BOUNDARY ISSUES: CONTAMINANTS IN PREY FISH AND CONSUMPTION ADVISORIES NEAR A SUPERFUND SITE IN BRUNSWICK, GEORGIA

by

TALIA R. LEVINE

(Under the Direction of Laurie A. Fowler)

ABSTRACT

At the Linden Chemicals and Plastics (LCP) Superfund Site in Brunswick, Georgia, chemical discharges have contaminated the Turtle-Brunswick River Estuary (TBRE) for over 25 years. Polychlorinated biphenyls (PCBs) and mercury are among site contaminants, and a PCB mixture, Aroclor 1268, is a recognized site pollutant. Previous studies documented persistent, bioaccumulative, and toxic (PBT) chemicals in TBRE wildlife, including Atlantic Bottlenose dolphins (*Tursiops truncatus*), and their prey. The TBRE is subject to fishing advisories, but studies suggest some anglers are consuming whole fish counter to advisory recommendations. To identify concentrations of PBTs to which humans and dolphins are exposed, and to assess advisory adequacy, three species of fish—southern kingfish (*Menticirrhus americanus*), Atlantic croaker (*Micropogonias undulatus*), and star drum (*Stellifer lanceolatus*)—were sampled within and outside of the TBRE. Results confirmed high concentrations of PCBs and total mercury, suggesting advisory boundaries should be expanded and additional management strategies be implemented.

INDEX WORDS: PBT, PCB, Aroclor 1268, mercury, Atlantic bottlenose dolphins, southern kingfish, Atlantic croaker, star drum, fishing advisory, Superfund

BOUNDARY ISSUES: CONTAMINANTS IN PREY FISH AND CONSUMPTION

ADVISORIES NEAR A SUPERFUND SITE IN BRUNSWICK, GEORGIA

by

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DEDICATION

For my mother, Barbara, who taught me that it's never too late to be what you might have been.

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Ecology is a science that deals with the interdependence of life. As I conclude my graduate work, I am keenly aware of the interdependence that research and education require. This was most evident to me in interacting with my committee who taught me skills that will serve me well beyond my master's.

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CHAPTER 1

INTRODUCTION

Problem Summary

In the United States, there are 1,322 sites on the Superfund National Priorities List, where hazardous materials, pollutants, and contaminants released into the surrounding environment are regulated pursuant to the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) (42 U.S.C. §§9601-9675; United States Environmental Protection Agency [EPA], 2022). Brunswick, Glynn County, Georgia is home to three NPL sites, including the Linden Chemicals and Plastics (LCP) Superfund site where chemical discharges have contaminated the Turtle-Brunswick River Estuary (TBRE) and the resident fish for over 25 years (Kannan et al., 1997; Maruya & Lee, 1998). Polychlorinated biphenyls (PCBs) and mercury are two site contaminants of concern (Agency for Toxic Substances and Disease Registry [ATSDR], 1996), and Aroclor 1268—an uncommonly used and highly-chlorinated PCB mixture—is a recognized PCB mixture from the LCP site (Kannan et al., 1997; Maruya & Lee, 1998).

Ecotoxicology research from the TBRE has documented high contaminant concentrations and resulting negative health effects in wildlife, including PCB concentrations in a piscivorous apex predator, the Atlantic bottlenose dolphin (*Tursiops truncatus*). Brunswick dolphins carry high body burdens of PCBs, among other contaminants (Balmer et al., 2011; Pulster et al., 2009), and health assessments have documented markers of impaired health in this population (Schwacke et al., 2012). Prey fish preferred by dolphins have been sampled in the TBRE and in estuaries to the north and south; homologs consistent with Aroclor 1268 have been identified in all three areas, with highest concentrations in Brunswick, suggesting fish as a potential vector moving Aroclor 1268 throughout the estuary (Maruya & Lee, 1998) and beyond the boundaries of the TBRE (Pulster et al., 2005; Wirth et al., 2014).

Dolphins and humans overlap in their prey fish preference, and both are apex predators and long-lived mammals (Bossart, 2011). This, combined with the tendency for dolphins' fat stores to accumulate anthropogenic toxins, make them sentinel species (Bossart, 2011), indicating contaminant burdens and resulting health effects that wildlife and humans consuming whole fish from the TBRE may experience. Though fishing advisories maintained by the Georgia Department of Natural Resources (GDNR) Environmental Protection Division (EPD) guide human anglers in the TBRE to fillet fish and remove skin, fat, dark meat, and guts to reduce some contaminant concentrations (GDNR, 2021), surveying efforts in Brunswick and along the Savannah River to the north have reported anglers consuming whole fish (Burger et al., 1999; McElwee, 2015). Additionally, some Brunswick anglers appear to be consuming larger portion sizes and more fish meals than advisories recommend (McElwee, 2015).

There is uncertainty as to whether local anglers know about, understand, or follow local advisories. Though advisories are posted on the GDNR EPD website, they are somewhat complicated. Advisories recommend frequency with which individual species can be safely consumed—no restrictions, 1 meal/week, 1 meal/month, or do not eat—in the four zones of the TBRE, with guidance varying by location (GDNR, 2021). However, advisory guidance is not consistently communicated across platforms anglers may use to select fishing spots, nor is it available at actual fishing locations. There are no advisory signs posted at TBRE fishing spots to reinforce advisory messaging, and GDNR's interactive fishing map—designed for angler use in identifying fishing spots and boating ramps—does not mention advisories.

Thesis Purpose

The high levels of contaminants previously documented in TBRE prey fish combined with inconsistencies in advisory communication create a potential public health issue. An important step in understanding the extent of human exposure to these contaminants is identifying concentrations in all preparations of fish consumed, including whole fish. Furthermore, dolphins feeding from the TBRE continue to carry high body burdens of PCBs and other contaminants, and some of their preferred prey items have yet to be sampled in this area. Therefore, this research was undertaken to quantify contaminant concentrations in three prey-fish species consumed by humans and/or dolphins. A significant focus of this research was using study results to develop recommendations for further human health assessments and advisory communication at the site.

Contaminant Sampling in Prey Fish

From 2019–2020, we sampled star drum (*Stellifer lanceolatus*), Atlantic croaker (*Micropogonias undulatus*), and southern kingfish (*Menticirrhus americanus*) to determine PCB and mercury concentrations at seven sites: the four advisory areas of the TBRE and three non-advisory sites outside the TBRE. Our species were selected based on dolphin and/or human prey preference. One of our study species—star drum—has not been sampled previously in the TBRE, yet it was the most abundant species observed in dietary analysis of South Carolina dolphins (Pate & McFee, 2012). In fish consumption surveying of Brunswick anglers, croaker and southern kingfish (or whiting) were reported as two of the most frequently consumed species (McElwee, 2015). Though fillets of these two species have been analyzed previously in the area, no past studies sampled whole-fish preparations of these species throughout all zones of the advisory areas.

Sampling whole-fish preparations of species preferred by Brunswick anglers is particularly important in understanding the contaminant concentrations to which humans are exposed. Current advisories are based on data derived from filleted-fish samples of eight target species—spotted seatrout (*Cynoscion nebulosus*), red drum (*Sciaenops ocellatus*), black drum (*Pogonias cromis*), spot (*Leiostomus xanthurus*), sheepshead (*Archosargus probatocephalus*), striped mullet (*Mugil cephalus*), blue crab (*Callinectes sapidus*), and penaeid shrimp (*Penaeus spp.*)—and three additional species— croaker, southern kingfish, and southern flounder (*Paralichthys lethostigma*) (EPS, 2018). The primary objective of collection activities is to collect three composite samples for each of the eight target species within each zone with a secondary objective of three composite samples per zone for croaker, southern kingfish, and southern flounder due to their popularity with recreational anglers (EPS 2018).

We sought to create a whole-fish data set of preferred species that mimicked the filleted-fish data used to create advisories. Filleted-fish concentrations may not accurately represent contaminant exposures of humans ingesting whole fish from the TBRE, particularly in the case of lipophilic contaminants like PCBs. Additionally, one of our study species—croaker—was poorly represented in both 2011 and 2017 sampling efforts with only 1 fish collected in Zone 3 in 2011, and 1 composite (3 total fish) collected in Zone 2 in 2017. Finally, we assessed PCBs and total mercury concentrations in our selected species as research has suggested synergistic effects of PCBs and methylmercury (Bemis & Seegal, 1999), and both negatively affect the brain and nervous system (EPS, 2011).

We also sampled study species within and outside of the TBRE advisory areas to assess whether advisory boundaries provide adequate protection for human anglers. Though past prey studies sampled areas outside the TBRE, including the Skidaway River (Maruya & Lee, 1998), Wassaw Sound (Pulster et al., 2005), Sapelo Sound (Wirth et al., 2014), St. Simons Sound (Maruya & Lee, 1998; Wirth et al., 2014), and Nassau Sound (Pulster et al., 2005), these studies did not assess the efficacy of fishing advisory boundaries.

Human Health Recommendations

Analyzing these results, as well as the fish-consumption advisory literature, we concluded this thesis with management recommendations regarding site institutional controls, including further human health assessments and increased advisory communication. Human health assessments conducted at the LCP site assume anglers are filleting fish but reports of whole-fish consumption and anglers exceeding both portion sizes and number of fish meals recommended by advisories are cause for concern. Health assessments typically take a conservative approach and leave a margin of error when evaluating risks at a site, yet in this case anglers engaging in risky fish-consumption behaviors do not appear to be represented by health assessments or protected by current institutional controls.

Thesis Structure

In this chapter, we introduced the problem that motivated our research and explained the structure of the remainder of the thesis.

In chapter 2, we provide a literature review of contaminant research in TBRE dolphins, prey fish, and human health assessments involving the LCP site marsh. We focused on human and dolphin research conducted in or near the LCP marsh/TBRE from 1994–present and associated management actions. We searched academic journals, agency records, and consultant reports to provide context for our research in this review.

In chapter 3, we present results of our 2019–2020 fish-sampling efforts for three species consumed by dolphins and/or humans—star drum, croaker, and whiting. We also discuss fish consumption habits in Brunswick and possible inaccuracies underlying some LCP human health assessments. Star drum were sampled, in part, to understand whether items *not* commonly consumed by humans (and frequently consumed by dolphins) could be contributing to the high levels of PCBs documented in Brunswick dolphins. Croaker and whiting, frequently consumed by human anglers, are subject to some of the most restrictive consumption advisories, including "Do Not Eat" status for the creeks most proximal to LCP (GDNR, 2021). Using our results and consumption estimates derived from McElwee (2015), we calculated daily intake of contaminants in the St. Simons Sound and Offshore locations to identify whether advisory boundaries are adequate for whole-fish consumers of croaker and whiting in Brunswick.

In Chapter 4, we discuss the history of fishing advisories in the TBRE and identify some best practices for fishing advisory communication that may prove beneficial in Brunswick. We conclude with suggestions for new agency-directed human health assessments and management recommendations for more effective advisory communication. We base these recommendations on our fish-sampling results and takeaways from the fish consumption advisory literature.

In Chapter 5, we review the conclusions of our findings.

Utility of Research

One goal of this research was to identify how requests for new human health assessments at the LCP site may be initiated. We learned about the ATSDR's role in conducting human health assessments at NPL-listed Superfund sites as mandated by section 300.400 of the National Oil and Hazardous Substances Pollution Contingency Plan (40 C.F.R. § 300.400). Though ATSDR indicated in its final public health assessment for LCP that the assessment process had concluded, new information may prompt a revision of their conclusions (ATSDR, 2014). ATSDR reviews environmental data from other agencies, Potentially Responsible Parties (PRP), or other third parties at the LCP site, and they request additional data be collected to fill “critical data gaps” if appropriate (ATSDR, 2014).

This thesis presents evidence of contaminant burdens in prey fish proximal to but outside of TBRE advisory areas. It also provides PCB and mercury data for whole fish samples of two human-preferred species collected throughout the TBRE. Our hope is that this information will prompt ATSDR to both revisit fish consumption habits of Brunswick anglers, and to request that fish sampling and analysis by PRPs be extended into the St. Simons Sound. This, in turn, could provide data necessary to compel expansion of the fishing advisory boundaries to protect human health more effectively. Therefore, our findings are also relevant to the GDNR EPD, which develops and updates advisories. Further, our findings are relevant for site PRPs—Honeywell and Georgia Power—and the consulting groups they employ to conduct fish monitoring as they will be impacted by any modification of current practices within the TBRE.

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CHAPTER 2

A HISTORY OF THE LCP SUPERFUND SITE: ATLANTIC BOTTLENOSE DOLPHINS, HUMAN HEALTH, AND FISHING ADVISORIES[1]

[1] Levine, T.R., Fowler, L.A., Bringolf, R.B., & Schacke, J.H. To be submitted to *Southeastern Naturalist*.

Abstract

In Brunswick, Georgia, a long history of industrial operations at the Linden Chemicals and Plastics (LCP) Superfund site has led to discharges of mercury and polychlorinated biphenyls (PCBs) into the Turtle-Brunswick River Estuary (TBRE). Ecotoxicology research has documented concentrations of these and other contaminants in a host of wildlife as well as their prey. Atlantic bottlenose dolphins (*Tursiops truncatus*) are sentinel species inhabiting the TBRE and given their high body burdens of contaminants and overlapping prey preference with human anglers, they may signal a need for further research on humans feeding from the TBRE and neighboring waters, particularly those consuming whole fish. This manuscript offers a review of the dolphin and human health research conducted in the TBRE, specifically involving LCP Superfund Site's Operable Unit 1 (the marsh).

Introduction

In the United States, there are 1,322 sites on the Superfund National Priorities List, where hazardous materials, pollutants, and contaminants released into the surrounding environment are regulated pursuant to the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) (42 U.S.C. §§9601-9675; United States Environmental Protection Agency [EPA], 2022). Brunswick, Glynn County, Georgia is home to three NPL sites, including the Linden Chemicals and Plastics (LCP) Superfund site where chemical discharges have contaminated the Turtle-Brunswick River Estuary (TBRE) and the resident fish for over 25 years (Kannan et al., 1997; Maruya & Lee, 1998). Polychlorinated biphenyls (PCBs) and mercury are two site contaminants of concern (Agency for Toxic Substances and Disease Registry [ATSDR], 1996), and Aroclor 1268—an uncommonly used and highly-chlorinated PCB mixture—is a recognized PCB mixture from the LCP site (Kannan et al., 1997; Maruya & Lee, 1998).

The TBRE is a highly productive ecosystem comprised of salt marsh and tidal creeks (Black & Veatch, 2011). The LCP marsh area is subject to semi-diurnal tides with tidal ranges that can exceed 9 feet in a cycle (EPA, 2015). The tidal marsh floods and is fully inundated for approximately one-to-four hours a day, varying with elevation, during which resident finfish and shellfish utilize the marsh (EPA, 2015). A myriad of additional organisms populate or make use of the marsh—indigenous marsh grasses, benthic salt marsh invertebrates, birds, reptiles, and terrestrial and marine mammals (EPA, 2015). One such marine mammal, Atlantic Bottlenose dolphins (*Tursiops truncatus*), also known as common bottlenose dolphins, have been studied extensively in Brunswick. Researchers have documented their high body burdens of PCBs and other contaminants (Balmer et al. 2011; Pulster & Maruya, 2008; Pulster et al., 2009), and their resulting markers of impaired health (Schwacke et al., 2012).

