The Public Health and Economic Impacts of Persistent, Bioaccumulative, and Toxic (PBT) Contaminants on U.S. Fisheries

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Abstract
Widely dispersed information from the public health, economic, and fisheries management literature is synthesized to examine the impacts of PBT contamination, including current and potential impacts on public health and the ongoing economic impacts this contamination has on the U.S. fishing industry.

Key Words: economic impacts, public health, fisheries, contamination

INTRODUCTION

High in protein, low in saturated fat, and containing Omega-3 fatty acids, fish and shellfish are important components of a healthy human diet (U.S. EPA, 2004b). In particular, evidence suggests that Omega-3 fatty acids protect against coronary heart disease and stroke, and also aid in the neurological development of fetuses (McMichael and Butler, 2005). These benefits, however, need to be weighed against the potential health risks associated with the consumption of fish and shellfish, including contamination from heavy metals like mercury, organic pollutants like polychlorinated biphenyls (PCBs) and dioxins, and pesticides such as chlordane and dichlorodiphenyl-trichloroethane (DDT). These contaminants have been labeled by the U.S. Environmental Protection Agency (EPA) as persistent, bioaccumulative, and toxic (PBT). PBT substances can build up in the food chain to levels that are harmful to humans and ecosystems (U.S. EPA, 2004a), and thus represent a growing threat not only to public health, but also to the economic and ecological viability of many fisheries.

This paper highlights the public health and economic implications of contaminated U.S. fisheries, with a focus on several primary PBT contaminants. A brief history of PBT contamination problems in fisheries will be presented, including a review of the public health impacts and the related economic costs. Current monitoring, notification, and management strategies for dealing with PBT contamination will be described, along with an examination of the efficacy of these actions and their implied economic cost to the fishing industry. The paper will conclude with a discussion of the future of commercial fisheries in the presence of PBT contamination, including some suggestions for alternative strategies that have the potential for reducing public exposure to PBT contaminants and improving the management of wild fish stocks.

PBT CONTAMINATION IN FISHERIES

The contamination of wild fish stocks, and the ensuing public health problems, is a world-wide phenomenon that began as far back as 800 B.C. (Tyson et al., 2004). In modern times, the first widely publicized case involved the PBT methylmercury and the associated poisonings that resulted from industrial discharges into southern Japan's Minamata Bay. Contamination of the bay itself began in the 1930s, with the first instances of human poisoning not reported until the 1950s with the birth of deformed babies to mothers who had experienced a lifetime of exposure to contaminated seafood (Powell, 1991). As of early 2005, Japan had officially recognized 2,955 poisoning victims, of which 1,784 had already died (although not necessarily directly due to methylmercury poisoning; Associated Press, 2005). An additional 15,000 individuals have registered as victims of the contamination, highlighting the long-term nature of public health and economic impacts when contamination problems do not manifest themselves immediately after exposure (Grimel, 2001).

The presence of harmful PBT contaminants in U.S fisheries is a growing environmental and public health concern. Although severe Minamata-type contamination incidents have not arisen in the U.S., the number of potential problems is large and expands as scientists come to better understand the biological and ecological consequences of exposure to both natural and manufactured chemicals. PBT contamination is a direct result of the industrialization of society, and PBT contaminants have been discharged into U.S. waters from a variety of industrial sources for decades. These contaminants accumulate in the tissues of fish and other aquatic organisms, with top predators in the food chain often having PBT concentrations a million times higher than that found in the water (U.S. EPA, 2005b).

