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Marine Pollution Bulletin 46 (2003) 522–524
MARINE POLLUTION BULLETIN
www.elsevier.com/locate/marpolbul

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Biomagnification

We applaud the recent effort of John S. Gray to provide an ecologist's perspective on biomagnification (Gray, 2002). As ecotoxicologists who have devoted a large amount of effort on this topic we are often frustrated by the misunderstanding surrounding the bioaccumulation process and the many contaminant publications that have ignored the influence of ecological variability. Unfortunately, we feel this paper does not give a balanced summary of the accumulated knowledge and literature on bioaccumulation and biomagnification. We believe this is mainly due to the restrictive search criteria used; only the term "biomagnification" in titles was searched, which resulted in a large body of work on the subject of biomagnification to be overlooked (see for example Connolly and Pedersen, 1988; Muir et al., 1988; Cabana et al., 1993; Kidd et al., 1998a,b; Gobas et al., 1999; Russell et al., 1999).

One example of the restrictive search criteria is the discussion of which exposure route, water or food, is important for uptake of contaminants in fish. Water is suggested as the most important exposure route to contaminants for fish on the 6th line of the abstract, where it is stated "However, bioconcentration (uptake from the surrounding water) is the most usual way that organic compounds are accumulated in organisms from invertebrates to and including fish". The importance of water versus diet exposure for organic contaminants is pursued further in Section 5. We are not suggesting that this is an invalid argument, although we do not agree with it, but our concern is that only a single paper (Randall et al., 1998) was used to justify that water and not diet is the most important exposure route to fish. Thus a long history of papers demonstrating that diet is the most important exposure route for hydrophobic recalcitrant chemicals to fish is ignored (see for example Thomann and Connolly, 1984; Bruggeman et al., 1984; Thoman, 1989).

A number of papers that have dealt with the issue of biomagnification of organic contaminants in aquatic food web are criticized for not considering alternative hypothesis for the higher concentrations at the top of the food web, namely bioconcentration. For example, Kidd et al. (1995) is criticized for assuming just biomagnification and not alternative routes of exposure explain high toxaphene levels in fish from a high Arctic lake. However, the objective of Kidd et al. (1995) was to determine if high levels of toxaphene in predatory fish were due to local sources of toxaphene in the lake or the "food-chain length" hypothesis. In our opinion Kidd et al. (1995) did consider alternative hypotheses for explaining increasing concentration up the food web by citing a number of papers which also dealt with the issue of food web magnification in lakes, including lipids (Rasmussen et al., 1990) and accumulation from water (Swackhamer and Hites, 1988). Kidd et al. also published a second paper on this food web (Kidd et al., 1998a) that directly addressed other factors that could explain the relationship between concentration and trophic status (as estimated from stable isotopes of nitrogen (δ^{15}N)), including lipids, fish age, fish size and lake characteristics. The conclusion of this paper was that biomagnification was indeed occurring in all three study lakes, even after removing the influence of lipids, age and size. The word biomagnification did not appear in the title of Kidd et al. (1998a) paper and would not have been found by the search criteria used for this paper. Interestingly, biomagnification does not appear in the title of Kidd et al. (1995) or in other papers criticized and used in this review paper (e.g., Muir et al., 1996; Metcalfe and Metcalfe, 1997). Of the 33 papers cited by Gray, only 9 have the word biomagnification in the title.

A second example of what we feel is an unbalanced representation of the literature on biomagnification is the discussion of differences between marine and freshwater food webs. It is suggested that for a chemical to biomagnify through a food web it must be structured with limited food choices. Such systems, it is argued, are found in freshwater environments and result from all food being eaten and thus all contaminants are passed on. The support for this hypothesis are two papers from 1973 to 1976 which found that DDT (Hargrave and Phillips, 1976) and mercury (Williams and Weiss, 1973) did not biomagnify based on relationships between Cs/K and DDT and mercury in marine systems. There have been numerous studies using δ^{15}N (e.g., Jarman et al., 1996; Broman et al., 1992), and that did not use δ^{15}N (e.g., Muir et al., 1988), that have shown biomagnification of organic contaminants up marine food webs. Although Jarman et al. (1996) and Broman et al. (1992) were cited by Gray, more weight was, without any explanation, placed on the earlier studies using Cs/K ratios, which did not find biomagnification, over these more recent studies using δ^{15}N, which did find biomagnification. This despite many recent papers