Dolphins and humans overlap in their prey preference, and both are apex predators and long-lived mammals (Bossart, 2011). These traits, combined with dolphins' fat stores that accumulate anthropogenic toxins, make them sentinel species (Bossart, 2011), indicating contaminant burdens and resulting health effects that wildlife and humans consuming whole fish from the TBRE may experience. Though fishing advisories are in place in the TBRE to guide human consumption, it is uncertain whether all fishers are aware of, understand, or follow advisory guidance.

Thus, we conducted the following literature review to explore the dolphin and human health research conducted at the LCP marsh to date and to identify the need for further study of potential human exposure to contaminants in fish. In the TBRE, a food web contaminated by legacy pollutants may combine with fish consumption behaviors that counter fishing advisory guidance, potentially creating an uncontrolled public health issue. Understanding the site's past as well as future needs may help local, state, and federal agencies to better manage risks from this site while protecting the health of Brunswick residents.

Figure 2.1: A map of the Linden Chemicals and Plastics (LCP) Superfund Site (red marker) and the Turtle-Brunswick River Estuary (TBRE) to the west of LCP.

Site History

Though LCP Chemicals was only in operation from 1979–1994, site legacy pollutants resulted from a long history of industrial use at the property beginning in 1919 or earlier (ATSDR, 2014; Environmental Planning Specialists [EPS], 2007 as cited in ATSDR, 2014).

Determining when contamination in seafood began is further complicated by the presence of 20 potentially hazardous waste sites in Glynn County as of 1996 (ATSDR, 1996).

Allied Chemical (now Honeywell) acquired the bulk of the property and constructed a chlor-alkali facility in 1956. Here, chlorine gas, sodium hydroxide solution, and hydrogen gas were produced using the mercury cell process, in which concentrated brine solution moved between graphite anodes and a mercury cathode (ATSDR, 2014; EPA, 2014, 2015). In 1979, LCP Chemicals of Georgia, Inc. purchased the facility and the site, and they continued operating the chlor-alkali plant with a modified process—forming hydrochloric acid by reacting chlorine and hydrogen—until 1994 (ATSDR, 2014; EPA, 2014). The current owner, Honeywell, purchased the property again in 1998 (EPS, 2011).

Site contaminants

Mercury, PCBs, and lead are the primary contaminants of concern at the LCP site (ATSDR, 1996). Studies of the LCP marsh sediment have found almost half of the mercury present is organic (ATSDR, 2014). Methylmercury, the most toxic mercury form (Reif et al., 2015), has bioaccumulated in TBRE fish, resulting from LCP's releases of elemental mercury and subsequent methylation in Purvis Creek and Turtle River sediments (ATSDR, 1994). Large quantities of mercury and PCBs were dispersed into the marshlands from site industrial operations between 1955–1979, with the EPA estimating a "loss" of over 380,000 pounds of mercury (ATSDR, 2014; EPA, 2011 as cited in ATSDR, 2014). Other sources report that more than 37 tons of PCBs and 440 tons of mercury were lost to the LCP marsh and surrounding areas (Kannan et al., 1998).

PCBs—complex mixtures of chlorinated biphenyls with varying weights of chlorine—were favored for their inert and heat-stable properties and were used in a variety of applications, including electrical insulators and capacitors (ATSDR, 2000; National Oceanic and Atmospheric Administration [NOAA], 2021). Commercial PCB mixtures were composed of a combination of 209 congeners—or individual chlorinated biphenyls—in addition to other contaminants introduced during production (ATSDR, 2000). Though the congener profile in sampled sediments suggested Aroclor 1268 was the dominant PCB mixture at the site, sediment studies also identified low concentrations of lower-chlorinated homologs consistent with Aroclor 1260 in sampled areas between the inner marsh and outer marsh creek (Kannan et al., 1997).

Closure and NPL listing

LCP violated their National Pollution Discharge Elimination System (NPDES) permit, issued pursuant to the federal Clean Water Act to control the discharge of pollutants into surface waters (33 U.S.C. §1342), for approximately one-third of their operational time, according to the Georgia Department of Natural Resources (GDNR) Environmental Protection Division (EPD) (ATSDR, 1994), and EPD revoked their permit in 1994 due to noncompliance (ATSDR, 1996). The LCP facility discontinued operations in February 1994 (ATSDR, 1994, 1996), at which time the Governor of Georgia requested EPA take immediate action to address the threat of chlorine gas releases at the site and the contaminant releases flowing into the site-adjacent saltwater tidal marsh (ATSDR, 2014; Glynn County Health Department [GCHD], 1999). The EPA responded with a Unilateral Administrative Order for Removal (UAO) in 1994 (Britt, 1995 as cited in ATSDR, 1996), and LCP was added to the Environmental Protection Agency's (EPA) National Priorities List (NPL) on June 17, 1996 (EPA, 2015).

LCP Marsh Management: Remediation and Institutional Controls

The LCP site is divided into three operable units (OU) due to its complexity— the marsh (OU1), the site groundwater/surface and subsurface soil in the former mercury cell building area

(OU2), and the remainder of the uplands (OU3) (EPA, 2015). OU1 consists of tidal marsh (662 acres) and tidal creeks (98 acres) representing approximately 760 acres of the LCP site (EPA, 2015).

Approximately 167,000 cubic yards of soil, sediment, and waste were removed from the LCP dry-land site from 1994–1997 (ATSDR, 2014). Following this, removals took place in approximately thirteen acres of the marsh and 2,650 linear feet of tidal channels from 1998–1999 (EPA, 2011 as cited in ATSDR, 2014). Site structures, including petroleum process buildings and mercury cell structures, were demolished in this same time frame, and the mercury cell building area was capped and fenced (ATSDR, 2014). The Record of Decision (ROD) for OU1 was issued in 2015, and the Consent Decree entered in July of 2017 (EPA, n.d.-b). Work on a pilot project to test efficacy of a thin-layer cover applied to sediment as part of the remediation design began in February of 2018 (EPA, n.d.-a).

Once listed on the NPL, a remedial investigation and feasibility study (RI/FS) is conducted to assess the nature and degree of site contamination (EPA, n.d.-c). The EPA issued an Administrative Order by Consent for the RI/FS in 1995, and consultants working on behalf of Honeywell subsequently completed the Baseline Ecological Risk Assessment (BERA) for OU1 and the Human Health Risk Assessment for OU1 (HHRA) in 2011 (Black & Veatch, 2011; EPS, 2011). The RI/FS was undertaken in part to characterize the potential risks to ecological and human health to support site remediation and decision-making (EPS, 2011).

Once risks have been assessed (RI), the feasibility study (FS) is conducted to consider potential remediation strategies (EPA, 2011). The EPA then recommends a Proposed Plan and accepts public comments on the plan for a set duration (EPA, 2011). A plan is decided upon and the rationale behind this explained in the ROD, following which the remedy is designed during the Remedial Design (RD) phase (EPA, 2011). Finally, remediation begins during the Remedial Action (RA) phase (EPA, 2011). Once a remedy is selected Under CERCLA, if hazardous substances, pollutants, or contaminants remain at a site following remediation, remedial action must be reviewed at least every five years after initiated to assess whether the selected remedy is protective of human and environmental health (EPA, n.d-e). Further action can be taken if required at a site (EPA, n.d-e).

As this process takes time, additional tools, such as institutional controls, are necessary to manage ongoing public health risks at the site during, and potentially following, site remediation. Institutional Controls (ICs) are "non-engineered instruments, such as administrative and legal controls," that, among other uses, help minimize human exposure to contaminants (EPA, 2012). There are different types of institutional controls, including "informational devices" that provide notification rather than an enforceable restriction (EPA, 2012). Fishing advisories are a type of informational device, but there is not standardization in terms of the agency which is responsible for setting them; the EPA states that they may be issued by federal, state, territorial, or tribal agencies (EPA, n.d.-d). The EPA offers national-level guidance for safe mercury levels in self-caught seafood, and they have published manuals to guide establishment of consumption advisories (Love et al., 2013). At the state-level, advisories are usually set by public health departments (Love et al., 2013).

Fish Studies in the TBRE

Advisory creation

Federal and state agencies—as well as consulting groups contracted by PRPs—have assessed contaminant concentrations and/or potential human health risks related to fish consumption near the LCP site. Prior to LCP's 1994 closure, results of fish sampling by the EPD

Toxic Substances Stream Monitoring Project and the US Fish and Wildlife Service (FWS) led to the establishment of fishing advisories and commercial seafood harvests closures in some TBRE waters (ATSDR, 1994); these original advisories have been expanded and remain in effect today (GDNR, 2021).

Non-advisory fish sampling

In addition to fish sampling conducted for the purpose of advisory creation and maintenance, other prey studies have been conducted in the TBRE to quantify contaminant concentrations in biota, identify contaminant movement throughout the food chain, and to better understand sources of contaminant concentrations documented in site apex predators, namely dolphins. Trends documented in these studies are relevant to a discussion of fish consumption and fishing advisory management in Brunswick as findings have included high concentrations of PCBs—particularly in fatty tissues— in fish species (Maruya & Lee, 1998), variability in interspecific and intraspecific PCB concentrations (Maruya & Lee, 1998; Pulster et al., 2005; Wirth et al., 2014), and movement of Aroclor 1268 throughout the estuary and beyond the boundaries of the TBRE (Maruya & Lee, 1998; Pulster et al., 2005; Wirth et al., 2014), all of which impact the efficacy of fishing advisories in protecting public health.

PCBs' affinity for fatty tissues was highlighted in the TBRE by Maruya and Lee's (1998) finding of PCBs in fish liver and ova of an order of magnitude higher than muscle tissue (Maruya & Lee, 1998). Though PCBs are often higher in whole fish than fillets, this varies, as do fillet-to-whole-fish PCB ratios between species. Amrhein et al. (1998) analyzed coho salmon (*Oncorhynchus kisutch*) and rainbow trout (*Oncorhynchus mykiss*) from Lake Michigan and calculated a fillet-to-whole-fish PCB ratio of 1.70 for coho salmon and 1.47 for rainbow trout, though individual fish had variable ratios, and a few had higher PCB concentrations in fillets than in whole-fish samples.

Kannan et al. (1998) found interspecific and intraspecific variation in Purvis Creek fish samples, with benthic detritivores such as striped mullet (*Mugil cephalus*) containing higher ∑PCB concentrations than other fish species sampled—such as yellow tail (*Bairdiella chrysoura*) and sea trout (*Cynoscion nebulosus*). Purvis Creek is located approximately 1km from the manufacturing complex of the LCP site, but intraspecific variability in ∑PCB concentrations of up to an order in magnitude was potentially caused by movement of fish along the contamination gradient (Kannan et al., 1998). Other studies also found intraspecific variability in PCB concentrations in individuals within the TBRE (Pulster et al., 2005; Wirth et al., 2014).

The unique congener profile of Aroclor 1268 is of use in assessing its movements in fish within and outside of the TBRE. Maruya & Lee (1998) noted contaminated food as a route of Aroclor 1268 transfer as PCB profiles in predator fish, their gut contents, and prey fish were consistent with Aroclor 1268 components. They also suggested that uptake of Aroclor 1268 initially occurred in resident prey fish that were later consumed by predator fish making seasonal use of the estuary. These predator fish, along with other mobile estuary species, then became contaminant "vectors" mobilizing hydrophobic contaminants throughout the estuary for potential consumption by other predators (Maruya & Lee, 1998). Further, similar ∑PCBs have been documented in Purvis Creek samples collected from 1996–1997 and those collected in 2003 (Pulster et al., 2005). This finding combined with the prevalence of highly-chlorinated congeners in these samples speaks to the persistence of Aroclor 1268, suggesting an extensive half-life in fish tissues and/or a large and bioavailable source of Aroclor 1268 (Maruya & Lee, 1998; Pulster et al., 2005).

Though researchers have documented decreasing concentration gradients in fish and shellfish with movement away from the point source contamination at the LCP site (Maruya & Lee, 1998), fish have been suggested as a likely vector carrying Aroclor 1268 not only throughout the TBRE (Maruya & Lee, 1998), but also to reference sites beyond the boundaries of the LCP site (Maruya & Lee, 1998; Pulster et al., 2005; Wirth et al., 2014). Studied reference sites have included portions of the St. Simons Sound, as well as locations to the north—Skidaway River, Wassaw Sound, and Sapelo Sound (Maruya & Lee, 1998; Pulster et al., 2005; Wirth et al., 2014)—and one location to the south, Nassau Sound (Pulster et al., 2005).

Pulster et al. (2005) compared total PCB concentrations in dolphin preferred prey fish from estuaries in three locations—Brunswick, Savannah, GA, and Jacksonville, Florida. Total PCB concentrations and congener profiles among estuaries differed, with Brunswick containing the highest ∑PCBs and most highly chlorinated homologs (Pulster et al., 2005). Jacksonville fish samples, however, contained a mix of less and more highly chlorinated homologs, indicating possible southern transport of Aroclor 1268 residues from LCP from sediment or fish, potentially occurring in some species during offshore spawning (Pulster et al., 2005).

A similar trend of potential migration of Aroclor 1268 offsite was noted in a 2009 study of sediment and dolphin and human-preferred fish from Brunswick and the National Oceanic and Atmospheric Administration's (NOAA) Sapelo Island National Estuarine Research Reserve (SI NERR) (Wirth et al., 2014). In general, mean PCB concentrations in skin-on fillets were 50–100 times higher in Brunswick fish than SI NERR fish. Both Brunswick and SI NERR fish, however, had PCB concentrations exceeding non-cancer risk thresholds; Brunswick had a larger proportion with all fish exceeding the lower threshold and 24 of 29 exceeding the upper threshold, while only two of 22 SI NERR fish exceeded the lower threshold (Wirth et al., 2014). All Brunswick fish exceeded lower and upper thresholds for cancer risks, while ten SI NERR fish exceeded the lower threshold for cancer risk, with five also exceeding the upper threshold (Wirth et al., 2014).

SI NERR and Brunswick fish tissues and sediments contained congener profiles associated with Aroclor 1268, though SI NERR and Brunswick PCB profiles for fish tissues were more similar than those for sediment (Wirth et al., 2014). Authors indicated that fish tissues may be an influential vector for passing PCBs to SI NERR predators such as resident dolphins (Wirth et al., 2014). Two subpopulations of dolphins exist on the Georgia coast, and they exhibit site-fidelity to their respective waters (Waring et al., 2015) As such, their health may provide vital information about the health of humans and wildlife feeding from the same regions.