The geographical extent of PBT contamination in U.S. fisheries is best illustrated by examining current fish consumption advisories. These advisories inform the public that unacceptable concentrations of chemical contaminants have been found in local fish, and may include recommendations to limit or avoid eating certain fish or fish caught from a specific waterbody type (U.S. EPA, 2005b). Each year the EPA compiles the National Listing of Advisories, which serves to catalog the fish advisory information provided to the EPA by states, tribes, territories, and local governments. The most recent listing was published in September 2005 based on 2004 data, and it included 3,221 advisories covering approximately 14 million lake acres, or 35% of the nation's total lake acreage (U.S. EPA, 2005b). In addition, the listing identified nearly 840 thousand river miles as being under advisories, representing

24% of the nation’s total. These figures do not include the Great Lakes and their connecting waters, all of which were under some type of advisory in 2004. With respect to marine systems, almost 65% of the U.S. coastline is currently under at least one advisory, with Alabama, Connecticut, Florida, Georgia, Hawaii, Louisiana, Maine, Massachusetts, Mississippi, New Hampshire, New Jersey, New York, North Carolina, Rhode Island, South Carolina, and Texas issuing advisories for all of their coastal waters. In aggregate, the entire Gulf of Mexico coast and over 90% of the U.S. Atlantic coast are under advisories for at least one species of fish, with the specific species generally varying by state. Among the Gulf Coast states (with the exception of Florida), however, statewide coastal advisories are in effect only for King Mackerel (*Scomberomorus cavalla*) because of mercury contamination (U.S. EPA, 2005b). The Pacific coast has several local areas under advisory, but no statewide advisories have been issued. Hawaii also has a statewide advisory in affect for the PBT contaminant mercury in several fish species.

Under programs currently active, states, tribes, territories, and local governments issue advisories for 36 different PBT contaminants, with almost 98% of the advisories involving only five PBT contaminants: mercury, chlordane, dioxin, PCBs and DDT. These five contaminants have received increased public attention because they pose considerable threats to public health. Specifically, these five contaminants have been linked to adverse effects on the human nervous and reproductive systems, and they are known to cause problems in the form of irregular fetal development, human cancer, and other genetic abnormalities (U.S. EPA, 2004a). In addition to the public health impacts, these contaminants also can significantly affect the economic viability of capture fisheries when harvesting prohibitions are instituted for contaminated areas. Given their importance to PBT contamination issues, the remainder of this section will focus solely on these five contaminants.

Mercury is a persistent metal that is distributed throughout the environment and originates from both natural sources and human activities. Its organic form, methylmercury, accumulates in the fatty tissues of fish and, once ingested, can cause irreversible human health effects (U.S. EPA, 2001). The human nervous system is very sensitive to all forms of mercury, and exposure to high levels of methylmercury can permanently damage the brain, kidneys, and developing fetus (ASTDR, 1999).

Dietary intake is the dominant source of mercury exposure for the general population, and over 76% of the 2004 National Listing of Fish Advisories focused on mercury contamination, including freshwater incidents in the states of Connecticut, Florida, Illinois, Indiana, Kentucky, Maine, Maryland, Massachusetts, Michigan, Minnesota, Missouri, Montana, New Hampshire, New Jersey, North Dakota, Ohio, Pennsylvania, Rhode Island, Vermont, Washington, and Wisconsin (U.S. EPA, 2005b). In addition, the coastal states of Alabama, Florida, Georgia, Louisiana, Maine, Massachusetts, Mississippi, New Hampshire, North Carolina, Rhode Island, South Carolina, and Texas issued statewide advisories for mercury in their coastal marine systems, while Hawaii instituted a statewide advisory for mercury in marine fish.[1] Humans with heavy dietary reliance on seafood have the highest concentrations of methylmercury in their tissues; individuals classified as poisoned in the Minamata case had mercury concentrations as high as 50-100 parts per million (ppm) compared to less than 1 ppm in those who consume only 10-20 grams of fish per day (Dewailly and Knap, 2006).

In contrast to the naturally occurring element mercury, PCBs are a group of synthetic organic chemicals that also can cause a number of harmful effects in humans. Once widely used as coolants and lubricants in transformers, capacitors, and other electrical equipment, PCB production ceased in the U.S. in 1977. Nonetheless, PCBs are still found in the environment and have been associated with acne-like skin conditions in adults and neurobehavioral and immunological changes in children (ATSDR, 2000). Studies have implicated PCBs in a variety of adverse human health effects on reproduction, neurobehavioral development, liver function, birth weight, and immune response (Dewailly and Knap, 2006). The major source of human PCB exposure is through the consumption of contaminated seafood, and the National Listing of Fish Advisories reported that there were over 4.6 million lake acres and more than 110 thousand river miles under PCB advisories in 2004 (U.S. EPA, 2005b). Indiana, Minnesota,

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[1] Two tribes have also issued mercury advisories in 2004. The Micmac tribe of Maine had two tribal statewide advisories in effect for mercury in freshwater and marine fish including lobster, while the Cheyenne River Sioux Tribe had one tribal statewide advisory for mercury in rivers, lakes, and stock ponds.

