PCBs in the Last Frontier: A Case Study on the Scientific Method

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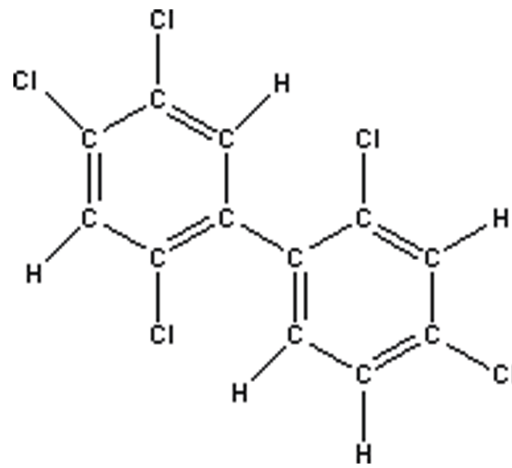
Part I—PCBs

Polychlorinated biphenyls (PCBs) are compounds that were once used as insulators in electrical transmission lines and in the production of polymers. Each PCB differs by the quantity and location of the chlorine atoms. An example of one of the many different PCBs is shown to the right.



2,2′,4,4′,5-Pentachlorobiphenyl

PCB production was halted in 1977 due to their potential toxicity, but the chemicals are still found in the environment due to their stability. Studies in remote areas of Alaska have shown that PCBs can even be found in lakes untouched by humans. There is no known natural process that produces PCBs, so all of the PCBs in existence are presumed to have been produced by humans.

Questions

1. What scientific observation about PCB distribution is described above?
2. Propose a hypothesis or "explanatory story" to explain the global movement of pollutants such as PCBs. Specifically, how could they end up in the most remote Alaskan lakes?
3. Propose a method, either through observations or direct experimentation, which would test your hypothesis from Question 2. (Note: Your approach may be on a local scale despite examining a global phenomenon.)

Part II—Global Transport

Later studies showed that the global circulation of PCBs was at least in part due to atmospheric transport. PCBs enter the atmosphere by several mechanisms including the burning of organic material and evaporation in warmer climates followed by condensation at higher latitudes. This explained how chemicals made by humans could be found in areas untouched by humans.

Questions

1. Come up with a hypothesis or "explanatory story" to answer the following question: Should PCB levels differ significantly in Alaskan lakes that are near each other and at the same altitude? (Keep in mind that a hypothesis is an educated guess, so it requires a reason why you think your answer is correct.)
2. Propose a method, either through observations or direct experimentation, which would test your hypothesis from Question 1.

Part III—Significant Difference?

Recent observations of PCB levels in arctic lakes have shown that the levels of PCBs are not the same in all lakes that are near each other and at the same altitude. In fact, lakes at the terminus (i.e., the start) of river systems had higher PCB levels than completely isolated lakes that were close by.

Questions

1. What possible "explanatory story" might explain the observation described above? (Hint: Think of species that leave a lake but return later in life.)
2. How would you test your hypothesis made above?

Part IV—Riddle Solved

Recent scientific studies have shown that sockeye salmon returning from the ocean to spawn in Alaskan lakes contain elevated levels of PCBs. After spawning the salmon die and their contents become part of the lake sediment and/or enter the food chain. The salmon are responsible for adding approximately six times as many PCBs to remote lakes as atmospheric circulation. The types of PCBs in the salmon also match those found in the ocean.

Question

1. Imagine yourself as a scientist working on this issue. What would you want to look at next?

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Delivery of pollutants by spawning salmon

Fish dump toxic industrial compounds in Alaskan lakes on their return from the ocean.

Pollutants are widely distributed by the atmosphere and the oceans[1]. Contaminants can also be transported by salmon and amplified through the food chain. Here we show that groups of migrating sockeye salmon (*Oncorhynchus nerka*) can act as bulk-transport vectors of persistent industrial pollutants known as polychlorinated biphenyls (PCBs), which they assimilate from the ocean and then convey over vast distances back to their natal spawning lakes. After spawning, the fish die in their thousands — delivering their toxic cargo to the lake sediment and increasing its PCB content by more than sevenfold when the density of returning salmon is high.

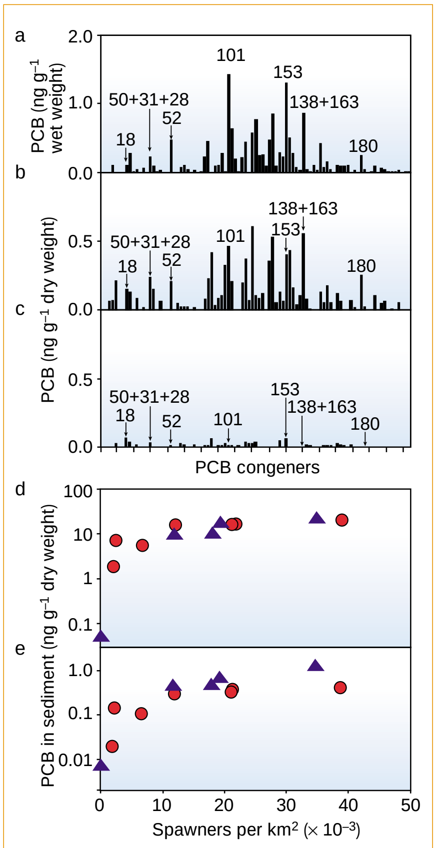

Figure 2 Surface sediments in Alaskan lakes show a similar pattern of polychlorinated biphenyl (PCB) congeners to that found in salmon returning to spawn, and sedimentary PCB concentrations are strongly correlated with the density of salmon returning. **a–c,** PCB congener patterns (numbers represent different congeners) in **a,** sockeye salmon from Frazer Lake; **b,** surface sediments from Frazer Lake (total escapement, about 11,700 spawners per km^2); and **c,** surface sediments from Spiridon Lake (no anadromous salmon return). The standard deviation for salmon densities over the past ten years was on average about 50% of the mean for each lake. **d, e,** PCB concentrations in lake-surface sediment are shown as a function of salmon escapement density as the sum of 127 PCB congeners (**d**) and as the single PCB congener 101 (**e**). Resampling in 2002 (triangles) confirmed the 1995–1998 data (circles). Further methodological details are available from the authors.