Atlantic Bottlenose Dolphins in the TBRE

Dolphin residents in bays, sounds, and estuaries are distinct from those inhabiting nearshore coastal waters; photo-identification and genetic research have documented resident estuarine dolphins in several inshore areas of the Southeast U.S. (Waring et al., 2015). Photo-identification research conducted by Balmer et al. (2011) from 2004–2009 revealed two distinct subgroups of Georgia dolphins with the Altamaha River/Sound as the boundary between subgroups. TBRE dolphins are part of the Southern Georgia Estuarine System Stock (SGES), and they carry contaminant burdens reflective of their long-term site fidelity in this area (Pulster & Maruya, 2008; Balmer et al., 2011; Kucklick et al, 2011), as well as distinct genetic differences from those in other areas of Georgia and South Carolina (National Marine Fisheries Service [NMFS], unpublished data as cited in, Waring et al., 2015).

The SGES is thought to contain 194 dolphins (Waring et al., 2015). Potential threats to their population include: a Category II commercial Atlantic blue crab/pot fishery with which they may interact, cetacean morbillivirus—an infection that can cause skin lesions, pneumonia, brain infections, and secondary infections (National Oceanic and Atmospheric Administration [NOAA], 2014)—and impaired health resulting from high PCB contaminant burdens (Waring et al., 2015). PCB burdens combined with their likely health effects have caused concern about the SGES's future health and viability (Waring et al., 2015). The NMFS has labeled the SGES a strategic stock as defined in the Marine Mammal Protection Act (MMPA) (Waring et al., 2015).

In 2004, Pulster et al. sampled blubber from live free-ranging dolphins in the TBRE and from stranded "fresh dead" animals along the northern part of the Georgia coast to quantify and compare concentrations of persistent organochlorine pollutants (POPs) including PCBs, organochlorine pesticides (OCPs) and chlorinated monoterpenes (toxaphene). PCBs were the most abundant class of POPs present for both TBRE and northern animals; in TBRE dolphins, PCBs represented an average of 81% of total POPs, and in northern animals, PCBs represented an average of 67% of total POPs (Pulster et al., 2009). TBRE dolphins, however, contained more Cl_8–Cl_{10} homologues—consistent with Aroclor 1268 composition—while stranded dolphins to the north contained congeners more ubiquitous in marine mammals throughout the world (Pulster et al., 2009). Though different studies have identified a range of threshold concentrations at which PCBs cause adverse health effects in dolphins—14μ/g lipid weight (Schwacke et al., 2002) and 17μ/g lipid weight (Kannan et al., 1997) among reported values—TBRE dolphins exceeded these values by up to an order of magnitude (Pulster et al., 2009).

Pulster and Maruya (2008) also assessed PCB congener patterns in inshore dolphin populations (free-range or stranded) and the contaminated prey-fish they consume to determine if patterns were linked by location. They found different congener patterns in Savannah dolphins and fish versus Brunswick dolphins and fish; in Brunswick, highly chlorinated congeners dominated both patterns. Further, Brunswick dolphins had congener patterns distinct from both Savannah dolphins and dolphins from other coastal estuaries, with their most abundant congeners (96, 199, and 208) coinciding with those comprising the bulk of Aroclor 1268 (Pulster & Maruya, 2008). These results indicated that dolphins feeding in their respective estuaries feed mostly within a small coastal or estuarine area (Pulster & Maruya, 2008). Importantly, authors noted the need to understand both primary sources and spatial extent of contaminated media in selecting management actions to reduce contaminant risks (Pulster & Maruya, 2008).

In a later study, Balmer et al. (2011) sampled Brunswick dolphins via remote biopsy from 2006–2007, and Sapelo Island dolphins from 2007–2008. One Brunswick male dolphin contained the highest levels of PCBs documented in any marine mammal in the world with concentrations 1.5 times greater than that of a transient Pacific killer whale (*Orcincus orca*) (Balmer et al, 2011). Killer whales feed upon other marine mammals and can carry large burdens of PCBs due to biomagnification, but dolphins feed primarily from lower trophic levels and their PCB concentrations would be expected to reflect this dietary difference (Balmer et al., 2011). Females in this study carried higher Aroclor 1268 proportions than males, suggesting highly chlorinated congeners may not offload during parturition and lactation as is generally seen with lower chlorinated congeners (Balmer et al., 2011).

Using photo-identification data to establish three ranging patterns—Brunswick, Sapelo, or Mixed—researchers found a negative relationship between proportion of Aroclor 1268 in dolphins and their distance from LCP. Of note, samples from dolphins in the Sapelo Sound reference site (~40km north) still contained proportions of Aroclor 1268, suggesting wider distribution of this contaminant than originally anticipated (Balmer et al., 2011). Further, Sapelo male dolphins had ∑PCBs comparable to other high levels seen in the southeast U.S. (Balmer et al., 2011).

Kucklick et al. (2011) expanded the spatial scope of POP analysis in dolphins by collecting 300 blubber samples from male dolphins in a total of 14 locations in the U.S. East Coast, Gulf of Mexico, and Bermuda. POPs varied significantly by sampling location, and once again, contaminant profiles in Brunswick and Sapelo dolphins differed from other regions. Authors noted that results indicated likely widespread contamination of the food web by Aroclor 1268 (Kucklick et al., 2011). The high PCB body burdens documented in TBRE dolphins have raised concerns about potential health effects they may face, particularly given their strategic stock status.

Mercury and PCB Health Effects in Dolphins

Both mercury and Aroclor 1268 are found in larger concentrations in higher trophic levels due to their tendencies to bioaccumulate and biomagnify (EPA, 2015). Long-term oral exposure to methylmercury in laboratory settings has resulted in kidney, stomach, and large intestine damage, blood pressure and heart rate alteration, reproductive and fetal development issues, and increased spontaneous abortions and stillbirths in animals (ATSDR, 1999). Animal studies have also demonstrated nervous system effects at lower mercury doses than with exposure to other bodily systems (ATSDR, 1999).

Though mercury has not been the focus of dolphin contaminant studies in the TBRE, stranded dead dolphins in the U.S. have contained high mercury concentrations in sampled tissues (Reif et al., 2015). Live dolphins sampled in the Indian River Lagoon (IRL), Florida had some of the highest mercury concentrations in the world in their blood and skin samples (Reif et al., 2015). These dolphins also had biological markers of impaired health, including renal, hepatic, hematologic, and immune impairments (Reif et al., 2015).

High concentrations of PCBs in marine mammals are thought to contribute to immunosuppression and reproductive effects (Kannan et al., 2000; Schwacke et al., 2002). Health assessments conducted in 2009 demonstrated Coastal Georgia dolphins' vulnerability to the toxic effects of PCBs (Schwacke et al, 2012). Schwacke et al. (2012) reported that 26% of sampled dolphins were anemic. Additionally, endocrine endpoints (total thyroxine, free thyroxine, and triiodothyronine) and immunity endpoints (T-lymphocyte proliferation and indices of innate immunity) decreased as PCB blubber concentrations increased in sampled animals (Schwacke et al., 2012). Several sampled dolphins were also smaller than expected based on their estimated ages (Schwacke et al., 2012).

Study authors noted that though more highly chlorinated PCB congeners such as Aroclor 1268 are thought to be more inert and less toxic than other less chlorinated Aroclors, their findings suggested Aroclor 1268 accumulation at concentrations high enough to cause significant health concerns in sampled animals. Mono-ortho congeners were also identified in higher levels in Georgia dolphins than those in reference sites, likely increasing the overall toxicity to dolphins when combined with more highly chlorinated congeners in these animals (Schwacke et al., 2012).

Of concern, some animal studies have suggested synergistic effects of PCBs and mercury, both present in the TBRE. Bemis and Seegal (1999) exposed in vitro striatal punches of adult rat brains to PCBs and methylmercury to understand which contaminants in fish tissues altered development and cognition in children born to mothers consuming contaminated fish, and whether contaminants acted independently or synergistically. The combination of methylmercury and a 1:1 mixture of Aroclors 1254 and 1260 led to synergistic depletion of the neurotransmitter dopamine in exposed tissues that exceeded the sole effect of either contaminant (ATSDR, 2000; Bemis & Seegal, 1999). Notably, study authors suggested fish consumption advisories should address synergistic effects of environmental contaminants (Bemis & Seegal, 1999).

Studies of contaminant concentrations and resulting health effects in TBRE dolphins have prompted concern regarding potential of human health risks from fish in the TBRE. Though human health assessments have been conducted in the LCP site (discussed below), none have involved biomonitoring and PCBs to our knowledge, and those testing mercury did not test for long-term ingestion.

Health Effects of Mercury and PCBs in Humans

Mercury and PCBs in the TBRE are a concern due to the range of negative health effects they can cause in humans who ingest large quantities of them. Methylmercury is readily absorbed in the gastrointestinal tract and quickly enters the bloodstream following consumption; from here, it moves freely to most tissues, including the brain (ATSDR, 1999). In pregnant women, it moves readily into a developing child's blood, brain, and tissues, or it can be passed to a child through breast milk (ATSDR, 1999). It is more dangerous for fetuses and children than adults as it may cause developmental issues (ATSDR, 1999). Ingestion of large amounts of mercury can also cause permanent damage to the brain and kidneys (ATSDR, 1999). The EPA lists methylmercury as a possible human carcinogen, and the FDA permits a maximum of 1 ppm of methylmercury in seafood products subject to interstate commerce (ATSDR, 1999).

In human studies, small increases in serum PCBs have been linked to reproductive, immune, cardiovascular, and neurological health effects (ATSDR, 2014). Some populations are more sensitive to PCBs than others, including children. Fetuses and children are more vulnerable to PCBs than adults as their target systems—brain, nervous system, immune system, thyroid, and reproductive organs—are still developing (ATSDR, 2000). Fetuses in the womb can be exposed to PCBs by their mothers when the mother releases PCBs that cross the placenta and enter fetal tissue, while infants are most likely to be exposed to PCBs through fats in breast milk as PCBs readily dissolve and accumulate in fat (ATSDR, 2000). EPA and the International Agency for Research on Cancer (IARC) have deemed PCBs a probable human carcinogen (ATSDR, 2000). The FDA's current residue limits for PCBs in foods for infants and juniors is 0.2 parts PCBs per million parts (ppm) and 2 ppm (or 2 mg/kg) for edible portions of fish and shellfish (ATSDR, 2000).

Mixture effects

The ATSDR also notes uncertainty in consideration of human health effects of PCBs based upon the varying structure of commercial PCB mixtures. Aroclors—a type of commercial PCB mixtures sold in the U.S.—differ by percent weight by chlorine (ATSDR, 2014). Very little toxicological data is available specific to Aroclor 1268, and thus ATSDR uses other mixtures—like Aroclor 1254—in evaluating harmful effects (ATSDR, 2014). Further, human conclusions that can be drawn from animal testing are limited by potential species differences in susceptibility or sensitivity to PCBs, and differences in length/level of exposure and composition of mixtures (ATSDR, 2000).

Disentangling effects of PCBs from other mixtures of contaminants humans may have been exposed to also complicates understanding of PCB-related health effects. The ATSDR (2000) reported health effects linked to human exposure to PCBs, some of which were associated with ingestion of contaminated food sources in Japan and Taiwan. These included liver, thyroid, dermal/ocular, immunological, neurodevelopmental, birth weight, and reproductive effects, as well as cancer (ATSDR, 2000). Here, subjects may have been exposed to a mixture of PCB congeners as well as other chemicals, which posed a challenge in attributing health effects solely to PCBs (ATSDR, 2000).

Of concern, studies have demonstrated that children who are exposed to low levels of PCBs, mercury, and lead—all present at the LCP site—demonstrated attention and impulse control issues following diminished learning of a performance task (ATSDR, 2014). Further, the ATSDR (2000) notes that limiting or preventing PCB exposure is the most effective way to reduce body burdens.

Human Health Assessments in the TBRE

A series of human health assessments have been undertaken related to OU1, with the ATSDR preparing three health consultations, one public health assessment, and a seafood consumption report (ATSDR, 2014, 2015).

ATSDR health consultations are relatively small-scale verbal or written responses to petitioned requests for information; they allow the ATSDR to respond quickly to concerns about specific site-related public health concerns, or concerns involving chemical releases or hazardous substances, following which additional public health actions may be recommended (ATSDR, 1996). Conversely, health assessments address site-specific issues in greater detail through evaluation of multiple data sources to determine whether past, current, or future exposure of hazardous substances is a concern. If exposures may cause harm to human health, ATSDR recommends additional action (ATSDR, 2014, 2015).

Exposure pathways

To assess the potential for harm, the ATSDR uses completed, potential, or eliminated exposure pathways to determine whether and how people may encounter contaminants. The pathway defines a contaminant's movements, while exposure, such as that occurring through inhalation, ingestion, or dermal contact, is necessary for a contaminant to harm human health (ATSDR, 2014). The ATSDR defines an exposure pathway as consisting of five elements: a contamination source, an environmental media, an exposure point, a human exposure route, and a receptor population. Completed exposure pathways fulfill all five elements, and they necessitate further study to determine whether contaminants may result in harmful health effects (ATSDR, 2014). Conversely, potential exposure pathways lack element information or certainty, but potential human exposure is a possibility (ATSDR, 2014). Finally, eliminated exposure pathways are dismissed when one or more element is found to be lacking (ATSDR, 2014).

ATSDR studies

The ATSDR's first LCP Health Consultation was published in 1994 in response to a petitioner's concerns about potential public health implications of ingesting contaminated fish from Purvis Creek and the Turtle River (ATSDR, 1994). ATSDR reviewed data from EPD and CRD's 1991–1993 sampling efforts and noted overall reductions in PCB and mercury concentrations with time in crab and fish (ATSDR, 1994). In their conclusions, however, they highlighted that bioaccumulation of mercury and PCBs could continue in fish until the contaminant source was removed, and thus advisories should be maintained until that time (ATSDR, 1994). Further, they identified LCP as a public health hazard due to uncontrolled release of mercury (ATSDR, 1996).

In 1996, a second health consultation followed—conducted after initial contaminant removal actions occurred at the LCP site—in which ATSDR labeled LCP an indeterminate health hazard due to inadequate data on contaminant exposure (ATSDR, 1996). At this time, the State of Georgia still maintained advisories for Purvis and Gibson Creeks, as well as intake recommendations for species of concern in unrestricted fishing areas (GDNR, 1996 as cited in ATSDR, 1996). ATSDR (1996) reviewed EPD data and methodology for determining LCP fishing advisory limits and found them protective of human health for both cancerous and noncancerous outcomes for PCBs.

Next, to better understand fish consumption practices and potential for related health outcomes from mercury exposure, the ATSDR worked with the Glynn County Health Department (GCHD) in 1998 to survey advisory area seafood and wild game consumption habits in two groups—target versus comparison—of Brunswick fishers (GCHD, 1999). The target group fishers had ingested seafood from the Turtle River and its tributaries, while the comparison group had not (GCHD, 1999). Fifty-one percent of the target group had caught fish from restricted areas in the past five years, and the target group self-reported more health symptoms than those in the comparison group who had not fished in advisory areas (GCHD, 1999). Their urine mercury concentrations, however, fell below the 20-µg mercury/g creatinine level used for mercury exposure testing (GCHD, 1999).