New York, and The District of Columbia issued statewide freshwater advisories for PCBs, while Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, and Rhode Island issued PCB advisories for all of their coastal marine waters.

Chlordane, another synthetic chemical and widely used as a pesticide in the U.S. prior to 1983, can cause damage to the nervous system and liver in humans at high levels of exposure.[2] Exposure occurs primarily from eating contaminated foods, such as root crops, meats, fish, and shellfish, or from touching contaminated soil (ATSDR, 1994). The National Listing of Fish Advisories identified chlordane advisories for nearly 850 thousand lake acres and 54 thousand river miles in 2004, even though many advisories have been rescinded in recent years because the chemical is no longer used and continues to degrade in the environment (U.S. EPA, 2005b).

Dioxins, chemicals that are formed during combustion processes such as commercial or municipal waste incineration and from burning fuels such as oil, wood, and coal, have been at the root of some of the more highly publicized environmental and human contamination incidents from PBTs, ranging from the use of dioxin-containing defoliants during the Vietnam war to the inadvertent contamination of groundwater at New York's Love Canal. High levels of exposure to dioxins can result in a number of adverse health effects, including chloracne, skin rashes, skin discoloration, excessive body hair, and liver damage. Although most dioxin exposure occurs through dietary intake of animal fats, it is thought that the majority of the U.S. population has a relatively low-level of exposure to dioxins (CFSAN). Consequently, the geographic extent of dioxin advisories is less widespread when compared to that of the other four major contaminants, accounting for only approximately 23 thousand lake acres and slightly more than 2,300 river miles under advisory in 2004 (U.S. EPA, 2005b).

The last of the five primary PBTs, DDT is a pesticide once widely used to control insects that damaged crops and carried diseases such as malaria. The use of DDT in the U.S was banned in 1972 because of damage to wildlife, but DDT is still used in some countries. Exposure to DDT, and the

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[2] The U.S. EPA banned all uses of chlordane in 1988 over concerns of harm to the environment and human health.

chemicals it breaks down to in the environment (DDE and DDD), occurs mostly from eating meat, fish, and poultry that contain small amounts of these compounds. Exposure to high levels of DDT can affect the nervous system and cause excitability, tremors and seizures. In women, DDE can lead to a reduction in the duration of lactation and an increased chance of premature birth (ATSDR, 2002). Although the use of DDT has been banned in the U.S. since 1972, the 2005 National Listing of Fish Advisories reported advisories for DDT, DDE, and DDD that covered more than 840 thousand lake acres and 69 thousand river miles (U.S. EPA, 2005b). California had the greatest number of DDT advisories in effect, followed by Maine and Massachusetts.

Economic Consequences of PBT Contamination

The persistent, toxic nature of PBT contaminants suggests that they have the potential for significant economic implications over long periods of time. PBT contamination leads to public health costs, losses to commercial fisheries, reduced recreation and tourism, and monitoring and management costs. PBT contaminants can pose significant threats to public health and the health effects of PBT exposure are often irreversible. Even so, little research exists concerning the linkage between PBT concentration and economic losses from poor health, primarily because most scientific efforts have examined linkages between exposure and health, not health and the ensuing impacts such as lost work days and reduced productivity (Brook, 2002).