doi:10.1016/S0025-326X(03)00094-8

on assigning trophic structure using $\delta^{15}N$ (see for example Hobson and Welch, 1992; Hobson et al., 1995; Kelly, 2000) and positive relationships between $\delta^{15}N$ and organic contaminants (Hop et al., 2002; Fisk et al., 2001; Jarman et al., 1996; Broman et al., 1992; Kidd et al., 1995) and mercury (Atwell et al., 1998) in marine systems. Many of these papers have considered other hypotheses and have accounted for variables, mainly lipids, which could explain the increases in concentrations with food webs. Could it be that Hargrave and Phillips (1976) and Williams and Weiss (1973) did not consider alternative variables?

Gray's review paper offers some mechanisms that may cause increased concentration of contaminants in higher trophic level organisms, which is biomagnification, such as longevity and size. As Gray indicates, these confounding factors need to be considered when assessing whether a chemical biomagnifies, but there are other factors to consider as well. For example, the higher feeding rate of homeotherms versus poikilotherms results in higher biomagnification rates in the homeotherms (Braune and Norstrom, 1989; Fisk et al., 2001; Hop et al., 2002). It is our opinion that these variables, as well as lipid content, have been considered in most papers published on the subject of biomagnification in the past 15 years and that a more comprehensive literature search would have revealed this.

In conclusion, Gray has presented some interesting and thought provoking ideas about biomagnification of contaminants in food webs but we feel this review has not adequately represented the accumulated knowledge on the subject.

References

Atwell, L., Hobson, K.A., Welch, H.E., 1998. Biomagnification and bioaccumulation of mercury in an arctic marine food web: Insights from stable nitrogen isotope analysis. Can. J. Fish. Aquat. Sci. 55, 1114–1121.

Braune, B.M., Norstrom, R.J., 1989. Dynamics of organochlorine compounds in heming gulls: III. Tissue distribution and bioaccumulation in Lake Ontario gulls. Environ. Toxicol. Chem. 8, 957–968.

Broman, D.C., Naf, C., Rolff, C., Zebuhr, Y., Fry, B., Hobbie, J., 1992. Using ratios of stable nitrogen isotopes to estimate bioaccumulation and flux of polychlorinated dibenzo-*p*-dioxins (PCDDs) and dibenzofurans (PCDFs) in two food chains from the northern Baltic. Environ. Toxicol. Chem. 11, 331–345.

Bruggeman, W.A., Opperhuizen, A., Wijbenga, A., 1984. Bioaccumulation of super-lipophilic chemicals in fish. Toxicol. Environ.Chem. 7, 173–189.

Cabana, G., Tremblay, A., Kalff, J., Rasmussen, J.B., 1993. Pelagic food chain structure in Ontario lakes: A determinant of mercury levels in lake trout (*Salvelinus namaycush*). Can. J. Fish. Aquat. Sci. 51, 381–389.

Connolly, J.P., Pedersen, C.J., 1988. A thermodynamic-based evaluation of organic chemical accumulation in aquatic organisms. Environ. Sci. Technol. 22, 99–103.

Fisk, A.T., Hobson, K.A., Norstrom, R.J., 2001. Influence of chemical and biological factors on trophic transfer of persistent organic pollutants in the Northwater Polynya marine food web. Environ. Sci. Technol. 35, 732–738.

Gobas, F.A.P.C., Wilcockson, J.B., Russell, R.W., Haffner, G.D., 1999. Mechanism of biomagnification in fish under laboratory and field conditions. Environ. Sci. Technol. 33, 133–141.

Gray, J.S., 2002. Biomagnification in marine systems: the perspective of an ecologist. Mar. Pollut. Bull. 45, 46–52.

Hargrave, B.T., Phillips, G.A., 1976. DDT residues in benthic invertebrates and demersal fish in St. Margarets Bay, Nova Acotia. J. Fish. Res. Board Canada 33, 1692–1698.

Hobson, K.A., Welch, H.E., 1992. Determination of trophic relationships within a high Arctic marine food web using stable-isotope analysis. Mar. Ecol. Prog. Ser. 84, 9–18.