This study, however, may not have adequately characterized all Brunswick advisory-area anglers and their potential risks from mercury consumption. The ATSDR noted several limitations of the study: 1. It did not necessarily reflect habits and health of subsistence fishers as only one target group participant identified as a subsistence fisher, 2. Hair testing would have been more suitable than urine testing to capture longer-term methylmercury exposure as study participants might have reduced their consumption during the study if their dietary recall surveys prompted reduced consumption of contaminated fish, 3. Urine mercury levels were set too high and should have been set at 2 µg/g rather than 20 µg/g, and 4. Only 4% of study participants were African American (9 of 211) despite representing 40% of the population within four miles of the LCP site at the time (ATSDR, 2014). The ATSDR also referenced a study conducted along the Savannah River that found African American participants ate more fish meals, larger fish portions, and more total ounces of fish per month than white respondents (Burger et al., 1999), and of concern, they stated the results of the Brunswick fish study should not be applied to African Americans residing in the area (ATSDR, 2014).

ATSDR's last action at the LCP site began with a draft public health assessment release in 2010 (final version published in 2014). In their public release, they called upon other agencies to collect additional environmental data, and in response, Environmental Planning Specialists (EPS) conducted sediment and fish sampling on behalf of Honeywell in the portion of the Altamaha Canal south of LCP that is tidally connected to the lower Turtle River (ATSDR, 2014). Of note, Aroclor 1268 was the only PCB congener detected in sampled fish tissues, indicating the LCP site as the probable source (ATSDR, 2014). Based on results of these efforts, lower Turtle River advisories were applied to the Altamaha Canal (ATSDR, 2014).

Concluding their action at the LCP site OU1, ATSDR labeled seafood ingestion in the Turtle River system a past completed exposure pathway in their 2014 assessment as GDNR fishing advisories were in place to prompt reduced contaminant exposure. They also noted that a Brunswick environmental non-governmental organization (NGO)— Glynn Environmental Coalition (GEC)—published a flyer entitled "Seafood Consumption Advisory for Turtle River" available in Brunswick to help guide residents' safe seafood consumption, and the GDNR published a brochure with recommendations specific to women consuming seafood. However, they acknowledged that some people may still be consuming contaminated fish if they are unaware of, or ignore, local advisories (ATSDR, 2014).

Human Health Baseline Risk Assessment

Prior to the ATSDR's publication of their 2014 health assessment, EPS (2011) released their Human Health Baseline Risk Assessment (HHRA) for OU1 on behalf of Honeywell. Intended to support site remediation decision-making, this assessment evaluated whether possible exposure and health risks at OU1 might result from constituents of potential concern (COPC)—those contaminants present at levels beyond EPA regional screening levels (RSL)—in site sediment and consumable biota (EPS, 2011). The EPA identified COPCs and calculated exposure point concentrations (EPC) for site contaminants (EPA, 2010 as cited in EPS, 2011) that were used in assessment calculations (EPS, 2011). Contaminant occurrence data was derived from fish and shellfish samples collected in the areas of the TBRE most proximal to the LCP site, zones 2 and 4, between 2002 and 2006 while fish species were chosen based upon likelihood of consumption derived from NOAA/GDNR Marine Recreational Fisheries Statistics Survey (MRFSS) data from 2001–2005 (EPS, 2011).

EPS used both central tendency exposure (CTE) and reasonable maximum exposure scenarios (RME) to represent risks ranging from midrange exposure (CTE) to those occupying the 90th percentile or above (RME) of the exposure distribution (EPS, 2011). They followed exposure assumptions detailed in EPA's *Exposure Factors Handbook Volumes I–III* (EPA 1997, as cited in EPS, 2011) with input from the GCHD's surveying efforts informing the high-quantity fish consumers' exposure. They used EPA's cancer slope factor for high-risk and persistent PCB mixtures of 2.0 per mg/kg-day for their assessment, and the Rfd of 0.00007 mg/kg-day for Aroclor 1016, based on its similarity to Aroclor 1268 in toxicity in humans (EPS, 2011). They used the EPA Rfd for mercury of 0.0001mg/kg-day (EPS, 2011).

EPS evaluated carcinogenic endpoints and non-carcinogenic endpoints; excess lifetime cancer risk (ELCR) values were used to estimate to what degree lifetime exposure to COPCs could potentially increase cancer risk over a 70-year lifespan, while hazard quotients (HQ) greater than 1 indicated the potential for non-carcinogenic health effects, summed for site COPCs to yield a hazard index (HI) (EPS, 2011). As previously discussed, this health assessment was aimed at supporting remediation-decision making (EPS, 2011). Assessment results exceeded values for cancer endpoints, non-cancer endpoints, or both in several consumption scenarios, including RME scenario recreational fishers, RME scenario high-quantity fish consumers, and CTE scenario high-quantity fish consumers (EPS, 2011). Per the EPA, COPCs become COCs when the site cancer risk is larger than 10^{-4}, or the non-carcinogenic HI exceeds 1, with these values serving as "triggers" for remedial action (EPA, 2018; EPS, 2011).

EPS noted that their assessment may have overestimated ingestion of contaminated fish from the LCP area since it drew upon the ATSDR/GCHD study in which respondents were asked about seafood consumed from all sources, but also that the small sample size and short duration of this study created additional uncertainty around consumption pattern findings (EPS, 2011). Further, EPS commented that Brunswick is unlikely to have subsistence fishers based on consumption rates reported in the ATSDR/GCHD study, citing a mean intake of 59 g/day in Columbia River tribes. However, as previously noted, the GCHD study had low African American participation, a low sample size, and only one subsistence fisher in the target group (EPS, 2011; GCHD, 1999). Finally, they argued that subsistence fishers are not likely in Brunswick based on zip codes associated with the MRFSS data; they reviewed incomes in zip codes coinciding with harvest of spot (*Leiostomus xanthurus*) or striped mullet—two species they noted as easily caught from shore—and determined average annual income of these zip codes ($37,847 from 2001–2005) was close to the average annual income of all zip codes in coastal Georgia ($38,193) (EPS, 2011).

Further fish consumption surveying in Brunswick

McElwee (2015) conducted fish consumption surveying in coastal areas from Brunswick to Sapelo Island in 2013– 2014, finding trends counter to some of the assumptions underlying the HHRA. Most surveying sites were consistent with those included in GDNR's MRIP surveying efforts (McElwee, 2015). A considerable portion of anglers consumed more fish than advisories accounted for with just over half of respondents reporting they consumed 12 oz. or more in a fish meal; those who consumed fish meals with greatest frequency also consumed the largest portions (McElwee, 2015). Additionally, more than a quarter of participants reported annual household incomes of less than $25,000 (29.2%), though 31% of respondents elected not to share their income (McElwee, 2015).

Using MRIP data, spotted sea trout (*Cynoscion nebulosus*), Atlantic croaker (*Micropogonias undulatus*), and southern kingfish (*Menticirrhus americanus*), also known as whiting, were identified as species frequently caught and kept by Brunswick fishers (McElwee, 2015). Consistent with this data, respondents reported the fish they most often consumed as follows: 56 of 113 respondents reported whiting, 22 out of 113 reported spotted sea trout, and 21 out of 113 reported croaker (McElwee, 2015). Additionally, while 75% of respondents said they "always or sometimes" filleted their catch, around 50% of participants reported "always or sometimes" ingesting whole fish (McElwee, 2015). Finally, 49.5% of respondents reported consuming 1 fish meal or more weekly, 52% had children in their homes who consumed their catch, and 55% of respondents said they had caught and consumed fish from Brunswick-area estuaries for 20 or more years (McElwee, 2015).

These consumption patterns suggested that anglers could be exposed to .074 µg/kg/day of PCB as compared to the ATSDR's Minimum Risk Level of .02 µg/kg/day for chronic duration exposure, above which sensitive populations might experience adverse health effects (ATSDR, 2000; McElwee, 2015). Conversely, consumption of a whole fish, as opposed to a fillet, may reduce the average mercury exposure concentration (McAuley et al., 2018). It follows, however, that fishers consuming *more* fish than advisories suggest might also be ingesting larger amounts of mercury than assumed.

The HHRA also assumed that contaminants stayed in the vicinity of the LCP site, however this may not be the case based on a growing body of research (Balmer et al., 2011; Pulster et al., 2005; Wirth et al., 2014). Evidence of Aroclor 1268 movement beyond the LCP site was documented in humans in a community ~40km to the north of Brunswick. A group of researchers became interested in the relationship between POPs in humans, dolphins, and prey fish of three coastal communities—Sapelo Island, Georgia, Miami, Florida, and Charleston Harbor, South Carolina—in which prior dolphin sampling documented body burdens of environmental contaminants (Backer et al., 2019).

On Sapelo Island, researchers recruited nine adults who were residents for a minimum of five years and who, for the last two years, had consumed two meals per week or more of local seafood. Study participants provided information on their hunting, fishing, and seafood consumption habits, and they, in turn, provided researchers with a sample of a fresh seafood catch. Subsequently, researchers collected blood samples from human participants, and they compared levels of a range of contaminants in human serum to concentrations found in seafood samples, Sapelo dolphins, and to those documented in relevant years and demographics of the National Health and Nutrition Examination Survey (NHANES) (Backer et al., 2019). Out of nine respondents, five reported consumption of gutted whole fish, one consumption of whole fish, three consumption of skin-on fillets, and one consumption of skinless fillets (Backer & Mellard, 2014).

Sapelo residents' blood contained median concentrations of mercury that fell between the 50^{th} and 95^{th} percentiles of NHANES comparison groups, with Miami residents testing the highest for mercury and Charleston residents the lowest (Backer et al, 2019). Researchers found Miami fish had four times the mercury concentration of Sapelo Island fish. They identified dioxin-like PCBs exceeding the 50^{th} percentile of relevant NHANES comparison groups in Sapelo Island and Miami human serum samples, though Miami dolphins containing higher concentrations of summed non-dioxin-like congeners than Sapelo and Charleston dolphins (Backer et al., 2019).

Of note, researchers found non-dioxin-like PCB congeners comprising Aroclor 1268 in the highest concentrations in Sapelo dolphins, humans, and fish with 52% Aroclor 1268 congeners in Sapelo residents' serum compared to 24% and 34% in Charleston and Miami residents. Sapelo fish contained 71% of Aroclor 1268 congeners versus 8.29% in Miami fish (Backer et al., 2019). Researchers also found Sapelo resident's serum samples exceeded 95^{th} percentiles for NHANES comparison groups for congeners 196, 199, and 206, while they fell between the 50^{th} and 95^{th} percentiles for 11 other congeners—146, 157, 167, 170, 172, 178, 180, 183, 187, 194, and 209 (Backer et al., 2019).

Sapelo Island fish, dolphins, and human serum contained medium concentrations of congeners 196, 199, and 206—all in Aroclor 1268—with fish and human concentrations at the same order of magnitude, while dolphins had concentrations up to three orders of magnitude greater. Study authors noted that their results suggested that marine mammal contaminant presence and concentrations are useful in indicating a need for further research in human populations, particularly where human data is lacking (Backer et al., 2019). These results raise questions about contaminant concentrations in Brunswick anglers and the types of health effects that may result from overconsumption of contaminated fish.

Future Research

Though fishing advisories are an important means of controlling potential public health risks at Superfund sites, some Brunswick anglers are still consuming whole fish and engaging in other risky fish-consumption behaviors. As previously discussed, the health assessments that have informed site decision-making are built upon assumptions that may not be true for all anglers. To summarize, the issues we found with these assumptions are as follows:

Table 2.1: Assumptions underlying human health assessments in the TBRE.

Assumption	**Issue**	**Need**	**Potential Risk**
Fishing advisories are protective	Not all anglers are following advisories	Improved fishing advisory communication and content	Underestimating exposure to site contaminants
	Lack of human biomonitoring data	More extensive fish consumption surveying	
All anglers are represented by HHRA	African American anglers and other POC are under-represented	More extensive fish consumption surveying	
No subsistence fishers	Lack of data	Whole-fish data on popular species	
All anglers fillet fish	50% always or sometimes eat whole fish		

Quantifying whole-fish contaminant concentrations is an important step in better understanding potential exposures of anglers who are not filleting their fish. Thus, whole-fish samples of species popular with recreational anglers should be analyzed for PBTs, particularly lipophilic contaminants, to characterize the extent of exposure for anglers and those with whom they share their fish. Further, additional fish consumption surveying should be conducted with the goal of capturing responses from those at-risk populations most likely to engage in risky fish consumption behaviors.

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CHAPTER 3

BOUNDARY ISSUES: CONTAMINANTS IN PREY FISH AND CONSUMPTION ADVISORIES NEAR A SUPERFUND SITE IN BRUNSWICK, GEORGIA [2]

[2] Levine, T.R., Fowler, L.A., Bringolf, R.B., & Schacke, J.H. To be submitted to *Environmental Health Perspectives*.

Abstract

PCBs and mercury are persistent, bioaccumulative, and toxic (PBT) chemicals that often prompt U.S. fishing advisories. At the Linden Chemicals and Plastics (LCP) Superfund Site in Brunswick, Georgia, chemical discharges have contaminated the Turtle-Brunswick River Estuary (TBRE) for over 25 years. PCBs and mercury are two site contaminants, and a PCB mixture, Aroclor 1268, is a site signature pollutant. Previous studies in the TBRE have documented high levels of PBT chemicals in Atlantic Bottlenose dolphins (*Tursiops truncatus*) and their prey. Dolphins are sentinel species indicating potential health risks humans may face if exposed to PBTs from ingesting whole fish. Of concern, some humans appear to be consuming whole fish, and human health assessments used to inform fishing advisories may not have represented consumption habits of all anglers. To identify concentrations of PBTs to which dolphins and humans consuming whole fish are exposed, and to assess whether existing fishing advisories are adequately protective of human health, three species of fish were sampled within and outside of the TBRE. Results support prior findings that contaminants have moved beyond the LCP site, and in some reference sites, fish tissue concentrations exceed those within certain advisory areas.

Introduction

Polychlorinated biphenyls (PCBs) and mercury are two EPA-designated persistent, bioaccumulative, and toxic (PBT) chemicals (40 C.F.R § 372) that also represent two of the five toxins upon which most United States (U.S.) fishing advisories are based (EPA, n.d.-d). Though mercury naturally occurs in the environment, mercury in fish may also result from municipal and industrial operations as well as fossil fuel use (GDNR, 2021). PCBs, however, are synthetic chemical mixtures, and though they are no longer in use (Carpenter, 2006), approximately 1.5

billion pounds of PCBs were manufactured from 1920 to 1979 when they were banned in the U.S. for the harm they cause to human and environmental health (National Oceanic and Atmospheric Administration [NOAA], 2021).

