7 How are seals, as top predators, impacted by toxic contaminants in Casco Bay and the Gulf of Maine?

Harbor seal (Phoca vitulina concolor), *the most abundant marine mammal in the Gulf of Maine and mid-Atlantic region.*

Peter Ralston

Introduction

Harbor seals *(Phoca vitulina)* are widely distributed in the temperate near-shore waters of the northern hemisphere and are important indicators of coastal contamination because they occupy a high trophic level, are long-lived (35-40 years), and accumulate high concentrations of persistent organic pollutants (POPs) and mercury through the food chain. Lipophilic (fat soluble) POPs including PCBs, dioxins, and DDT build up in fatty tissues such as blubber and have been shown to cause immune- and endocrine-disrupting effects in seals and other marine wildlife (De Swart *et al.* 1994, De Guise *et al.* 2001). Evidence amassed over three decades suggests that these compounds have caused reproductive impairment, hormone abnormalities, and population declines in seals inhabiting industrialized regions of Europe, North America, and Asia. It is widely believed that immunotoxic chemicals such as PCBs and dioxins have played a role in the recurring distemper virus outbreaks and mass mortalities reported among seals since the 1980s, by altering the animals' normal immune resistance to disease (Dietz *et al*. 1989, Van Loveren *et al.* 2000, Harding *et al.* 2002). Unlike POPs, mercury preferentially accumulates in muscle and liver tissue, and at high levels, may place young seals at risk for liver damage and immune and neurotoxic effects following exposure *in utero* and through nursing (AMAP 1998, Shaw 2002).

Seals as Sentinels

Dr. Susan Shaw and co-workers at the Marine Environmental Research Institute (MERI), Center for Marine Studies, in Blue Hill, Maine, have been studying the impacts of environmental pollutants on seals in the Gulf of Maine and along the mid-Atlantic coast since 2001 as part of the *Seals as Sentinels* project. This project has generated the first extensive data reported in 25 years on levels and effects of toxic contaminants in northwestern Atlantic harbor seals *(Phoca vitulina concolor)*.

At present, there are an estimated 99,340 harbor seals inhabiting the northwestern Atlantic coast extending from the Gulf of Maine southward to the coast of New Jersey (Gilbert *et al*. 2005). Considered relatively non-migratory, harbor seals feed on a variety of fish including hake, herring, alewife, haddock, redfish, and winter flounder in coastal and estuarine environments and are exposed to contaminated habitats and prey across their range. In the southerly portion of the range, coastal urban development has resulted in some of the densest concentrations of human populations in North America, and environmental pollution has been a concern at least since the 1950s. Similar to European seals, the harbor seal population has experienced a series of mass mortalities since the 1980s (Geraci *et al*. 1982, Duignan *et al.* 1995). The most recent event occurred in 2004 among harbor seals in southern Maine where approximately 300 animals, primarily pups, were found dead on beaches in and around Saco Bay. The possible role of immunotoxic chemicals (*e.g.,* PCBs, dioxins) in these outbreaks is not clear.

