MARINE ENVIRONMENT

Persistent pollutants, persistent threats

Polychlorinated biphenyls remain a major threat to marine apex predators

By Paul D. Jepson[1] and Robin J. Law[2]

Persistent organic pollutants (POPs) are chemical substances that persist in the environment, accumulate in the food web, and pose a risk of adverse effects in humans and wildlife (1). The potentially devastating effect of POPs on wildlife was first identified in the early 1960s (2). In the late 1960s, polychlorinated biphenyls (PCBs) were detected in high concentrations in wildlife in Sweden (3). After PCB use and manufacture were banned in 1979 (US), 1981 (UK), and 1987 (EU), levels started to decline slowly in all biota around the world (4–6). In 2004, the Stockholm Convention committed over 90 signatory countries to phase out or eliminate large stocks or other sources of POPs including PCBs (1). Yet, PCBs continue to threaten the survival of marine predators. Concerted efforts are thus still needed to mitigate PCB pollution.

Since legislative restrictions on different POPs have been introduced, tissue concentrations of POPs including PCBs and DDTs have declined, and many wildlife populations have recovered. For example, populations and reproductive indices of grey seal, otter and white-tailed sea eagle recovered in Sweden (Europe) during the 1980s as tissue PCB and DDT concentrations fell substantially from the 1960s and 1970s to 2010 (5, 7). Most avian marine apex predators, including herons, gulls, ospreys, petrels, and skua, are no longer listed as threatened on the IUCN Red List. Half of the remaining sea eagle species are still threatened with extinction due to a range of threats, potentially including PCBs (8). Among pinnipeds, only the Hawaiian and Mediterranean monk seals and several species in restricted habitats in close proximity to humans like Saimaa ringed seals, Ungava harbor seals and Caspian seals are still threatened with extinction (8).

Banned organochlorine pesticides like DDT and dieldrin have also declined significantly in marine apex predators in Europe. However, PCBs have stopped declining and still persist at excessively high concentrations in some cetaceans, including killer whales (orcas) and bottlenose dolphins, in the Northeast Atlantic (6, 9) and many cetacean species in the Mediterranean Sea (6, 10). High PCB concentrations in European cetaceans from 1990-2012 were widely associated with long-term population declines and low or zero rates of reproduction, consistent with severe PCB-induced population level effects (6). Further research is needed to assess the full impact of PCB exposure on cetaceans in Europe, particularly in Iberian (NE Atlantic), Mediterranean, and Black Sea countries that have the highest exposures.

So are high PCB concentrations just a European problem? Not necessarily. The high trophic level and longevity of most marine apex predators globally mean that accumulation of PCBs and other POPs is an inevitable consequence (see the figure) (4). The relatively long lactation period in cetaceans also enables considerable transmission of PCBs from mother to calf. The killer whale remains the most highly PCB-contaminated species on Earth, with very high concentrations found in individual killer whales throughout their range (4, 6, 11). After humans, killer whales may once have been the most widely distributed mammalian species on Earth, with a historic distribution of "pole to pole and everywhere in between" (8). Yet, in recent years, high killer whale numbers have only been found near the less polluted Arctic and Antarctic regions (4, 8, 11, 12).

Other longlived marine apex predator species that may still be at risk from PCB pollution include false killer whales and coastal bottlenose dolphins, ringed seals in the Baltic Sea, all marine mammal species in the Mediterranean and Black Seas, beluga in St Lawrence River, Canada, polar bears in the Arctic, and some sea eagle species in the Northern hemisphere (8). In Southeast Asia, China's recent industrialization and agricultural expansion is thought to have increased concentrations of PCBs and other POPs and may have played a role in the probable extinction of the Yangtze River dolphin and in threatening the Critically Endangered Yangtze finless porpoise (8). PCBs and DDT may also play a role in ongoing population declines of Indo-Pacific finless porpoises, Indo-Pacific humpback dolphins, Ganges River dolphins in India/Bangladesh, and Indus River dolphins in Pakistan (8).

Although experiments have shown that PCBs have toxic effects in fish, empirical evidence of PCB toxicity in wild fish is lacking (13). Fish also lack maternal transfer of POPs through fat-rich milk (8, 13). Nonetheless, some apex predator sharks are relatively long-lived species that feed at a similar tropic level to killer whales but have not been rigorously assessed for PCB (or other POP) exposures (8). Further research is needed on PCB exposures in apex predator sharks like the great white shark to assess if PCB exposures are likely to have significant population-level effects. There has been a clear lack of sightings, bycatch, or strandings of great white sharks in the past 20 to 30 years, particularly in the highly PCB-contaminated NE Atlantic and Mediterranean Sea regions (8). Other apex predator sharks potentially impacted by PCBs include bull sharks, great hammerheads, short-fin mako and tiger sharks (8).

POPs including PCBs are not static. They transfer over long distances from industrialized to non-industrialized regions, including the Arctic, mainly through cycles of atmospheric volatilization and condensation called global distillation (14), with killer whales and polar bears accumulating the highest Arctic exposures (11). In East Greenland polar bears, blubber PCBs increased unexpectedly between 2010 and 2013, resulting in PCB concentrations that were as high in 2013 as in 1983 (15). Whatever the cause, the recent increase in PCBs and other POPs in polar bear blubber is a worrying trend if it were to continue, emphasizing the importance of continued monitoring of legacy POPs in Arctic biota.

Future research should investigate pathways of PCB contamination of the marine environment. What sources are PCB inputs from land and which are recycled in the marine environment? Future monitoring should also assess PCB levels in marine sediments, discharges, and freshwater outflow. At a European policy level, PCB exposures in comparison to established marine

1 Institute of Zoology, Zoological Society of London, Regent's Park, London NW1 4RY, UK. Email: paul.jepson@ioz.ac.uk
2 Cefas (Lowestoft Laboratory), Pakefield Road, Lowestoft, Suffolk, NR33 0HT, UK; Institute of Zoology, Zoological Society of London, Regent's Park, London NW1 4RY, UK

Fig 1. There is an urgent need to review current methods of PCB mitigation in the marine environment—both in Europe and elsewhere.

mammal PCB toxicity thresholds should be used to assess whether marine mammal populations reach "Favourable Conservation Status" under *EC Habitats Directives*. PCBs should also be included as a cetacean "indicator" for populations under the EU's *Marine Strategy Framework Directive* (under Descriptor 8).

Perhaps most importantly, there is an urgent need to review current methods of PCB mitigation in the marine environment—both in Europe and elsewhere. This should include full compliance with the Stockholm Convention to significantly reduce PCB contamination of the marine and terrestrial environment by 2028. This is the critical issue for future conservation success. PCB mitigation measures include the safe disposal or destruction of large stocks of PCBs and PCB-containing equipment, limiting the dredging of PCB-laden rivers and estuaries, reducing PCB leakage from old landfills *(6)*, limiting PCB mobilization in marine sediments, and regulating demolition of PCB-containing precast buildings such as tower blocks built in the 1950s to 1980s *(6)*.

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