Once released into the environment, the fate of PCBs varies based upon their degree of chlorination with more highly chlorinated congeners adsorbing strongly to sediment where their half-lives last for months to years (ATSDR, 2000). Because PCBs have low solubility in water and low volatility, continued releases from sediments that serve as environmental reservoirs of PCBs may occur for a long period of time (EPA, 1999). The stable and lipophilic properties of PCBs also lead to bioaccumulation in fatty tissues of organisms in exposed food chains (ATSDR, 2000).

The EPA partners with states, tribes, and federal agencies to survey water quality through National Aquatic Resource Surveys (NARS) (EPA, n.d.-f). NARS assess water quality as well as contaminant concentrations in fish tissues in U.S. waters—rivers and streams, coastal areas (including estuaries and Great Lakes nearshore areas), lakes, and wetlands (EPA, n.d.-f). In the 2013–2014 survey of rivers and streams, 1,853 rivers and streams were randomly sampled in the lower 48 states (EPA, 2020). Mercury exceeded the EPA fish tissue-based water quality criterion recommendation in 24% of river miles (25,119 river miles) in fish fillet composites, and PCBs exceeded EPA's human health fish tissue benchmark in 40% of river miles sampled (24,583 river miles) (EPA, 2020). Though human-health indicators for mercury were slightly better than those in rivers in EPA's National Coastal Condition Assessment (NCCA) with 55% of estuarine areas sampled for fish fillet tissues at or below the EPA's human health benchmark for mercury, 43% of estuarine areas were not sampled, and PCBs were not included in chemical analyses

(EPA, 2021). Additionally, 55% of estuarine areas were rated in poor condition based on ecological effects of contaminated fish, and 10% of areas were not sampled (EPA, 2021).

Approximately one-fifth of potential or current Superfund sites publicly listed on the EPA Facility Registry Service (FRS) are 25 miles or less from the East or Gulf Coast (Union of Concerned Scientists [UCS], 2020). The Linden Chemicals and Plastics (LCP) Superfund site in Brunswick, Georgia, provides an example of a coastal Superfund site where ecological and human-health effects are linked through persistent contaminants. At this site, mercury and PCB releases have contaminated the Turtle-Brunswick River Estuary (TBRE) and its resident fish for over 25 years (Kannan et al., 1997; Maruya & Lee, 1998).

Studies of LCP marsh sediment have found almost half of mercury present is organic (ATSDR, 2014). Methylmercury, the most toxic mercury form, has bioaccumulated in TBRE fish, resulting from LCP's releases of elemental mercury and subsequent methylation in Purvis Creek and Turtle River sediments (ATSDR, 1994; Reif et al., 2015). Aroclor 1268—a highly chlorinated and infrequently used PCB mixture—is recognized as a point source PCB from the LCP site (Kannan et al., 1997; Maruya & Lee, 1998). This mixture represented less than 1 percent of U.S. sales from 1957 to 1971 (USDA, 1972 as cited in Cantwell et al., 2006), and subsequently, studies of health effects of PCBs have been heavily weighted towards less-chlorinated mixtures that are more commonly used than 1268 (Schwacke et al., 2012). The unique congener profile of Aroclor 1268 has also allowed study of its movements in biota, including dolphins, within and outside of the TBRE.

Atlantic bottlenose dolphins in the TBRE

Dolphins are sentinel species (Bossart, 2011), and they reveal potential contaminant burdens, contaminant profiles, and subsequent health issues that humans fishing from the TBRE may encounter. Photo-identification and genetic research have documented distinct genetic differences and long-term site fidelity of the Southern Georgia Estuarine System Stock (SGES)—the subgroup including dolphins inhabiting the TBRE (Balmer et al., 2011; National Marine Fisheries Service [NMFS], unpublished data as cited in Waring et al., 2015; Waring et al., 2015). High concentrations of PCBs have been well documented in SGES dolphins (Balmer et al., 2011; Pulster et al., 2009). Of concern, though different studies have identified a range of threshold concentrations at which PCBs cause adverse health effects in dolphins—14μ/g lipid weight (Schwacke et al., 2002) and 17μ/g lipid weight (Kannan et al., 1997) among reported values—TBRE dolphins exceeded these values by up to an order of magnitude (Pulster et al., 2009).

Additionally, Brunswick dolphins have been shown to have PCB congener profiles more reflective of Aroclor 1268 composition than those congener patterns in dolphins inhabiting other estuaries (Pulster & Maruya, 2008; Pulster et al., 2009; Balmer et al., 2011; Kucklick et al., 2011). Researchers have studied trends in PCB contamination and congener patterns in different estuaries across different trophic levels and have found highly chlorinated congeners in Brunswick fish and dolphins (Backer et al., 2019; Pulster & Maruya, 2008). Further, dolphins at Sapelo Island, approximately ~40km north of the TBRE, still contain proportions of Aroclor 1268 as well as ∑PCB concentrations comparable to those seen in other populations with high PCB levels in the southeast U.S. (Balmer et al., 2011). Based on the distinct contaminant profiles seen in Sapelo and Brunswick dolphins as compared to other populations, researchers have indicated likely widespread contamination of the food web by Aroclor 1268 (Kucklick et al, 2011).

Wildlife in the vicinity of the TBRE—including clapper rails (*Rallus longirostris*), least terns (*Sternula antillarum*), diamondback terrapins (*Malaclemys terrapin*), loggerhead sea turtles (*Caretta caretta*), and American alligators (*Alligator mississippiensis*)—have been the subject of a growing body of ecotoxicology research (Balmer et al., 2011; Bauer, 2019; Cumbee et al., 2008; Robinson et al., 2015; Schwacke et al., 2012). Prey items, such as invertebrates and fish, consumed by these and other organisms have also been studied in the TBRE and neighboring waterways (Backer et al., 2019; Prince et al., 2020; Pulster et al., 2005; Wirth et al., 2014) with several studies focusing on contaminant levels in prey fish consumed by dolphins and/or humans (Backer et al, 2019; Pulster et al., 2005; Wirth et al., 2014).

High contaminant body burdens of TBRE dolphins and indications of resulting health effects have raised concern about both the SGES dolphins and the other wildlife and humans feeding on seafood from the TBRE. As such, researchers have sought to quantify contaminant concentrations and their spatial extent in prey fish preferred by dolphins and humans alike.

Fish Studies in the TBRE

Prey studies have been conducted in the TBRE to quantify contaminant concentrations in biota, identify contaminant movement throughout the food chain, and to better understand sources of contaminant concentrations documented in site apex predators, namely dolphins. Findings have included high concentrations of PCBs—particularly in fatty tissues— in sampled TBRE fish species (Maruya & Lee, 1998), variability in interspecific and intraspecific PCB concentrations (Maruya & Lee, 1998; Pulster et al., 2005; Wirth et al., 2014), and movement of Aroclor 1268 throughout the estuary and beyond the boundaries of the TBRE (Maruya & Lee, 1998; Pulster et al., 2005; Wirth et al., 2014), all of which impact the efficacy of fishing advisories in protecting public health.

Kannan et al. (1998) found interspecific and intraspecific variation in Purvis Creek fish samples, with benthic detritivores such as striped mullet (*Mugil cephalus*) containing higher ∑PCB concentrations than other fish species sampled—such as yellow tail (*Bairdiella chrysoura*) and sea trout (*Cynoscion nebulosus*). Purvis Creek is located approximately 1km from the manufacturing complex of the LCP site, but intraspecific variability in ∑PCB concentrations of up to an order in magnitude was potentially caused by movement of fish along the contamination gradient (Kannan et al., 1998). Other studies also found intraspecific variability in PCB concentrations in individuals within the TBRE (Pulster et al., 2005; Wirth et al., 2014).

The unique congener profile of Aroclor 1268 is of use in assessing its movements in fish within and outside of the TBRE. Maruya & Lee (1998) noted contaminated food as a route of Aroclor 1268 transfer as PCB profiles in predator fish, their gut contents, and prey fish were consistent with Aroclor 1268 components. They also suggested that uptake of Aroclor 1268 initially occurred in resident prey fish that were later consumed by predator fish making seasonal use of the estuary. These predator fish, along with other mobile estuary species, then became contaminant "vectors" mobilizing hydrophobic contaminants throughout the estuary for potential consumption by other predators (Maruya & Lee, 1998).

Though researchers have documented decreasing concentration gradients in fish and shellfish with movement away from the point source contamination at the LCP site (Maruya & Lee, 1998), fish have been suggested as a likely vector carrying Aroclor 1268 not only throughout the TBRE (Maruya & Lee, 1998), but also to reference sites beyond the boundaries of the LCP site (Maruya & Lee, 1998; Pulster et al., 2005; Wirth et al., 2014). Studied reference sites have included portions of the St. Simons Sound, as well as locations to the north—

Skidaway River, Wassaw Sound, and Sapelo Sound (Maruya & Lee, 1998; Pulster et al., 2005; Wirth et al., 2014)—and one location to the south, Nassau Sound (Pulster et al., 2005).

Since movement of Aroclor 1268 beyond the boundaries of the TBRE has been well documented, as have the site fidelity and contaminant burdens of subpopulations of dolphins in coastal Georgia, Backer et al. (2019) explored the relationship between persistent organic pollutants (POPs) in humans, dolphins, and prey fish in three coastal communities—Sapelo Island, Georgia, Miami, Florida, and Charleston Harbor, South Carolina—in which prior dolphin sampling documented body burdens of environmental contaminants (Backer et al., 2019).

On Sapelo Island, researchers recruited nine adults who were residents for a minimum of five years and who, for the last two years, had consumed two meals per week or more of local seafood. Study participants provided information on their hunting, fishing, and seafood consumption habits, and they, in turn, provided researchers with a sample of a fresh seafood catch (Backer et al., 2019). Subsequently, researchers collected blood samples from human participants, and they compared levels of a range of contaminants in human serum to concentrations found in seafood samples, Sapelo dolphins, and to those documented in relevant years and demographics of the National Health and Nutrition Examination Survey (NHANES) (Backer et al., 2019).

Sapelo residents' blood contained median concentrations of mercury that fell between the 50^{th} and 95^{th} percentiles of NHANES comparison groups, with Miami residents testing the highest and Charleston residents the lowest (Backer et al, 2019). Researchers found Miami fish had four times the mercury concentration of Sapelo Island fish. They also identified dioxin-like PCBs exceeding the 50^{th} percentile of relevant NHANES comparison groups in Sapelo Island

and Miami human serum samples, though Miami dolphins containing higher concentrations of summed non-dioxin-like congeners than Sapelo and Charleston dolphins (Backer et al., 2019).

Of note, researchers found non-dioxin-like PCB congeners comprising Aroclor 1268 in the highest concentrations in Sapelo dolphins, humans, and fish with 52% Aroclor 1268 congeners in Sapelo residents' serum compared to 24% and 34% in Charleston and Miami residents. Sapelo fish contained 71% of Aroclor 1268 congeners versus 8.29% in Miami fish (Backer et al., 2019). Researchers also found Sapelo resident's serum samples exceeded 95th percentiles for NHANES comparison groups for congeners 196, 199, and 206, while they fell between the 50th and 95th percentiles for 11 other congeners—146, 157, 167, 170, 172, 178, 180, 183, 187, 194, and 209 (Backer et al., 2019).

Sapelo Island fish, dolphins, and human serum contained medium concentrations of congeners 196, 199, and 206—all in Aroclor 1268—with fish and human concentrations at the same order of magnitude, while dolphins had concentrations up to three orders of magnitude greater. Study authors noted that their results suggested that marine mammal contaminant presence and concentrations are useful in indicating a need for further research in human populations, particularly where human data is lacking (Backer et al., 2019).

These results raise questions about contaminant concentrations in Brunswick fishers catching seafood closer to the source of pollution and the types of health effects that may result from overconsumption of contaminated fish. They also highlight the widespread contamination of the food web by Aroclor 1268 (Kucklick et al., 2011) beyond the boundaries of the LCP site.

Human Health Assessments in the TBRE

Federal and state agencies as well as consulting groups contracted by PRPs, have assessed potential human health risks related to fish consumption surrounding the LCP site. Fish sampling activities have focused on prey fish and other edible seafood tissues consumed by humans, wildlife, or both. Results of these efforts led to fishing advisory implementation prior to LCP's 1994 closure that remain in effect today.

Though Brunswick residents were surveyed on fish and wild game consumption habits and urine-mercury tested by the Glynn County Health Department (GCHD) in partnership with the Agency for Toxic Substances and Disease Registry (ATSDR), this study did not include PCB biomonitoring, and it also may not have adequately characterized all Brunswick advisory-area anglers and their potential risks from mercury consumption. The ATSDR noted several limitations of the study: 1. It did not necessarily reflect habits and health of subsistence fishers as only one participant from the target group identified as a subsistence fisher, 2. Hair testing would have been more suitable than urine testing to capture longer-term methylmercury exposure, 3. Urine mercury levels should have been set at 2 μg/g rather than 20 μg/g, and 4. Only 4% of study participants were African American (9 of 211) despite representing 40% of the population within four miles of the LCP site (GCHD, 1999; ATSDR, 2014). The ATSDR also referenced a study conducted along the Savannah River that found African American participants ate more fish meals, larger fish portions, and more total ounces of fish per month than white respondents (Burger et al., 1999), and of concern, they stated the results of the Brunswick fish study should not be applied to Brunswick African Americans (GCHD, 1999; ATSDR, 2014).

Despite efforts of a Brunswick environmental non-governmental organization (NGO)—Glynn Environmental Coalition (GEC)— and the GDNR in maintaining educational materials regarding fishing advisories and their increased relevance to special populations like women and children, the ATSDR has acknowledged that some people may still be consuming contaminated fish if they are unaware of, or ignore, local advisories (ATSDR, 2014).

The EPA required Human Health Baseline Risk Assessment (HHRA) for LCP's OU1 was published in 2011 and was intended to support site remediation decision-making (EPS, 2011). This assessment evaluated whether possible exposure and health risks at OU1 might result from constituents of potential concern (COPC)—those contaminants present at levels beyond EPA regional screening levels (RSL)—in site sediment and consumable biota (EPS, 2011).

EPS stated that their assessment may have overestimated ingestion of contaminated fish from the LCP area since it drew upon the ATSDR/GCHD study in which respondents were asked about seafood consumed from all sources, but they also noted that the small sample size and short duration of this study created additional uncertainty around consumption pattern findings (EPS, 2011). Further, EPS commented that Brunswick is unlikely to have subsistence fishers based on consumption rates reported in the ATSDR/GCHD study, citing a mean intake of 59 g/day in Columbia River tribes. However, as previously discussed, the GCHD study had low African American participation, a low sample size, and only one self-reported subsistence fisher in the target group (EPS, 2011; GCHD, 1999).

Finally, they argued that subsistence fishers are not likely in Brunswick based on zip codes associated with the MRFSS data; they reviewed incomes in zip codes coinciding with harvest of spot or striped mullet—two species easily caught from shore—and determined average annual income of these zip codes ($37,847 from 2001–2005) was close to the average annual income of all zip codes in coastal Georgia ($38,193) (EPS, 2011). In contrast, the U.S. Census Bureau (USCB) reported a 2019 median household income of $28,032 in Brunswick with 34.7% of residents in poverty (USCB, 2021).