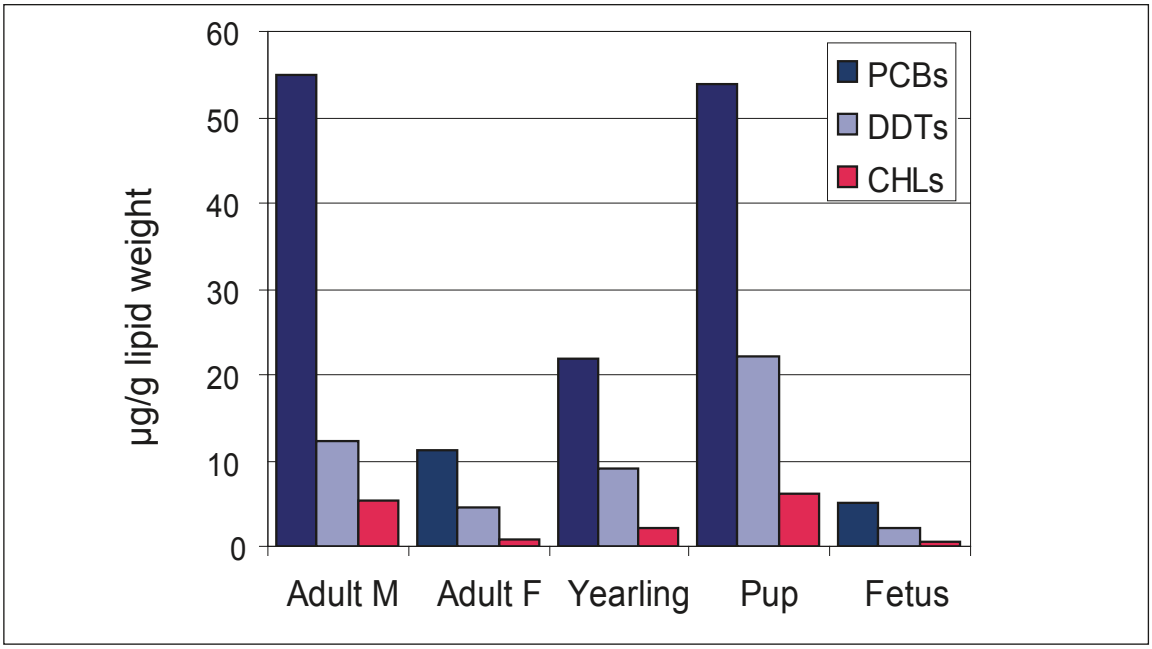

Figure 7-1: *Major POPS (PCBs, DDT, CHLs) (µg/g, lipid wt) in harbor seal blubber by age class*

Contaminant Levels in Seals

A total of 34 stranded harbor seals *(Phoca vitulina concolor)* and 3 gray seals *(Halichoerus gryphus)*, primarily pups and yearlings, were collected by MERI at locations along the coast from Mount Desert Island, Maine to Long Island, New York between 1991 and 2001-2002. Seal blubber, liver, and kidney samples were analyzed for a wide range of organic contaminants and metals. PCBs, DDT, and chlordane-related compounds (CHLs), chemicals which were banned in the U.S. in the late 1970s, were the predominant organic compounds found in harbor seal tissues, reflecting the extreme persistence of these substances in the marine food chain. The highest concentrations were found in the adult male harbor seals and pups, with mean PCBs of 55 and 54 µg/g, lipid weight (lw), respectively, followed by the yearlings, adult females, and fetuses (see Figure 7-1). Gray seals tend to have lower levels of POPs than harbor seals (PCBs 18-27 µg/g, lw) which is likely due to their pelagic migratory patterns and feeding habits.

The accumulation pattern in the harbor seals reflects an age-dependent increase in adult males, whereas females lower their levels by transferring a proportion of their body burdens to pups (Addison and Brodie 1977). In phocid (true or earless) seals, lipophilic POPs are transferred from maternal lipid stores to some extent during gestation but particularly during lactation, so that the body burdens of PCBs and DDTs are often higher in pups at weaning than in their mothers. Although MERI did not examine mother-pup pairs, levels in pups were five times higher than those in adult females. Compared with the fetuses, pups had PCB burdens an order of magnitude higher, reflecting the greater importance of breast milk as an exposure route.


Cynthia Stroud

Harbor seal mother making first contact with newborn pup, mid-coast Maine.

Lactational transfer may also pose an increased toxic risk to pups compared with that of adult exposure through feeding. As the lactating seal does not feed, the bulk of her circulatory lipids are derived from the blubber layer rather than from lipid sources in her diet (Addison and Brodie 1987). During the fasting period, as the mother loses weight, the nursing pup may be exposed to the more toxic PCBs mobilized from the mother's fat stores, as compared with lower chlorinated, relatively less toxic PCBs which, if the mother were feeding, would be obtained from fish.

Persistent Organic Pollutants

Figure 7-2a shows mean concentrations of PCBs and DDTs in blubber of harbor seals (all ages) from different regions of the northwestern Atlantic. The animals from southern Maine were harbor seal pups and yearlings collected in Cape Elizabeth (Casco Bay), Saco, Wells and Kennebunk. Across the range, PCB concentrations in these seals exceed the estimated threshold value of ~17µg PCB/g, lw (ppm) in blubber for adverse effects including effects on immune and endocrine functions in the species (Kannan *et al*. 2000). Region-wide, the highest concentrations were found in the seals from Narragansett Bay/Long Island Sound, although this distribution undoubtedly reflects the large effect of age class on body burdens.

