted and has lower growth, that the growth reduction must be related to the pollution (McGourty et al., 2009). However, growth differentials can easily be caused by not accounting for these major growth drivers. We contend that future studies addressing the important question of whether pollution affects growth must account for and eliminate variations due to other major growth drivers before evaluating whether growth was impacted by the pollution in question.

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References

Adams, S.M., Shepard, K.L., Greeley Jr., M.S., Jimenez, B.D., Ryon, M.G., Shugart, L.R., McCarthy, J.F., Hinton, D.E., 1989. The use of bioindicators for assessing the effects of pollutant stress on fish. Marine Environmental Research 28, 459–464.

Bengtsson, B.E., 1979. Increased growth in minnows exposed to PCBs. Ambio 8, 169–170.

Bengtsson, B.E., 1980. Long-term effects of PCB (Clophen A50) on growth, reproduction and swimming performance in the minnow, *Phoxinus phoxinus*. Water Research 14, 681–687.

Desaulniers, D., Leingartner, K., Wade, M., Fintelman, E., Yagminas, A., Foster, W.G., 1999. Effects of acute exposure to PCBs 126 and 153 on anterior pituitary and thyroid hormones and FSH isoforms in adult Sprague Dawley male rats. Toxicological Sciences 47, 158–169.

Harrad, S.J., Sewart, A.P., Alcock, R., Boumphrey, R., Burnett, V., Duarte-Davidson, R., Halsall, C., Sanders, G., Waterhouse, K., Wild, S.R., 1994. Polychlorinated biphenyls (PCBs) in the British environment: sinks, sources and temporal trends. Environmental Pollution 85, 131–146.

Jardine, L.B., Burt, M.D.B., Arp, P.A., Diamond, A.W., 2009. Mercury comparisons between farmed and wild Atlantic salmon (*Salmo salar* L.) and Atlantic cod (*Gadus morhua* L.). Aquaculture Research 40, 1148–1159.

Kefford, B.J., Nugegoda, D., 2005. No evidence for a critical salinity threshold for growth and reproduction in the freshwater snail Physa acuta. Environmental Pollution 134, 377–383.

Kimbrough, R.D., 1995. Polychlorinated-biphenyls (PCBs) and human health: an update. Critical Reviews in Toxicology 25, 133–163.

Knezovich, J.P., Harrison, F.L., Wilhelm, R.G., 1987. The bioavailability of sediment-sorbed organic chemicals: a review. Water, Air, and Soil Pollution 32, 233–245.

Levin, B.R., Stewart, F.M., Chao, L., 1977. Resource-limited growth, competition, and predation: a model and experimental studies with bacteria and bacteriophage. The American Naturalist 111, 3–24.

McCarthy, I.D., Fuiman, L.A., Alvarez, M.C., 2003. Aroclor 1254 affects growth and survival skills of Atlantic croaker *Micropogonias undulatus* larvae. Marine Ecology Progress Series 252, 295–301.

McGourty, C.R., Hobbs, J.A., Bennett, W.A., Green, P.C., Hwang, H., Ikemiyagi, N., Lewis, L., Cope, J.M., 2009. Likely population-level effects of contaminants on a resident estuarine fish species: comparing *Gillichthys mirabilis* population static measurements and vital rates in San Francisco and Tomales Bays. Estuaries and Coasts 32, 1111–1120.

Migliore, L., Godeas, F., De Filippis, S.P., Mantovi, P., Barchi, D., Testa, C., Rubattu, N., Brambilla, G., 2010. Hormetic effect(s) of tetracyclines as environmental contaminant on *Zea mays*. Environmental Pollution 158, 129–134.

Mitchell, J.B., 2006. Factors Affecting Bioaccumulation of Polychlorinated Biphenyls in Six Fish Species in Logan Martin Reservoir, Alabama. Auburn University, Auburn, AL, p. 70.

Olsson, M., Reutergardh, L., 1986. DDT and PCB pollution trends in the Swedish aquatic environment. Ambio 15, 103–109.

Olsson, P.E., Westerlund, L., Teh, S.J., Billsson, K., Berg, A.H., Tysklind, M., Nilsson, J., Eriksson, L.O., Hinton, D.E., 1999. Effects of maternal exposure to estrogen and PCB on different life stages of zebrafish (*Danio rerio*). Ambio 28, 100.

Pereira, M.G., Walker, L.A., Best, J., Shore, R.F., 2009. Long-term trends in mercury and PCB congener concentrations in gannet (*Morus bassanus*) eggs in Britain. Environmental Pollution 157, 155–163.

Phillips, B.L., 2009. The evolution of growth rates on an expanding range edge. Biology Letters 5, 802–804.

Pickhardt, P.C., Folt, C.L., Chen, C.Y., Klaue, B., Blum, J.D., 2002. Algal blooms reduce the uptake of toxic methylmercury in freshwater food webs. Proceedings of the National Academy of Sciences of the United States of America 99, 4419–4423.

Reiser, D.W., Greenberg, E.S., Helser, T.E., Branton, M., Jenkins, K.D., 2004. In situ reproduction, abundance, and growth of young-of-year and adult largemouth bass in a population exposed to polychlorinated biphenyls. Environmental Toxicology and Chemistry 23, 1762–1773.

Rypel, A.L., 2010a. Mercury concentrations in lentic fish populations related to ecosystem and watershed characteristics. Ambio 39, 14–19.

Rypel, A.L., 2010b. River impoundment and sunfish growth. River Research and Applications (Published Online).

Rypel, A.L., Bayne, D.R., 2009. Hydrologic habitat preferences of select southeastern USA fishes resilient to river ecosystem fragmentation. Ecohydrology 2, 419–427.

Rypel, A.L., Bayne, D.R., Mitchell, J.B., 2006. Freshwater drum growth from lotic and lentic habitats in Alabama. Transactions of the American Fisheries Society 135, 987–997.

Rypel, A.L., Findlay, R.H., Mitchell, J.B., Bayne, D.R., 2007. Variations in PCB concentrations between genders of six warmwater fish species in Lake Logan Martin, Alabama, USA. Chemosphere 68, 1707–1715.

Shigihara, A., Matsumura, Y., Kashiwagi, M., Matsumoto, K., Igawa, M., 2009. Effects of acidic fog and ozone on the growth and physiological functions of *Fagus crenata* saplings. Journal of Forest Research 14, 394–399.

Stearns, S.C., 1976. Life-history tactics: a review of the ideas. The Quarterly Review of Biology 51, 3–47.

Vos, J.G., Dybing, E., Greim, H.A., Ladefoged, O., Lambre, C., Tarazona, J.V., Brandt, I., Vethaak, A.D., 2000. Health effects of endocrine-disrupting chemicals on wildlife, with special reference to the European situation. Critical Reviews in Toxicology 30, 71–133.

Ward, D.M., Nislow, K.H., Chen, C.Y., Folt, C.L., 2010. Rapid, efficient growth reduces mercury concentrations in stream-dwelling Atlantic salmon. Transactions of the American Fisheries Society 139, 1–10.

Waters, T.F., 1977. Secondary production in inland waters. Advances in Ecological Research 10, 91–164.

West, G.B., Brown, J.H., Enquist, B.J., 2001. A general model for ontogenetic growth. Nature 413, 628–631.