Sockeye salmon spawn in freshwater after spending most of their life in the ocean, and die after spawning. They acquire more than 95% of their biomass in the north Pacific Ocean[2,3] and then return to their nursery lakes, which may be more than 1,000 km from the ocean[4]. The lipids accumulated by salmon to fuel this long upstream migration sequester PCB compounds: from a PCB concentration of less than 1 ng per litre in the ocean[5,6], sockeye salmon accumulate PCBs to a concentration of 2,500 ng per gram of lipid[7]. This means that one million adult salmon could transport more than 0.16 kg of PCBs to the spawning area, which is comparable to the amount of fugitive PCBs released annually from hazardous waste incinerators[8]. Fat-soluble PCBs are transported to freshwaters, where they enter aquatic and terrestrial foodwebs[7].

During 1995, 1997, 1998 and 2002, we collected sediment cores from eight lakes, providing a range of salmon-return densities from 0 to 40,000 spawners per km^2 (Fig. 1). Surface sediments (0–2 cm in thickness), representing the past 5.3 ± 3.5 years of accumulation on the basis of our calculated sedimentation rates, were extracted for PCB analysis. We also measured PCB concentrations in muscle tissue of sockeye salmon ($n = 5$) to identify the signature of the source (Fig. 2a).

Surface sediments of Frazer Lake (which has annual salmon returns of 11,700 fish per km^2) show patterns and concentrations of the most abundant PCBs that are similar to those carried by spawning sockeye returning to that lake (Fig. 2b). In particular, the PCB congeners designated as 101, 118, 153 and 138 + 163 were among the most abundant in both sockeye salmon and Frazer Lake sediments. More telling are the concentrations and patterns in Spiridon Lake, which receives no salmon spawners (Fig. 2c). Concentrations of PCBs in sediments from this lake are tenfold lower, and include a greater proportion of lighter congeners, which are effectively transported by air[9].

The PCB concentration and accumulation rate in sediment correlate strongly with the density of salmon returning ($r^2 > 0.9$; Fig. 2d, e). For example, lakes with annual salmon returns of fewer than 5,000 spawners per km^2 contained accumulated PCB concentrations of less than 2 ng g^{-1} (or less than 500 ng m^{-2} yr^{-1}) in their surface sediments, compared with about 20 ng g^{-1} (or about 3,700 ng m^{-2} yr^{-1}) for the lake with the highest density of returning salmon (40,000 spawners per km^2).

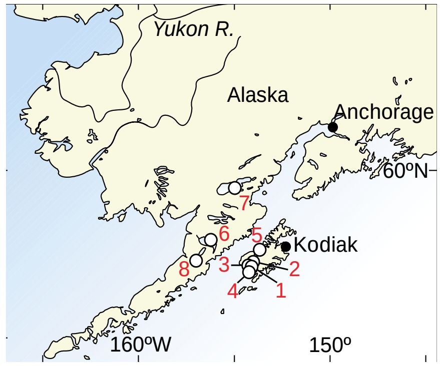

Figure 1 Location of the eight lakes where surface sediments and sockeye salmon were collected: 1, Frazer; 2, Karluk; 3, Red; 4, Olga; 5, Spiridon; 6, Becharof; 7, Iliamna; 8, Ugashik.

Lakes with the highest densities of spawning salmon would contribute 0.12 kg fish biomass per m^2, or 6,000 ng PCB m^{-2} yr^{-1}. Some PCB might be lost by degradation and recycling to the water column. These values may be compared with a background PCB accumulation of about 1,000 ng m^{-2} yr^{-1} for 11 lakes distributed from mid-latitudes up to the Arctic in Canada[9]. The transport of PCBs by 40,000 salmon per km^2 could therefore result in a roughly sixfold increase above atmospheric loading in a remote setting, a prediction that compares well with our observations (Fig. 2d, e).

The amount of PCBs transported by sockeye salmon to these lakes is greater than the traditional assignment from atmospheric pathways. Returning sockeye salmon act as 'biological pumps' by transporting contaminants upstream, where pollutants may affect their offspring and/or predators such as bears, eagles and humans. Whether these contaminants affect juvenile salmon survival is as yet unknown, but they are suspected of causing immunosuppression[10]. Ironically, the marine-nutrient pump, which historically has increased successful recruitment, may now pose a risk to some of these populations.

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Reading Guide: Krummel et al., 2003

As you read the paper, respond to the following questions:

1. What is the major finding of the paper?
2. What experiment did the researchers do (as described by the paper)?
3. What are the 2-3 major findings?
4. Describe what is shown in each section of figure 2.
5. Use the space below to write some figures from the paper you might want to use in a class discussion on this paper. Such as the concentration of PCB in the ocean.