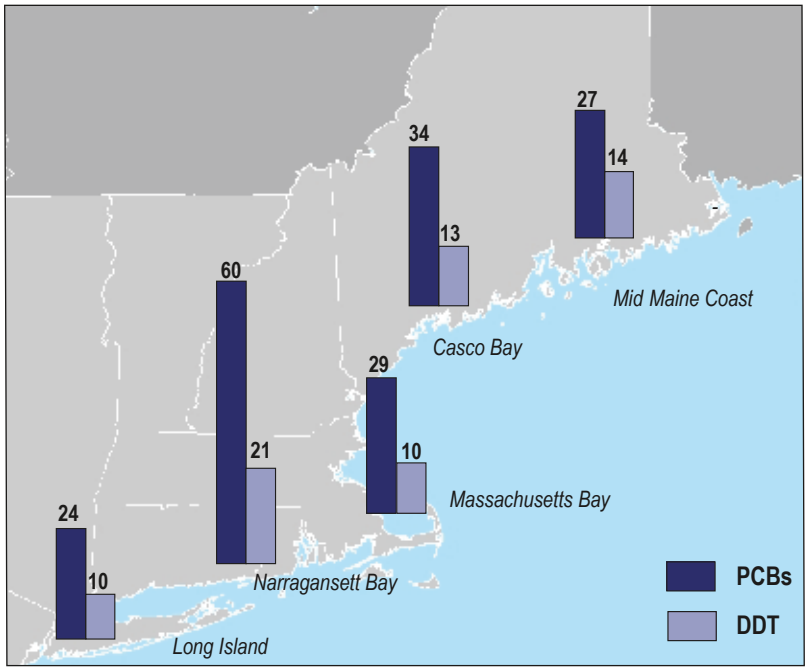

Figure 7-2a: *PCB and DDT concentrations (µg/g, lipid wt) in blubber of NW Atlantic harbor seals*

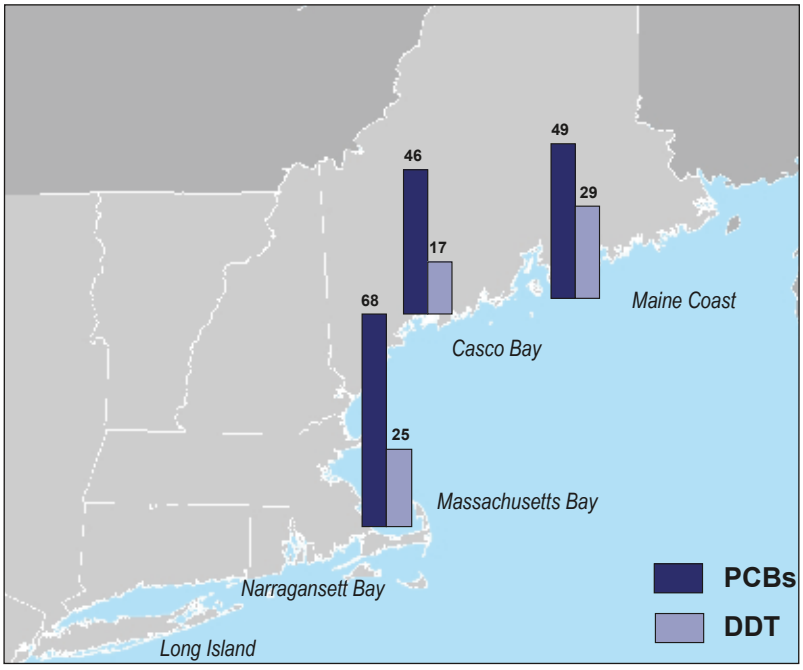

Figure 7-2b: *PCB and DDT concentrations (µg/g, lipid wt) in blubber of harbor seal pups*

Figure 7-2b shows the higher PCB and DDT levels in harbor seal pups from three regions—mid-coast Maine, southern Maine, and Massachusetts Bay. The highest PCB concentrations (mean 67.5 µg/g, lw) were found in pups from Massachusetts Bay, whereas levels were slightly lower (mean 46 and 49 µg/g, lw) in pups from Casco Bay/southern Maine and eastern Maine, respectively. In the four pups from Casco Bay/southern Maine, PCB concentrations were highly variable, ranging from 11 to 110 µg/g, lw.