Hobson, K.A., Ambrose Jr., W.G., Renaud, P.E., 1995. Sources of primary production, benthic-pelagic coupling, and trophic relationships within the Northeast Water Polynya: Insights from $\delta^{13}C$ and $\delta^{15}N$ analysis. Mar. Ecol. Prog. Ser. 128, 1–10.

Hop, H., Borgå, K., Gabrielsen, G.W., Kleivane, L., Skaare, J.U., 2002. Food web magnification of persistent organic pollutants in poikilotherms and homeotherms from the Barents Sea. Environ. Sci. Technol. 36, 2589–2597.

Jarman, W.M., Hobson, K.A., Sydeman, W.J., Bacon, C.E., McLaren, E.B., 1996. Influence of trophic position and feeding location on contaminant levels in the Gulf of the Farallones food web revealed by stable isotope analysis. Environ. Sci. Technol. 30, 654–660.

Kelly, J.F., 2000. Stable isotopes of carbon and nitrogen in the study of avian and mammalian trophic ecology. Can. J. Zool. 78, 1–27.

Kidd, K.A., Schlindler, D.W., Muir, D.C.G., Lockhart, W.L., Hesslein, R.H., 1995. High concentrations of toxaphene in fishes from a subarctic lake. Science (Washington) 269, 240–242.

Kidd, K.A., Hesslein, R.H., Ross, B.J., Koczanski, K., Stephens, G.R., Muir, D.C.G., 1998a. Bioaccumulation of organochlorines through a remote freshwater food web in the Canadian Arctic. Environ. Pollut. 102, 91–103.

Kidd, K.A., Schlindler, D.W., Hesslein, R.H., Muir, D.C.G., 1998b. Effects of trophic position and lipid on organochlorine concentrations in fishes from subarctic lakes in Yukon Territory. Can. J. Fish. Aquat. Sci. 55, 869–881.

Metcalfe, T.L., Metcalfe, C.D., 1997. The trophodynamics of PCBs, including mono- and non-ortho congeners, in the food web of North-Central Lake Ontario. Sci. Total Environ. 201, 245–272.

Muir, D.C.G., Ford, C.A., Rosenberg, B., Norstorm, R.J., Simon, M., Beland, P., 1996. Persistent organochlorines in beluga whales (*Delphinapterus leucas*) from the St. Lawrence River Estuary. 1. Concentrations and patterns of specific PCBs, chlorinated pesticides and polychlorinated dibenzo-*p*-dioxins and dibenzofurans. Environ. Pollut. 93, 219–234.

Muir, D.C.G., Norstrom, R.J., Simon, M., 1988. Organochlorine contaminants in Arctic marine food chains: Accumulation of specific polychlorinated biphenyls and chlordane-related compounds. Environ. Sci. Technol. 22, 1071–1079.

Randall, D.W., Connell, D.S., Yang, R., Wu, R.S.S., 1998. Concentration of persistent lipophilic compounds are determined by exchange across the gills and not through the food chain. Chemopshere 37, 1263–1280.

Rasmussen, J.B., Rowan, D.J., Lean, D.R.S., Carey, J.H., 1990. Food chain structure in Ontario lakes determines PCB levels in lake trout (*Salvelinus namaycush*) and other pelagic fish. Can. J. Fish. Aquat. Sci. 47, 2030–2038.

Russell, R.W., Gobas, F.A.P.C., Haffner, G.D., 1999. Role of chemical and ecological factors in trohpic transfer of organic chemicals in aquatic food webs. Environ. Toxicol. Chem. 18, 1250–1257.

Swackhamer, D.L., Hites, R.A., 1988. Occurrence and bioaccumulation of organochlorine compounds in fishes from Siskiwit Lake, Isle Royale, Lake Superior. Environ. Sci. Technol. 22, 543–548.
Thoman, R.V., 1989. Bioaccumulation model of organic chemical distribution in aquatic food chains. Environ. Sci. Technol. 23, 699–707.
Thomann, R.V., Connolly, J.P., 1984. Model of PCB in the Lake Michigan lake trout food chain. Environ. Sci. Technol. 18, 65–74.
Williams, P.M., Weiss, H.V., 1973. Mercury in the marine environment: concentration in seawater and in a pelagic food chain. J. Fish. Res. Board Canada 30, 293–295.

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