One study that did attempt to examine the linkage between health and the economic impacts of PBT contamination was a 1996 investigation of children born to women who had eaten Lake Michigan fish contaminated with PCBs. The study demonstrated that prenatal exposure to PCBs led to lower full-scale and verbal IQ scores, with the strongest effects related to memory and attention (Jacobson and Jacobson, 1996). The most highly exposed children were three times more likely to have low average IQ scores and twice more likely to be at least two years behind in reading comprehension. If the exposure of women to PCB contamination occurs on a wide enough scale, the magnitude of the economic costs to society would be tremendous given that a single point decrease in the average IQ for the population can potentially lead to lost earnings in excess of $31 billion annually (Muir and Zegrac, 2001).[3] In a separate study that examined the relationship between child development and methylmercury exposure, researchers found that 316,000 to 637,233 children each year have cord blood mercury levels higher than levels that have been associated with loss of intelligence, measured in IQ points (Trasande et al., 2005). This potential loss of intelligence may cause reduced economic productivity over the lifetime of these children, a cost that was estimated to be $8.7 billion annually (Trasande et al., 2005). Although this latter study did not consider specific sources of exposure, the primary means by which humans are exposed to methylmercury is through fish consumption.

Several studies examining the economic effects of exposure to PBTs contaminating the New York Bight-Hudson River Estuary were summarized by Ofiara and Seneca (2001). Estimates of the excess cancer risk, and the associated economic losses, from the consumption of PBT-contaminated seafood were examined for a variety of species, contaminants, contamination levels, and rates of seafood consumption. Excess risk and the resulting economic impacts were highest for PCB-contaminated white catfish and white perch, each ranging from $5.3 to $70.4 billion in losses. The net economic costs associated with excess cancer mortality from consuming PCB contaminated striped bass ranged from $3.7 billion to $21.7 billion (assuming low consumption rates) up to $8.8 billion to $51 billion (assuming a high consumption rate). For contaminated bluefish, impacts ranged from $3.7 to $50.4 billion depending on consumption rate. Dioxin-associated risk was smaller in magnitude than PCB-related risk, and as a result dioxin-contaminated striped bass economic impacts ranged from $1.3 billion to $9.1 billion. Additive risks were also examined by the authors because many species are affected by more than one contaminant. Striped bass, a predatory species, not surprisingly exhibited the highest levels of excess risk and additive risk, with PCB accounting for the highest individual contaminant risk in this species, followed by DDT and chlordane. Taken together, the additive risks of contamination in striped bass were estimated to generate public health losses that ranged in value from $1.7 billion to $34.6 billion. Given

[3] All reported impacts were adjusted to reflect year 2000 U.S. dollars.

the breadth of the studies surveyed by Ofiara and Seneca (2001), their estimates were at times necessarily based on imprecise data. Regardless, the reported values highlight the potential sizeable public health losses that may be caused by the consumption of contaminated seafood over a lifetime.

In addition to the public health-related economic impacts, commercial and recreational fishery closures resulting from PBT contamination can also have significant economic consequences. Waterbodies in New Bedford Harbor and the Buzzards Bay areas of Massachusetts have been closed to lobster harvesting since 1979 as a result of PCB contamination, forcing local lobsterman to travel greater distances or discontinue harvesting (McConnell and Morrison, 1986). Those who steam to unclosed areas for harvesting were estimated to incur an increase in costs of $1,749 annually (McConnell and Morrison, 1986). While no economic estimates of losses are available, the Hudson River commercial and recreation fishery also has been subject to closures and fish consumption advisories for most of the past 30 years due to the presence of high levels of PCB contamination in fish (NYSDEC, 2001). For example, recreational fishing in the upper Hudson River was prohibited from 1976 until 1995, after which the fishery was designated as catch and release only. Considering this, along with the continuing closure and harvest restrictions on a number of potentially important commercial species, it is realistic to assume that untapped fishery resources and reduced recreational fishing opportunities have led to significant economic losses.

While the direct economic effects associated with PBT contamination in commercial and recreational fisheries are often large and extend over a long period of time, the indirect economic impacts may also be significant. For example, a hypothetical study by Jackus et al. (2002) estimated the surplus losses from decreased demand following negative publicity and public awareness concerning mercury contamination. After estimating supply and demand models for striped bass in the Chesapeake Bay, the effect of a potential consumption advisory was modeled as a leftward shift of the demand curve. The resulting combined producer and consumer surplus losses exceed $0.5 million solely for the commercial striped bass market in the Maryland portion of the Chesapeake Bay.