As is clear from Figures 7-2a and 7-2b, harbor seals from the northwestern Atlantic have elevated tissue burdens of toxic organic contaminants that place them at risk for adverse health effects (Shaw *et al*. 2005). This is especially true for the seal pups, which may be vulnerable to health impacts when concentrations are an order of magnitude lower (Shaw *et al*. 1999). In fact, the levels of PCBs found in these pups were 18 times higher than the concentrations (~3 µg/g, lw) associated with altered immune and endocrine function biomarkers (indicators) in stranded, rehabilitated harbor seal pups from the California coast (Shaw *et al*. 1999).

One of these markers is the lymphocyte proliferation assay. Lymphocytes are a type of white blood cell—T and B cells—involved in immune response to foreign substances. The assay measures the ability of the circulating lymphocytes to respond to foreign substances *in vitro* (*i.e,* in cell culture). This assay is an important indicator of contaminant-induced alterations in nonspecific immune function. A lowered proliferative response is indicative of an animal's reduced ability to resist infection by viruses and other pathogens, while an enhanced response may reflect autoimmune disease or cancer. Recently, Levin *et al.* (2005) reported enhanced lymphocyte proliferative responses in free-ranging harbor seals from British

Columbia with mean PCB concentrations in blubber as low as 2.5 g/g, lw. This is consistent with earlier findings by Shaw *et al.* (2003) of PCB-dioxin-related immune enhancement in free-ranging adult harbor seals from the Gulf of Maine.

Thyroid hormone levels and retinols (vitamin A) in plasma are important biomarkers of contaminant-induced endocrine disruption. Adequate levels of thyroid hormones and vitamin A are critical to normal growth and development, including development of the immune system, the reproductive system, and the brain. Exposure to PCBs and related POPs can reduce hormone and retinol levels in animals and humans by various mechanisms such as competitive binding to receptors on carrier proteins.

MERI

Week-old harbor seal pup rescued at Blue Hill Falls, mid-coast Maine.

Mercury and Other Metals

Concentrations of mercury found in liver of the adult harbor seals are shown in Figure 7-3 (Shaw, unpublished data). Seal liver and kidney samples were also tested for arsenic, cadmium, chromium, lead, silver, selenium, copper and zinc, but these metals were not detected at levels of concern. While hepatic (liver) mercury levels in the younger seals were relatively low, concentrations in adult seals (mean 64.8 µg/g, wet weight) exceed the threshold level of 60 µg/g, ww, for liver damage in mammals (AMAP 1998). Elevated mercury levels are known to be common in livers of marine mammals, and seals have evolved biochemical mechanisms involving selenium to detoxify (demethylate) and store mercury in the form of less toxic (divalent) mercury-selenide complexes (Wagemann *et al.* 2000). However, the ability to detoxify and store mercury may not be present in newborn and young seals following exposure to the mother's burden *in utero* and while nursing, thus, these young and developing seals may be at risk for mercury-related neurotoxicity and other effects.