The limitations with the above studies suggest that human health assessments used to inform fishing advisories and site remediation activities may not have represented consumption behaviors of all Brunswick fishers.

Fish consumption surveying in Brunswick and Sapelo Island

McElwee (2015) conducted fish consumption surveying in coastal locations from Brunswick to Sapelo Island in 2013– 2014, finding trends counter to some of the assumptions underlying the HHRA. A considerable portion of anglers consumed more fish than advisories accounted with just over half of respondents reporting they consumed 12 oz. or more in a fish meal; those who consumed fish meals with greatest frequency also consumed the largest portions (McElwee, 2015). Further, more than a quarter of participants reported annual household incomes of less than $25,000 (29.2%), though 31% of respondents elected not to share their income (McElwee, 2015).

Using data from the Marine Recreational Information Program (MRIP)—a nationwide program that identifies habits of recreational fishermen through intercept interviews—spotted sea trout, southern kingfish (or whiting), and Atlantic croaker were identified as species frequently caught and kept by Brunswick fishers (McElwee, 2015). Consistent with this data, respondents reported the fish they most often consumed as follows: 56 of 113 respondents reported whiting, 22 out of 113 reported spotted sea trout, and 21 out of 113 reported croaker (McElwee, 2015). Additionally, while 75% of respondents said they "always or sometimes" filleted their catch, around 50% of participants reported "always or sometimes" ingesting whole fish (McElwee, 2015). Finally, 49.5% of respondents reported consuming 1 fish meal or more weekly, 52% had children in their homes who consumed their catch, and 55% of respondents said they had caught and consumed fish from Brunswick-area estuaries for 20 or more years (McElwee, 2015).

These consumption patterns suggested that anglers could be exposed to .074 μg/kg/day of PCB as compared to the ATSDR's Minimum Risk Level of .02 μg/kg/day, above which sensitive populations might experience adverse health effects (ATSDR, 2018; McElwee 2015). Conversely, consumption of a whole fish, as opposed to a fillet, may reduce the average mercury exposure concentration (McAuley et al., 2018). It follows, however, that fishers consuming *more* fish than advisories suggest might also be ingesting larger quantities of mercury than assumed.

These results were in line with other regional studies assessing fish consumption along the Savannah River. Burger et al. (1999) explored how fishing and fish consumption habits differed by ethnicity, income, education, age, and employment in a group of 258 anglers intercepted on the Savannah River. Of note, study authors canvassed three sections of the Savannah River for 54 days, with only 10 of the 268 fishers they engaged declining interviews. This population was intended to describe not only those fishing on the Savannah River, but also fishing in similar areas in the region (Burger et al., 1999).

Respondents were white (70%), African American (28%) or other (2%), primarily male (89%), and had an average annual income of $21,490 (Burger et al., 1999). Researchers found that African Americans consumed fish more frequently and ate larger portions of fish than Caucasians, but quantity per serving and fish meals per month were positively correlated for both African Americans and Caucasians. They also found that some anglers exceeded total consumption values used to represent recreational (19 kg/year) and subsistence (50 kg/year) fishers. Further, 85% ± 2 of fishers reported consuming whole fish, and many respondents noted that their children and wives ate the fish they caught, with children beginning to eat fish between the ages of 3–5 (Burger et al., 1999).

Based on their results, authors noted the importance of understanding how exposure variables are distributed rather than focusing solely on parameters such as averages, as averages do not represent those at highest risk. They concluded by noting the need for site-specific information (fisher demographics and consumption) necessary to assess and manage risks at a site, stating, "It is impossible to target the population at risk if sufficient information on the population is not available (Burger et al., 1999, pg. 437)."

Methods

Study site

The study site for this research was the LCP Superfund site marsh, more specifically, the four-advisory areas—Zone 1, Zone 2, Zone 3, and Zone 4—of the TBRE, as well as three reference sites—the St. Simons Sound (SS Sound), St. Simons Offshore (Offshore), and Sapelo Sound (North). Zone 1 represents the Upper Turtle and Buffalo Rivers, Zone 2 the Middle Turtle River, Zone 3 the Lower Turtle and South Brunswick Rivers, and Zone 4 Purvis and Gibson Creeks. Fish were collected from August 2019–November 2019 and again in March 2020 using the following methods:

Equipment Preparation

Equipment in contact with fish (ice chests, ice scoop, collection basket, water bucket) were washed with detergent and rinsed with distilled water between uses. The collection basket (in which sample fish were kept before processing) and water bucket (used to hold ambient water from sampling site) were rinsed with distilled water when changing between zones in the TBRE.

Sample Collection

Fish samples were collected by trawling vessels, hook-and-line, and cast net over two seasons—fall of 2019 and spring of 2020. The GA DNR research vessel—The Anna—was used to collect target samples by trawl net in three reference sites: St. Simons Offshore, St. Simons Sound, and Sapelo Sound. The UGA Marine Extension (MAREX) Bulldog, a UGA MAREX skiff, and the Georgia Dolphin Ecology Program boat—Nai'a—were used to collect samples within the four zones of the LCP advisory area in the Turtle-Brunswick River Estuary (TBRE)—Upper Turtle & Buffalo Rivers, Middle Turtle River, Lower Turtle & South Brunswick Rivers, and Purvis & Gibson Creeks. A hand-pulled 12-ft naked shrimp net was used for trawling on the smaller vessels. As bottom conditions vary throughout the TBRE, areas in each zone where depth and bottom conditions were favorable were trawled until collection quota was met for each species in each zone, or until the boat was no longer available for use. All non-target species were discarded. Additionally, hook-and-line fishing was used to supplement catch and better represent specimens that anglers may catch during recreational fishing. Only one sampling trip was completed during Spring 2020 after which COVID-related shutdowns occurred.

Sample Preservation

Each fish kept as a sample was rinsed with ambient water from the sampling location and submerged in ice. Using nitrile gloves, specimens were then wrapped in solvent-rinsed aluminum (double-rinsed in acetone), labeled, placed in a Ziploc bag, and placed on wet ice for a maximum of 36 hours. Samples were then preserved on dry ice until such time as they were placed in a -80° C freezer (a maximum of 7 days on dry ice). Field blanks were processed in the field, exposing solvent-rinsed aluminum pieces to the same processing protocols as fish samples to assess any introduction of contaminants to samples during laboratory or field activities.

Sample Processing

Fish were shipped to ALS Environmental in Kelso, Washington for PCB and mercury analyses. Whole fish were homogenized, and composite samples created. Composite samples ranged from 1–18 individual fish (n = 25 samples croaker/119 total fish, n = 27 samples whiting/74 total fish, n = 23 samples star drum/135 total fish). Composites were selected based on length-at-age distribution data. Field blank foils were rinsed with lab water, and rinsate was analyzed for contaminants introduced during solvent-rinsing of foils and subsequent field work. PCB congeners in fish tissues were analyzed using Analysis Method 8082A, and total mercury in fish tissues using Analysis Method 1631E. Surrogate percent recovery for fish tissue samples averaged 107.10% with an acceptance range from 70–130%.

Statistical Analysis

∑PCB data were lipid normalized and species-by-zone means calculated for purposes of visualization of interspecific comparison. Where sample-specific lipid information was unavailable, the lipid value for the fish closest in length from the same sampling season was used. Lipid-transformations were made using the following equation (adapted from EPA, 1997):

$C_{lw} = C_{ww}/(\text{lipid percentage}/100)$

where:

C_{lw} = lipid weight concentration

C_{ww}= wet weight concentration

(lipid percentage/100) = lipid fraction

Non-lipid transformed ∑PCB data was summed for all Aroclors and mean ∑PCB concentrations calculated for each species within each zone. North zone samples were discarded for PCB analyses as no PCBs were detected, likely due to sensitivity of congener analyses versus Aroclor analyses. Data were cube-root transformed. The Shapiro-Wilk test for normality was used to assess the data's normality of distribution, and data were visually assessed via density plot and histogram. One large whiting sample from Zone 4 was omitted from analyses due to extreme Aroclor interference (606% percent recovery of the surrogate versus a 70–130% acceptance range).

A one-way ANOVA was performed for each species to test the effect of zone on ∑PCB concentrations. Tukey's honest significant difference test (HSD) was used for post-hoc analyses. A mean ratio of Aroclor 1268/∑PCBs was calculated by zone and species. Finally, linear regression of length versus ∑PCBs was plotted to visually assess this relationship by zone and species.

Mean total mercury concentrations were calculated by species and zone. Total mercury concentration data were then log-transformed and tested for normality via the Shapiro-Wilk normality test. A one-way ANOVA was performed for each species to test the effect of zone on total mercury concentration.

Results

Differences in PCBs among zones

Lipid-normalized mean ∑PCBs are presented along with mean ∑PCBs of non-lipid-normalized concentrations in Table 3.1. Croaker means by zone (non-lipid-normalized) were: 51.00 ng/g ww (Offshore), 30.50 ng/g ww ± 11.50 (St. Simons Sound), 98.40 ng/g ww ± 55.36 (Zone 1), 87.50 ± 5.50 (Zone 2), 84.17 ng/g ww ± 28.96 (Zone 3), and 203.50 ng/g ww ± 63.47 (Zone 4). Whiting means by zone were: 21.14 ng/g ww ± 4.47 (Offshore), 76.33 ng/g ww ± 12.24 (St. Simons Sound), 317.40 ng/g ww ± 114.01 (Zone 1), 98.50 ± 64.50 (Zone 2), 56.50 ng/g ww ± 9.71(Zone 3), and 346.67 ng/g ww ± 31.80 (Zone 4). Star drum means by zone were: 26.00 ng/g ww (Offshore), 22.50 ng/g ww ± 6.59 (St. Simons Sound), 100.00 ng/g ww ± 33.00 (Zone 1), 71.25 ng/g ww ± 16.84 (Zone 2), 37.67 ng/g ww ± 20.51 (Zone 3), and 39.75 ng/g ww ± 3.79 (Zone 4). Mean Aroclor 1268/∑PCB ratios are also summarized in Table 3.1.

Table 3.1: Summary statistics of PCBs in whole-fish composite samples of Atlantic croaker, whiting, and star drum from six sampling locations (four advisory zones of the TBRE and two outside sites). Number of composite samples (N), Mean lipid-transformed ∑PCBs, mean ∑PCBs, minimum/maximum ∑PCB ranges, and mean PCB ratio (Aroclor 1268/∑PCB) are presented with respective standard errors (se).

Zone	N	Mean ∑PCBs, lipid weight basis, µg/g (se)	Mean ∑PCBs, ng/g ww (se)	Min and Max ∑PCBs (ng/g ww)	Mean PCB Ratio (se)
Croaker					
Offshore	1	2.83	51.00	--	1.0
SS Sound	2	1.87 (0.05)	30.50 (11.50)	19.00–42.00	1.0
Zone 1	5	3.64 (2.05)	98.40 (55.36)	0–302.00	0.46 (0.44)
Zone 2	2	16.29 (8.84)	87.50 (5.50)	82.00–93.00	1.0
Zone 3	6	5.21 (2.44)	84.17 (28.96)	20.00–220.00	1.0
Zone 4	8	34.62 (17.21)	203.50 (63.47)	22.00–560.00	1.0
Whiting					
Offshore	5	1.80 (0.65)	21.14 (4.47)	6.70–32.00	1.0
SS Sound	3	1.09 (0.16)	76.33 (12.24)	57.00–99.00	1.0
Zone 1	5	18.69 (10.61)	317.40 (114.01)	137.00–730.00	0.96 (0.09)
Zone 2	2	6.58 (3.00)	98.50 (64.50)	34.00–163.00	0.93 (0.10)
Zone 3	4	8.12 (3.67)	56.50 (9.71)	34.00–78.00	1.0
Zone 4	3	31.20 (7.39)	346.67 (31.80)	310.00–410.00	1.0
Star Drum					
Offshore	5	0.44	26.00	--	1.0
SS Sound	3	1.05 (0.22)	22.50 (6.59)	9.00–37.00	1.0
Zone 1	5	10.29 (3.96)	100.00 (33.00)	67.00–133.00	0.51 (0.17)
Zone 2	2	7.37 (1.40)	71.25 (16.84)	43.00–120.00	0.83 (0.20)
Zone 3	4	3.13 (1.03)	37.67 (20.51)	0–138.00	0.66 (0.43)
Zone 4	4	5.08 (0.41)	39.75 (3.79)	34.00–50.00	1.0

Figure 3.1 shows mean lipid-transformed ∑PCB concentrations (µg/g ww) with standard error (se) for croaker, whiting, and star drum by zone, and Figure 3.2 shows mean ∑PCB concentrations (ng/g ww) with se for croaker, whiting, and star drum by zone.

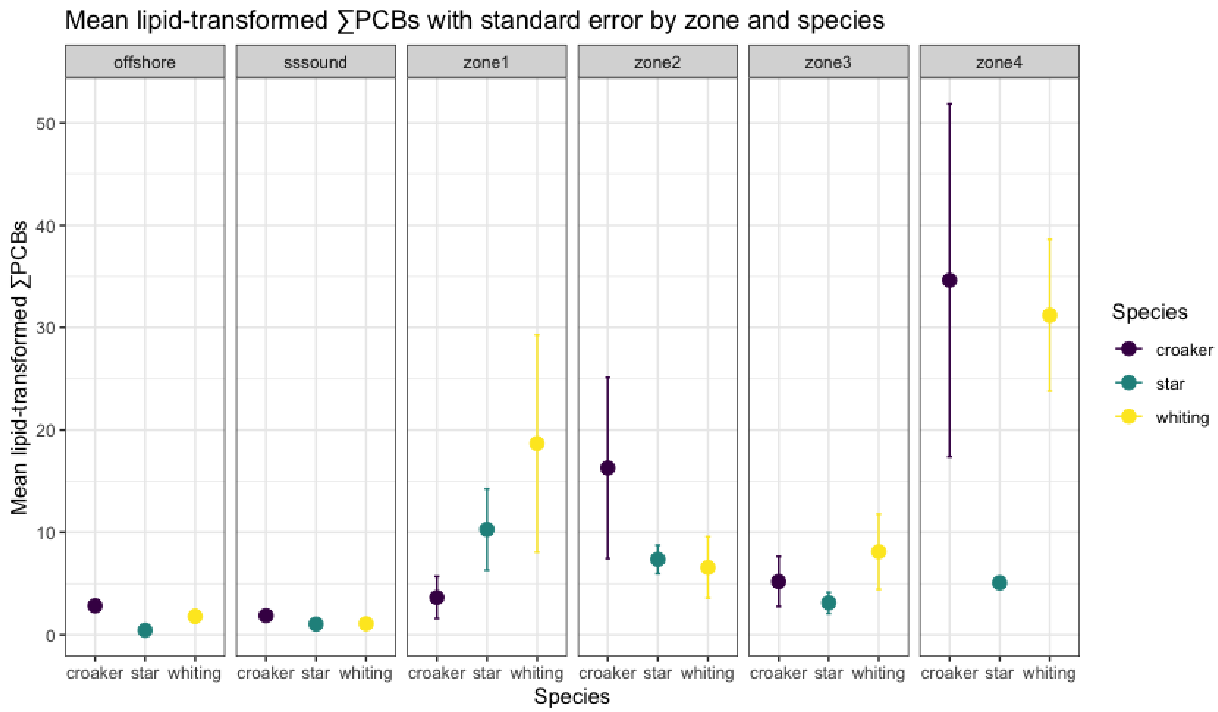

Figure 3.1: Mean lipid-transformed ∑PCB concentration (µg/g ww) and standard error (se) of croaker, whiting, and star drum from six sampling locations (four advisory zones of the TBRE and two outside sites).