MANAGING CONTAMINATED FISHERIES

PBT pollutants have the ability to travel long distances, to travel easily among air, water, and land, and to linger for generations in people and the environment (U.S. EPA, 2004a). These characteristics present challenges in reducing the public health risks from PBT contaminants. While federal, state, local, and tribal agencies have various responsibilities for safeguarding the public against effects of PBT contaminants in fish, most management strategies encompass long term pollution control, environmental remediation, and the issuance of health advisories with recommendations about limiting fish consumption and/or adopting other risk-reducing behaviors.

The FDA and EPA are the federal agencies most involved with limiting consumer contaminant exposure. The FDA develops advisories and sets maximum allowable contaminant levels for commercially marketed fish. The EPA is also active in many areas relating to fish contamination, particularly with controlling pollutant releases and issuing consumption advisories. Both agencies actively provide technical assistance and guidance to state, local, and tribal agencies. Many states rely on FDA consumption guidelines for advisories and consult frequently with the FDA about how to address particular fish contaminant situations (U.S. EPA, 2005a). This cooperative approach makes sense in part because the FDA has the scientific expertise to determine federal tolerances, action levels, and guidance levels for many of the most harmful contaminants present in fish. Examples of action limits above which the FDA will take legal action to remove products from the market include 0.1 ppm for mercury, 20 ppm for PCBs, 0.3 ppm for chlordane, and 5 ppm for DDT (U.S. FDA, 2000). States often use these same action limits for issuing consumption advisories

To augment the activities of the FDA, the EPA has already taken action against many of the PBT contaminants present in the nation's fish supply, making it a priority to reduce risks to human health and the environment from existing and future exposure to priority PBT pollutants (U.S. EPA, 2004a). A four-part strategy was developed by the EPA that includes the development and implementation of national action plans to reduce priority PBT pollutants and prevent new PBT pollutants from entering the marketplace (U.S. EPA, 2004a). Mercury emissions have been greatly reduced since 1990, and will be reduced further by the implementation of the Clean Air Mercury Rule (CAMR) to regulate mercury emissions from coal-fired power plants. CAMR, the first in the world of its kind, created a market-based cap and trade program to permanently reduce mercury emissions. Although these programs aim to significantly reduce the new deposition of contaminants into the environment, their persistence makes it likely that many of them will remain in the nation's fish stocks for some time to come.

As alluded to above, consumption advisories and safe eating guidelines are the primary management strategies that have been used in the U.S. to reduce consumer exposure to contaminants in fish. Simply defined, consumption advisories are recommendations for voluntary action, informing the public that excessive concentrations of chemical contaminants have been found in local fish. These advisories may include recommendations to limit or avoid eating certain fish species or fish caught in specific waterbodies. An advisory may be issued for the general population or for sensitive subpopulations such as pregnant women, nursing mothers, and children (U.S. EPA, 2005b). Each state or tribe is responsible for developing their own advisory programs and issuing consumption advice. This heterogeneous structure leads to program variability across the U.S., but, in general, there are five major types of advisories and bans that are issued (U.S. EPA, 2005b):

1. No-consumption advisories for the general population, issued when contaminant levels in fish pose a health risk to the general public;
2. No-consumption advisories for sensitive subpopulations, issued when contaminant levels in fish pose a health risk to sensitive subpopulations;
3. Restricted-consumption advisories for the general population, issued when contaminant levels in fish may pose a health risk if too much fish is consumed;
4. Restricted-consumption advisories for sensitive subpopulations, issued when contaminant levels in fish may pose a health risk if too much fish is consumed by those in the sensitive subpopulation; and
5. Commercial fishing bans, issued when high levels of contamination are found in fish caught for commercial purposes.

In addition to the advisories issued by individual states, the federal government has also issued fish consumption advisories pertaining to mercury. In the first ever joint advisory, the EPA and FDA recommended that women who might become pregnant, women who are pregnant, nursing mothers and young children avoid eating shark, swordfish, king mackerel, and tilefish because of the high levels of mercury in the fish (U.S. EPA, 2004b). The agencies also advised limiting consumption of albacore tuna to 6 ounces per week for the same target population.