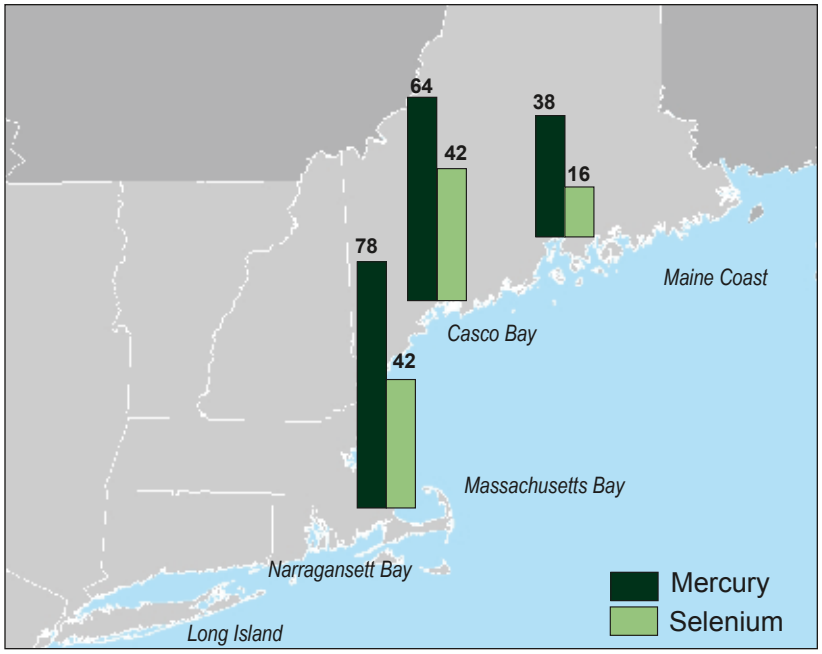

Figure 7-3: *Mercury and Selenium concentrations (µg/g, wet wt) in liver of adult harbor seals*

Temporal Trends

DDT and, to a lesser extent, PCB burdens in northwestern Atlantic harbor seals have declined from the very high levels reported in the 1970s (Gaskin *et al.* 1973, Shaw *et al.* 2005). Between 1971 and 2001, DDT levels in harbor seal blubber (all ages) decreased by ~82% while PCB levels decreased by ~66%. In the adult males and pups, a smaller decline of ~45% in PCB levels was observed over this thirty year period. This is consistent with trends in other industrialized areas where a more rapid decline of DDT was observed after these compounds were banned (Kennish 1992), while PCBs are still being released from stockpiled residues (Tanabe 1988). In seals from the highly polluted Baltic Sea, DDT levels have decreased by 72-85% since the 1970s, while PCB levels showed only

a minor decrease of 25% in females and no decrease in males (Nyman *et al.* 2002). A similar trend was observed in most Arctic marine mammal populations (AMAP 2000).

To examine changes over the past decade, MERI compared contaminant levels in blubber of yearling harbor seals collected in 1991 and 2001-2002 (Shaw *et al.* 2005). Due to the small sample size (n=3) of the 1991 samples, no conclusions could be drawn, but the data show only small decreases in absolute concentrations of the major contaminant groups, PCBs, DDTs, and CHLs, in seal blubber over this ten-year period, suggesting an equilibrium in environmental cycling of these POPs in the northwestern Atlantic.

Global Comparisons

The levels of PCBs and DDTs found in northwestern Atlantic harbor seals are at the upper middle of the contamination spectrum on a global scale (see Figure 7-4). PCB concentrations in the adult males and pups (55 and 54 µg/g, lw) are approaching the high levels reported in stranded seals from the polluted Baltic Sea, Wadden Sea, western Mediterranean, and Caspian Sea (Luckas *et al*. 1990, Borrell *et al*. 1997, Kajiwara *et al*. 2002), and are slightly higher than levels reported in blubber of harbor seals from the the coasts of Denmark (Storr-Hansen and Spiid 1993), eastern England (Law *et al.* 1989) and northern Ireland found during the 1988 morbillivirus epizootic (an epidemic among animals) (Mitchell and Kennedy 1992). Compared with Pacific coast seals, PCB concentrations in the harbor seal pups, including the four pups from Casco Bay/southern Maine, are three-fold higher than those reported in stranded harbor seal pups from southern Puget Sound, Washington, an area considered relatively polluted (Shaw 1998, Hong *et al.* 1996), and an order of magnitude higher than the levels reported in stranded harbor seal pups from the California coast (Shaw *et al.* 1999).

DDT concentrations in harbor seal pups sampled by MERI were similar to those of Baltic seals and western Mediterranean monk seals *(Monachus monachus)* (Luckas *et al.* 1990; Borrell *et al.* 1997), reflecting the widespread production and application of DDT in these areas. However, DDT levels in the pups were an order of magnitude lower than the extremely high concentrations found in Caspian seals *(Phoca caspica)* (Kajiwara *et al*. 2002), reflecting recent uses of this pesticide in the former USSR (Federov 1999).