The lipid-corrected ∑PCB data failed the Shapiro-Wilk test for normality, but ∑PCB data (ng/g ww) passed the Shapiro-Wilk test for each species following cube-root transformation ($W = 0.94987$, $p = 0.2692$ for croaker, $W = 0.94653$, $p = 0.2692$ for whiting, and $W = 0.91826$, $p = 0.0801$ for star drum). Separate one-way ANOVAs were performed for each species to test the effect of zone on ∑PCBs. The ANOVA detected a significant difference in the effect of Zone on

$\sum$PCBs in whiting between groups ($F(5, 16) = 11.24$, $p < 0.001$), but the one-way ANOVAs for croaker and star drum did not yield any significant results.

Tukey's HSD identified significant differences in mean $\sum$PCB values between the following groups: Offshore and Zone 1 ($p = 0.0023$, 95% C.I. = [1.7442, 5.8152]), Offshore and Zone 4 ($p = 0.0003$, 95% C.I. = [1.9683, 6.6692]), SS Sound and Zone 4 ($p = 0.03383$, 95% C.I. = [0.1664, 5.4221]), Zone 1 and Zone 3 ($p = 0.0111$, 95% C.I. = [-4.8353, -0.5172599]), and Zone 3 and Zone 4 ($p = 0.0072$, 95% C.I. = [0.7572, 5.6735]).

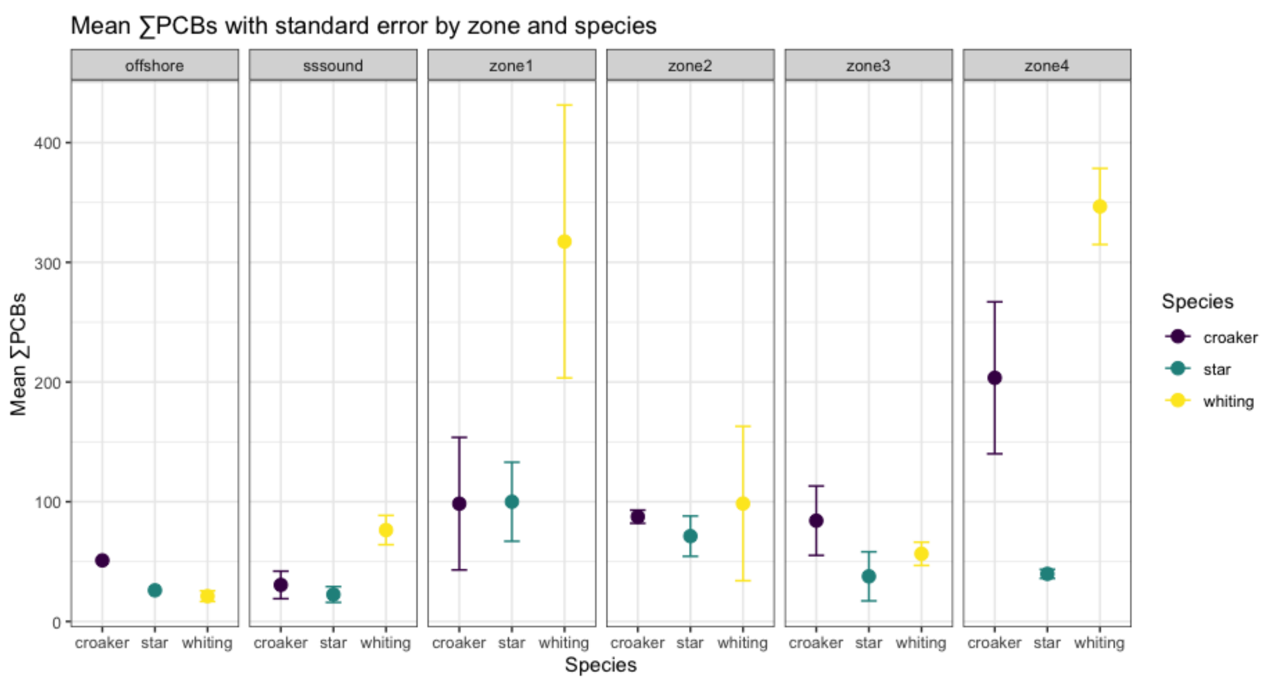

Figure 3.2: Mean $\sum$PCB concentration (ng/g ww) and standard error (se) for six sampling locations (four advisory zones of the TBRE and two outside sites) in croaker, whiting, and star drum.

Visual inspection of length versus ∑PCBs regression plots (Figure 3.3) demonstrated a positive relationship between length and ∑PCBs in all species and zones aside from croaker in Zone 2 and whiting in St. Simons Sound. Slope of regression lines varied considerably by zone.

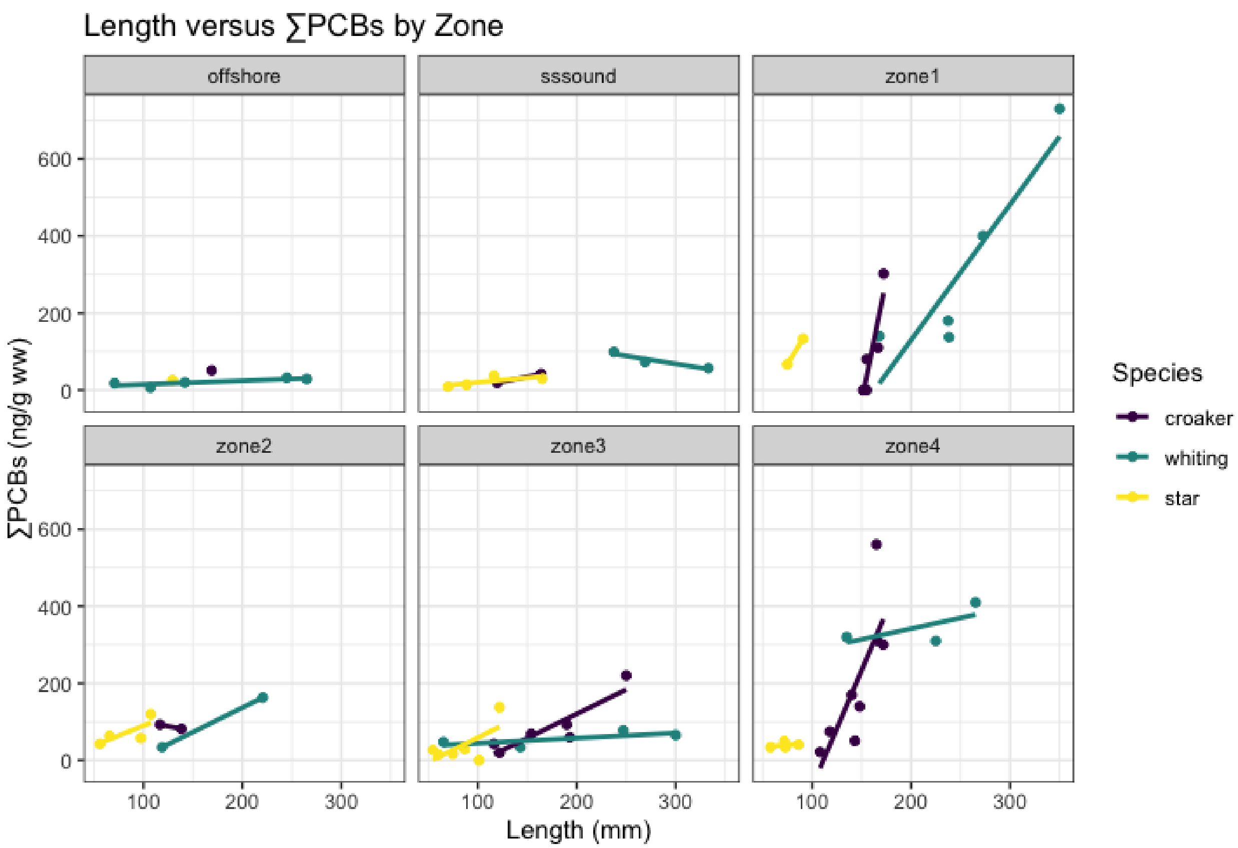

Figure 3.3: Regression lines (length versus ∑PCB concentration, ng/g ww) of six sampling locations (four advisory zones of the TBRE and two outside sites) in croaker, whiting, and star drum.

Zone differences in total mercury

Mean total mercury concentration was calculated for each species and zone. Results are summarized in Table 3.2. Croaker means by zone were: 18.00 ng/g ww (North), 41.60 ng/g ww

(Offshore), 27.50 ng/g ww ± 12.20 (St. Simons Sound), 77.56 ng/g ww ± 24.27 (Zone 1), 39.25 ± 8.25 (Zone 2), 36.23 ng/g ww ± 6.75 (Zone 3), and 57.66 ng/g ww ± 17.62 (Zone 4). Whiting means by zone were: 41.64 ng/g ww ± 23.91 (North), 45.72 ng/g ww ± 18.74 (Offshore), 114.93 ng/g ww ± 15.07 (St. Simons Sound), 333.66 ng/g ww ± 130.95 (Zone 1), 113.00 ± 48.00 (Zone 2), 74.30 ng/g ww ± 35.98 (Zone 3), and 234.48 ng/g ww ± 59.74 (Zone 4). Star drum means by zone were: 22.00 ng/g ww ± 6.60 (North), 42.60 ng/g ww (Offshore), 42.93 ng/g ww ± 15.95 (St. Simons Sound), 41.60 ng/g ww ± 1.70 (Zone 1), 72.28 ± 11.75 (Zone 2), 36.48 ng/g ww ± 9.60 (Zone 3), and 52.18 ng/g ww ± 1.88 (Zone 4). Mean total mercury concentrations with standard error by zone and species are presented in Figure 3.4.

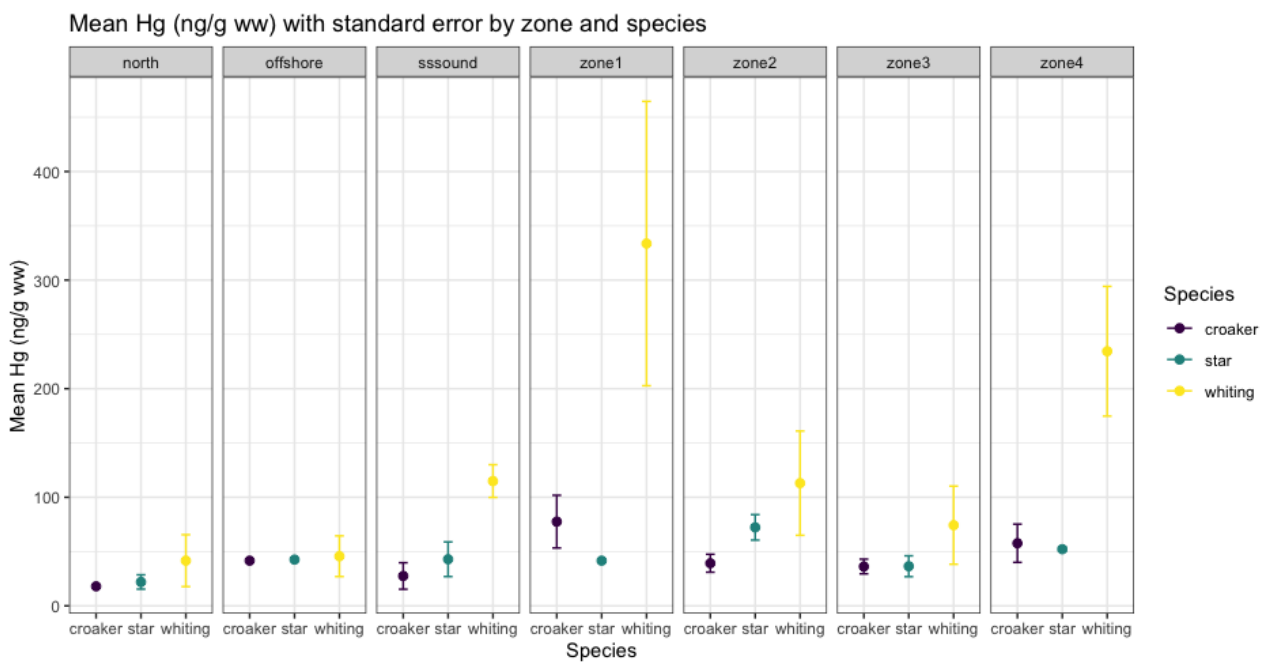

Figure 3.4: Mean total mercury concentration and standard error (se) for seven sampling locations (four advisory areas of the TBRE and three outside sites) in croaker, whiting, and star drum.

Table 3.2: Summary statistics of mercury in whole-fish composite samples of Atlantic croaker, whiting, and star drum from seven sampling locations (four advisory zones of the TBRE and three outside sites). Mean total mercury concentrations (ng/g ww) and minimum/maximum ranges are presented with their respective standard errors (se).

Zone	N	Mean Mercury Concentration ng/g (se)	Min and Max Mercury Concentration (ng/g ww)
Croaker			
North	1	18.00	--
Offshore	1	41.60	--
SS Sound	2	27.50 (12.20)	15.30–39.70
Zone 1	5	77.56 (24.27)	31.70–163.00
Zone 2	2	39.25 (8.25)	31.00–47.50
Zone 3	6	36.23 (6.75)	17.80–66.20
Zone 4	8	57.66 (17.62)	10.00–168.00
Whiting			
North	2	41.64 (23.91)	4.18–134.00
Offshore	1	45.72 (18.74)	15.40–105.00
SS Sound	4	114.93 (15.07)	88.80–141.00
Zone 1	2	333.66 (130.95)	63.30–803.00
Zone 2	4	113.00 (48.00)	65.00–161.00
Zone 3	6	74.30 (35.98)	12.00–142.00
Zone 4	4	234.48 (59.74)	71.90–336.00
Star Drum			
North	2	22.00 (6.60)	15.40–28.60
Offshore	1	42.6	--
SS Sound	4	42.93 (15.95)	18.40–86.80
Zone 1	2	41.60 (1.70)	39.90–43.30
Zone 2	4	72.28 (11.75)	44.10–95.90
Zone 3	6	36.48 (9.60)	16.60–79.30
Zone 4	4	52.18 (1.88)	48.80–56.40

Total mercury concentration data were log-transformed, and the one-way ANOVA was significant for the effect of zones on mercury concentration for whiting $F(6, 20) = 3.392$, $p = 0.0179$. Tukey's HSD Test for multiple comparisons identified differences in the means of Zone 1 and North sampling locations ($p = 0.0230$, 95% C.I. = [0.2442, 4.5385]).