Do Current Strategies Work?

The PBT programs have made progress in minimizing the use of PBT contaminants and reducing the amounts that are released into the environment. These reductions, however, do not necessarily lead to decreases in the contaminant concentrations found in fish, at least in the short-run. In order to provide a baseline for tracking progress in dealing with PBT contaminants, the EPA conducted the 2000-2003 National Lake Fish Tissue Study to estimate the national distribution of 268 PBT chemicals in fish tissue from lakes and reservoirs in the contiguous United States (U.S. EPA, 2005c). Given their persistence in the environment, it may be a decade or more before progress on reducing human exposure to fish-borne PBTs can be definitively demonstrated.

Perhaps one of the difficulties the national PBT programs will encounter when trying to demonstrate reduced human exposure relates to the potential effectiveness of consumption advisories that depend on voluntary consumer behavior. Consumer reactions to advisories have previously been inconsistent, and the advisories ultimately will only be effective if consumers are aware of them and are willing/able to translate awareness into behavior (Shimshack et al., 2005). Shimshack, Ward, and Beatty (2005) examined consumer response to the 2001 FDA methylmercury fish advisory and found that a large group of at-risk consumers did not respond to the advisory, particularly in the case of less-educated and less-informed consumers. Additionally, they found that providing public information may lead to a broader response than intended, as non-targeted consumers also reduced fish consumption after the mercury advisory. These unintended responses can have significant effects on overall public health. Fish consumption advisories raise the possibility of the classic risk-risk trade-off: by avoiding one risk, that of contaminant exposure, consumers may incur another risk, adverse health consequences due to lower Omega-3 fatty acid intake (Cohen et al., 2005). Trade-offs from consumption altering policies were recently examined in a study by the Harvard Center for Risk Analysis (Cohen et al., 2005). If women of childbearing age shift their consumption from higher mercury fish to lower mercury fish (i.e., adhere to recommendations), positive public health benefits are realized. If non-targeted consumers also reduce their level of fish consumption, substantial overall public health losses can occur, particularly with respect to the sub-population of elderly men. This study brings up another interesting, though currently unaddressed question: if subpopulations such as women of childbearing age reduce their consumption of fish with high mercury concentrations, then will other groups, particularly the poor, increase their mercury exposure (Willett, 2005)? If the informed public reduces demand for mercury contaminated fish, market forces will lead to reduced prices for those species, thereby making it more likely that they will be consumed by the poor and/or less informed consumers (Willett, 2005).

CAN CONTAMINATION MANAGEMENT BE IMPROVED?

As the scope and scale of PBT contamination problems in fisheries expand, new approaches must be developed to confront the increasing threats that contamination poses to public health and the economic viability of the fishing industry. A recent approach to managing PBT contaminant exposure is the introduction of the nation's first line of certified low-mercury fish under the Safe Harbor brand name (Hirsch, 2006). In a current test, Safe Harbor is marketing a low-mercury line of fresh fish in Northern California supermarkets to see if consumers would increase fish purchases if they were provided with more information about the product's mercury content. Safe Harbor utilizes a new analytical device that measures mercury content in less than a minute, and they aim to only market fish that test well below the FDA's recommended action exposure level of 1 ppm. While labeling that conveys nutritional or environmental information to consumers is not new in the U.S. seafood market,[4] this is the first time labels have been used in an attempt to understand how individual consumers respond to specific information about mercury contamination in their potential purchases. More investigation will be needed to determine if this labeling scheme will lead to significant reductions in mercury exposure among consumers, and ultimately to improvements in public health. A mirror-image of the Safe Harbor market approach occurred in 1991 when California began requiring that Gulf of Mexico oysters be labeled with a warning about potential contamination from *Vibrio vulnificus* (Keithly and Diop, 2001). In that instance, consumer reaction to the oyster label led to significantly depressed market prices for Gulf oysters, not only in California but across the nation (Keithly and Diop, 2001). Given this experience, it is plausible that market prices for seafood products not labeled as low mercury could similarly fall, an outcome that would heighten Willett's (2005) concern that the poor may ultimately be exposed to higher contaminant levels as a result of public dissemination of contamination information. Perhaps equally likely outcomes, however, would be that the Safe Harbor fish will either be awarded a price premium by consumers, or that consumers on the whole will disregard the label.