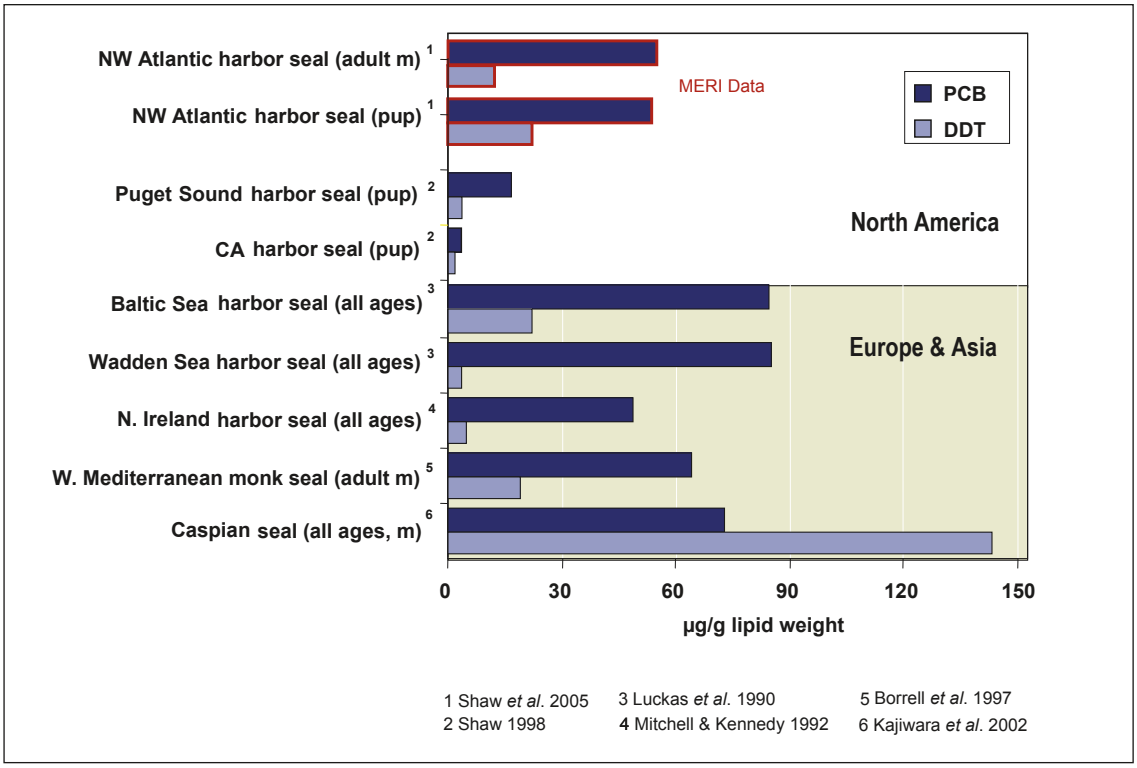

Figure 7-4: *PCB and DDT concentrations (µg/g, lipid wt) in pinnipeds from different regions*

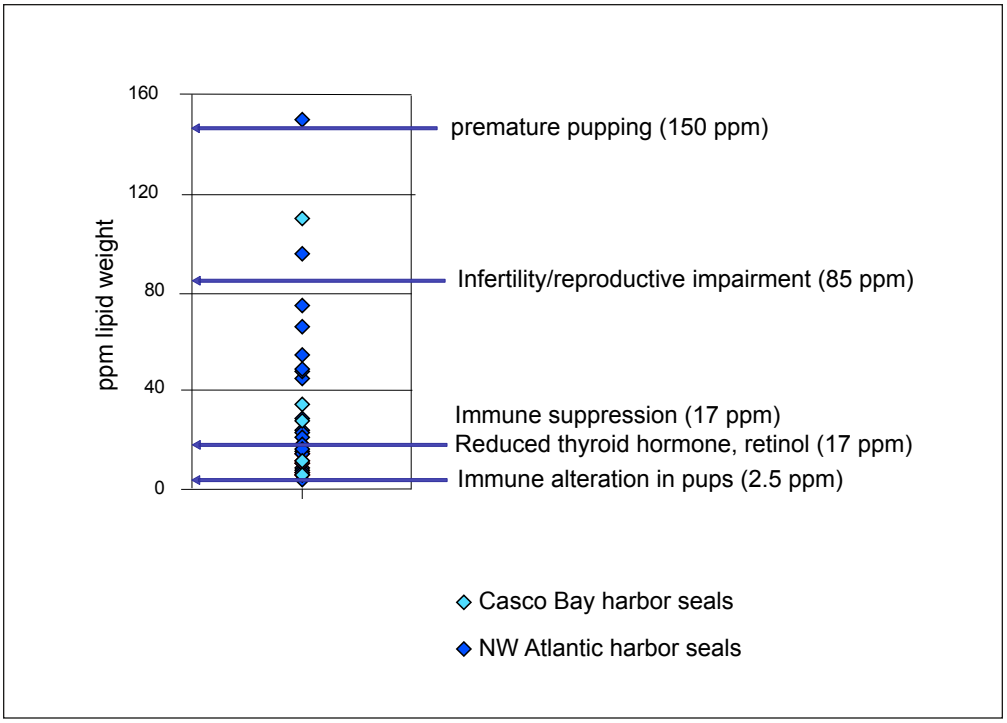

Figure 7-5: *PCB concentrations (ppm, lipid wt) in NW Atlantic harbor seals and estimated threshold levels of effects in pinnipeds*

Mercury levels in liver of the adult harbor seals (males and females) were similar to those reported in adult seals from other polluted areas including grey and ringed seals (*Phoca hispida*) from the Baltic and harp seals (*Phagophilus groenlandicus*) from the Greenland Sea (Nyman *et al.* 2002; Fant *et al.* 2001; Brunborg *et al.* 2005). Their mercury levels were two-fold higher than the levels found in Greenland hooded seals *(Crystophora cristata)* (Brunborg *et al.* 2005) and an order of magnitude higher that those of ringed seals from Svalbard, Norway, (Fant *et al.* 2001). Much higher concentrations (mean 134-4250 µg/g, ww) were reported in livers of dolphins from the Mediterranean Sea (Frodello *et al*. 2000).

Cynthia Stroud

Harbor seal with three-week old nursing pup

Toxic Impacts: Conclusions

As shown in Figure 7-5, PCB burdens in harbor seals from the northwestern Atlantic exceed the estimated threshold level of 17µg PCB/g, lw in blubber for adverse effects on immune function (Kannan *et al*. 2000), and fall within the estimated threshold level of 25-77 µg PCB/g, lw for reproductive effects in marine mammals (AMAP, 2000). PCB burdens in the pups, including those from Casco Bay/southern Maine, are an order of magnitude higher than the concentrations associated with reduced immune responses and hormone levels in stranded harbor seal pups from California (Shaw *et al.* 1999) and with altered immune responses in free-ranging pups from British Columbia (Levin *et al.* 2005). Moreover, in a previous study MERI reported significant correlations between dioxin-like compounds in plasma and altered immune responses in free-ranging adult harbor seals from the Gulf of Maine (Shaw *et al.* 2003).

Mercury concentrations found in liver of adult harbor seals exceed the estimated threshold level of 60 µg/g lw for liver damage in mammals (AMAP 1998), suggesting that harbor seal pups may be exposed to harmful levels of mercury during gestation and lactation. These observations, together with reports of at least two, and possibly three large-scale outbreaks of viral disease among these seals since the 1980s, suggest that the population is currently at risk for contaminant-related health effects. Although the present study was limited by a small sample size distributed over a large geographic area, the toxic impacts of the current POP and mercury body burdens in these seals would be expected to be considerable, particularly among the pups, leading to developmental deficits and compromised immune resilience, which in turn, may place them at risk for future disease outbreaks.

The data generated by the *Seals As Sentinels* project are the first extensive, region-wide data in 25 years on levels and effects of toxic contaminants in harbor seals from the northwestern Atlantic. While levels of the legacy POPs (PCBs, DDT) are slowly declining in marine biota, blubber concentrations in northwestern Atlantic harbor seals declined only slightly over the ten-year period 1991-2001, suggesting that these compounds are at equilibrium in the marine ecosystem. Moreover, thousands of new chemicals are being released every year, and we have recently documented the presence of the widely used flame retardants polybrominated diphenyl ethers (PBDEs), perfluorooctanesulfonate (PFOS), and related perfluorinated chemicals at relatively high concentrations in harbor seal tissues (Shaw *et al*. 2006a,b). These compounds of emerging concern are now being studied for their capacity to biomagnify and provoke effects in marine mammals and humans.

In view of the past vulnerability of northwestern Atlantic harbor seals to viral outbreaks, there is a clear need for continued research on larger sample sizes to ascertain body burdens and toxic impacts of the complex mixtures of contaminants to which these seals are exposed.

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