Information and perception play important roles in consumption decisions. Public health gains could be realized through the design and implementation of a focused education and information campaign. Advisory information needs to be presented in ways that are not confusing to the consumer. Consumption guidelines need to be to be specific. Oceans Alive, a campaign by the Environmental Defense Fund, presents consumption advice based on species and population group.[5] For example, women and children are advised to avoid consuming swordfish, while men can safely consume one swordfish meal per week. The information is presented in a color-coded manner, and can be printed for

[4] An early example of labeling in the U.S. seafood market is the "dolphin-safe" tuna label. A more recent example is the law requiring retailers to provide country-of- origin information for seafood they sell, as well as whether the product is wild or farm-raised.

[5] This information is available from the Oceans Alive website http://www.oceansalive.org/eat.cfm?subnav=healthalerts.

easy reference. Education efforts like this show promise, and may reduce the unintended responses to consumption advisories. However, the information needs to be widely available, reaching all fish consumers. Information regarding contaminated seafood is most often disseminated through television or print media, and consequently does not reach all of its target audience. Shimshack et al. (2005) suggest public transportation advertising and in-store signs as potential methods for improved educational outreach.

Although the EPA has striven to reduce the amounts of PBT contaminants in the environment, the persistent and bioaccumulative nature of these contaminants is problematic. Even significant reductions in new releases of PBT pollutants may not result in significant decreases in the level of PBT contaminants present in fish. Alternative approaches may be needed in order to reduce the public's long-term exposure beyond that achieved through voluntary responses to state consumption advisories. One potential alternative that has not yet been considered is to reexamine the way size-based fisheries management is conducted. As currently implemented, most management plans focus on supporting recruitment to the fish stocks and survival to reproductive age by imposing minimum size limits on captured fish. PBT contaminants are bioaccumulative, however, and that often results in a positive relationship between fish size and the levels of contaminant concentration. This paradoxically leads to a situation where management plans designed to protect stocks for ecosystem purposes and for future human use actually increase the levels of PBT exposure experienced by consumers. An alternative would be a more directed, size-based management of contaminated marine fisheries that explicitly accounts for contamination and public health issues when determining optimal harvesting regimes. Intuitively, this approach might require the harvesting of younger, smaller fish with the objective of allowing older, larger fish to serve as both a breeding stock and PBT sink. How this type of management might work needs to be explored within the context of an empirical bioeconomic model that combines population, toxicological, and economic information into the decision making process. A model such as this could be used to generate policy relevant management suggestions under varying management objectives and ultimately reduce the amount of contaminants reaching consumers.

CONCLUSION

Contamination of U.S. fisheries is a growing threat not only to public health, but also to the economic and ecological viability of many fisheries. The economic impacts of contamination can be staggering, ranging from increased public health costs and direct losses in commercial fisheries to reduced revenues from curtailed recreation and tourism. The scope and scale of PBT contamination problems in fisheries are clearly expanding and having an impact on how the harvesting and processing sectors operate and on how consumers perceive seafood products. Managers must continually confront the increasing threats that contamination poses to public health and the economic viability of the fishing industry. Current strategies to reduce human exposure are reactive in nature, but the potential for serious loss suggests a greater need for proactive management to prevent contamination. While the EPA is working to significantly reduce PBT contaminants in the environment, it could be many years before substantial improvements are seen from these efforts. In the meantime, management should be focused on reducing human exposure to contaminants. In particular, management options that reduce perception and bias in decision making, proactively control the contaminant levels that reach the marketplace, and provide for integrated analysis and coordinated action across political boundaries should be considered in an attempt to reduce public health risks from seafood consumption.

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