One-way ANOVAs for croaker and star drum were insignificant, therefore we were unable to reject the null hypothesis that total mercury concentration differs by zone for both croaker and star drum. The highest mean concentration of total mercury was found in whiting (333.66 ± 130.95 ng/g 22) in Zone 1, farther from the LCP site than Zone 4 located closer to the contaminant source.

Croaker also had a higher mean total mercury concentration in Zone 1 (77.56 ± 24.27 ng/g ww) than in Zone 4 (57.66 ± 17.62 ng/g ww). All three species had higher total mercury levels in some outside sites (either Offshore or St. Simons Sound) than in Zone 3, and star drum had higher levels in Offshore and St. Simons Sound samples than in both Zone 1 and Zone 3. Star drum had the highest total mercury in Zone 2, another zone farther from the LCP site than Zone 4. Total mercury concentrations were lowest in the North sampling location for all species.

Discussion

Previous studies have identified high concentrations of PCBs, particularly Aroclor 1268, in dolphins and prey fish from both within and beyond the boundaries of the TBRE (Balmer et al., 2011; Kannan et al., 1998; Maruya & Lee, 1998; Pulster et al., 2005). Our results aligned with past findings except for our north sampling location, in which no PCBs or Aroclor 1268 were detected. As previously discussed, our results may have differed from past research given differences in sensitivity of congener analyses versus Aroclor analyses (the method we used for analyses); given this and the likelihood of lower PCB concentrations in these samples, we excluded them from analyses.

Our analyses of whiting via two separate one-way ANOVAs for mercury and PCBs both yielded significant differences. Mean concentrations of ∑PCBs differed significantly in whiting from our Offshore sampling location as compared to Zones 1 and 4. Significant differences were also detected between mean ∑PCB concentrations in comparisons of St. Simons Sound and Zone 4, Zone 1 and Zone 3, and Zone 3 and Zone 4 ($p = 0.0072$, 99% C.I. = [0.1285, 6.3022]). St. Simons sound, the reference site most proximal to the TBRE advisory areas, only significantly differed from Zone 4. St. Simons Sound encompasses many popular fishing spots in Glynn County and is not, to our knowledge, part of the sampling protocol for the LCP site.

Additionally, though Offshore mean whiting ∑PCB concentration differed significantly from Zones 1 and 4, it did not differ significantly from Zones 2 and 3, and our Offshore locations were approximately ~5.5km from the end of advisory areas in the mouth of the TBRE.

Our one-way ANOVAs for croaker and star drum yielded no significant differences for either ∑PCBs or mercury, and though these results should be interpreted with caution given low sample sizes, these studies suggest the boundary of the fishing advisory area of the TBRE—ending at the mouth of the St. Simons Sound—is not sufficient. Though public health and wildlife health implications of this finding differ, the occurrence of elevated levels of Aroclor 1268—attributed to the LCP site— in fish beyond the advisory boundary are a management issue for humans and wildlife alike.

Additionally, our results indicated that some current advisories may require updates in species-specific guidance. For example, ∑PCBs were comparable in whiting in Zone 1 and Zone 4 and mean total mercury higher in Zone 1 than Zone 4. However, currently whiting are subject to the strictest "Do Not Eat" advisory in Zone 4 because of mercury and PCBs but are designated as "1 meal/week" in Zone 1 where our results indicated higher contaminant levels. Though our PCB concentrations detected in Zone 4 were lower than previous findings, our findings of Zone 1 PCB concentrations in whiting suggest a "1 Meal/Month" as a more appropriate advisory. Of concern, among other fishing access points, two large residential developments—Oak Grove Island and Blythe Island—both have boat docks within this area from which people can fish.

Croaker offshore samples had higher ∑PCB concentrations than St. Simons Sound samples, though they did not exceed any of the TBRE zone means. Pulster et al. (2005) suggested that the presence of elevated concentrations of congener patterns associated with Aroclor 1268 in Nassau Sound, Florida samples could be attributed to species-specific life-history behaviors, such as offshore spawning (Pulster et al., 2005). This is a potential cause of our finding of elevated Aroclor 1268 in Offshore croaker samples as these samples were collected in October 2019. Croaker's spawning activities vary with latitude but are known to occur in warm ocean waters between September and December (Atlantic States Marine Fisheries Commission [ASMFC], 2010).

Our second sampling season was cancelled following COVID-19 shutdowns after completion of only one sampling trip. As such, we lacked adequate sample sizes to answer one of our planned research questions—how does age class (determined by length-at-age distributions) impacts contaminant concentrations throughout the TBRE?

We plotted regression lines of length versus PCB concentrations to visually explore this relationship. For our five sampling locations where we had more than one sample represented, all regression lines but two—croaker in Zone 2 and whiting in the St. Simons Sound—had a positive relationship between length and ∑PCBs (ng/g ww). Zone 2 represents a broader stretch of the Turtle River, but it is unclear why croaker would have this negative relationship. Again, a larger sample size would be required to further explore this trend. Croaker and whiting in Zone 1, and croaker in Zone 4 had dramatic increases in ∑PCB concentrations in somewhat small size intervals, potentially suggesting fish of a certain life stage are spending increased feeding time in the tidal creeks (Zone 4) and upper stretches (Zone 1) of the TBRE.

Visual inspection of regression of length versus ∑PCB concentrations in sampling zones also demonstrates the variability in contaminant concentrations among sites as well as within some species. In Zone 1, for example, dramatic increases in concentration occurred in croaker as they gained ~25–75mm of length. This is further illustrated by a large range of up to an order in magnitude in ∑PCB concentrations in some samples of the same species from within a zone, such as Zone 4 croaker ranges of 22.0–560.0 ng/g ww and Zone 1 whiting concentrations that ranged from 137.0–730.0 ng/g ww.

Though total mercury concentrations cannot be attributed to a specific source in the same way as Aroclor 1268, mean mercury concentrations were somewhat in line with expectations with North samples of croaker and whiting containing lower concentrations in the less industrialized Sapelo Sound, and some zones of the TBRE more proximate to the LCP site containing higher mercury concentrations—though croaker and whiting had higher mean total mercury concentrations in Zone 1 than in Zone 4, closer to the LCP site, and star drum had higher total mercury in Zone 2 samples than in Zone 4.

As in our analyses for PCBs, we did not detect any significant differences in croaker mean total mercury concentrations between zones, but significant differences were detected in mean mercury concentrations for whiting between Zone 1 and the North sampling location.

Here, too, samples exhibited variability as whiting concentrations in Zone 1 ranged from 63.30–803.0 ng/g ww.

Our ∑PCBs for all species ranged from 20–730 ng/g ww. These were consistent with Maruya and Lee's (1998) findings of whole-body striped mullet (*Mugil cephalus*) ∑PCB concentrations ranging from 570–990 ng/g ww but an order of magnitude lower in some samples. Pulster et al. (2005) found ∑PCBs ranging from 459–3,100 ng/g, and again, our samples were sometimes the same order of magnitude, and sometimes one to two orders of magnitude lower. We found ∑PCB levels in whole fish up to an order of magnitude higher than in Charleston Harbor, Cooper River, and Ashley River in South Carolina (Fair et al., 2018). Our findings, however, were two to three orders of magnitude lower than those in young of the year bluefish from the Upper Harbor of New Bedford Harbor in southeastern Massachusetts (Deshpande et al., 2013).

Both our ∑PCB and mercury findings were similar to those identified in Oregon's Willamette River in sites sampled at varying distances from the Portland Harbor Superfund Site (Sethajintanin et al., 2003). Our mean mercury results were also similar to mean mercury in fish muscle-tissue samples from the Savannah River, though some of our means were an order of magnitude lower (Burger et al., 2001).

Though the TBRE is subject to fishing advisories, some of the assumptions underlying these advisories may not apply to all fishers in Brunswick. As previously mentioned, the ATSDR remarked that GCHD fish consumption survey results should not be applied to African American anglers due to low African American representation (GCHD 1999). Studies that have captured larger percentages of African American fishers in the Brunswick area (McElwee, 2015) have reported consumption practices counter to advisory guidance including: consumption of whole fish, exceeding recommended portion sizes, and exceeding recommendation of frequency of consumption of some species. As filleted fish samples are analyzed to inform advisory guidance, these consumption trends may signal an exposure scenario that has been unaccounted for in health assessments to date in Brunswick.

Research with human subjects in Sapelo Island has revealed similar contaminant profiles in fish, dolphins, and humans feeding from the same waters, suggesting dolphins may be indicators of the health of humans in the same coastal areas (Backer et al., 2019). Brunswick dolphins carry high body burdens of PCBs and have signs of impaired health and immunity (Balmer et al., 2011; Schwacke et al., 2012). Further, though Brunswick residents were tested for mercury exposure in the GCHD fish consumption study, no PCB testing has been done on these residents to our knowledge. If Brunswick fishers are consuming whole fish, they may be exceeding ATSDR Minimum Risk Levels (MRL), even outside of advisory areas where, in theory, it should be safe to consume whole fish.

McElwee used the average ounces of fish consumed by surveyed fishers from Brunswick to Sapelo and the average PCB concentration of skin-on filets (gutted) found by Wirth et al. in the TBRE to calculate PCB daily intake (DI) (per the EPA's formula). This DI was 0.074 µg/kg/day as compared to the ATSDR's MRL of 0.02 µg/kg/day for chronic duration exposure exceeding 365 days (ATSDR, 2000; McElwee, 2015). Using mean concentration of whiting we identified in the St. Simons Sound, 76.33 ng/g ww, we calculated a DI of 0.04 µg/kg/day. This value is twice that of the ATSDR MRL and is based on average PCB concentration in whole fish whiting in a non-advisory area. Croaker did not exceed the PCB MRL for St. Simons Sound, but it did in Offshore samples with a DI of 0.027 µg/kg/day.

Mercury concentrations outside of TBRE advisory areas did not exceed the ATSDR MRL of 0.3 µg/kg/day, though whiting had higher mean concentrations of mercury in the St. Simons Sound than in both Zones 2 and Zone 3 (114.93 ng/g ww ± 15.07 in St. Simons Sound, 113 ng/g ww ± 48 in Zone 2, 74.30 ng/g ww ± 35.98 in Zone 3).

Our conclusions—including higher ∑PCB levels in whiting in the St. Simons Sound than Zone 3 and higher ∑PCBs in offshore croaker than St. Simons Sound samples—suggest that advisory boundaries may need to be extended. This decision should be made as part of a wider monitoring effort involving sampling of prey species in non-advisory areas proximal to the TBRE to better capture contaminant concentrations in those frequently consumed by recreational anglers. Additionally, more extensive social surveying in Brunswick, with efforts to capture those anglers who have not been well represented in past efforts, is necessary to understand whether whole-fish consumption and/or subsistence fishing is common in this area, and to confirm species and preparations most-preferred by these anglers. As remedial plans proceed in OU1, contaminant concentrations in prey fish should also be monitored in the TBRE *as well as* areas proximal to the TBRE to ensure remediation adequately addresses site contaminant migration and mobilization into the food web since this phenomenon has been well studied and documented repeatedly.

As part of this study, we fished at many local piers within and outside of the advisory areas, and we launched boats from docks within advisory areas. Of concern, no advisory signs were present at any location. This suggests that, at a minimum, advisory signs should be placed on docks, piers, and bridges within advisory areas as early as possible to protect public health. Signage should also indicate the role filleting fish plays in reducing lipophilic contaminants like

PCBs and the variation in contaminant concentrations that exists in different species, and individual fish, within the TBRE.

A recent study documented similarity in contaminant profiles in humans, dolphins, and prey fish in three coastal communities, including Sapelo Island. Study authors noted that their results suggested that marine mammal contaminant presence and concentrations are useful in indicating a need for further research in human populations, particularly where human data is lacking (Backer et al., 2019). To our knowledge, no studies of Brunswick fishers to date have documented ∑PCB concentrations in humans or longer-term measures of mercury ingestion. These biological markers are essential to understanding whether humans in Brunswick too reflect contaminant concentrations from the estuaries from which they feed, and this research should be prioritized.

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CHAPTER 4

FISHING ADVISORIES IN BRUNSWICK: HISTORY, CURRENT STATE, AND LOOKING FORWARD

Introduction

Fishing advisories are a type of institutional control used to manage potential public health risks at Superfund sites (EPA, 2012). However, their efficacy in doing so relies upon public knowledge and adherence to advisory recommendations. In Brunswick, Georgia, fishing advisories were established in the Turtle-Brunswick River Estuary (TBRE) adjacent to the Linden Chemicals and Plastics (LCP) Superfund site in the early 1990's to address fish contaminated with polychlorinated biphenyls (PCBs) and mercury (Agency for Toxic Substances and Disease Registry [ATSDR], 1994]).

This chapter includes a summary of the history of the TBRE-related fishing advisories in Brunswick, the current state of TBRE advisories, and the recommendations for advisory amendment based on results of contaminant monitoring in fish popular with recreational anglers conducted from 2019–2020. It concludes with recommendations for improved advisory communication in Brunswick based on the results of our research, conversations with local anglers and non-governmental organizations (NGOs) tasked with protecting environmental and public health, and our observations from fishing at many advisory locations during our research.

Advisories: Creation, Current Status, and Opportunities for Amendment

Federal and state agencies—as well as consulting groups contracted by potentially responsible parties (PRPs)—have assessed contaminant concentrations and/or potential human health risks related to fish consumption near the LCP site. Prior to LCP's 1994 closure, results of fish sampling by the Georgia Department of Natural Resources (GDNR) Environmental Protection Division (EPD) Toxic Substances Stream Monitoring Project and the US Fish and Wildlife Service (FWS) led to the establishment of fishing advisories and commercial seafood harvests closures in some TBRE waters (ATSDR, 1994); these original advisories have been expanded and remain in effect today.

Advisory calculation and sampling activities

Prior to 1995, advisories were based on Food and Drug Administration (FDA) action levels (ATSDR, 1996). Since that time, the fish consumption guidelines (FCG) have been calculated using a risk-based approach incorporating the Environmental Protection Agency's (EPA) carcinogen potency factors and noncarcinogen reference doses (GCHD, 1999). Recommendations are derived from contaminant concentrations in fish fillets with skin, fat, and organs removed (EPS, 2018).

In a 2004 memo, Randall Manning—the Environmental Toxicology Coordinator for the EPD at the time—reported that data used to develop the FCG were evaluated yearly, and resulting guidelines were based upon the most restrictive of EPA's potency factors for carcinogenicity or reference doses for non-cancer toxicity. To this end, shellfish and/or finfish were collected in 1991, 1992, 1993, 1995, 1997, and 2002. In 2002, a consulting group—GeoSyntec Consultants—conducted sampling on behalf of Honeywell in the TBRE (Manning, 2004). No additional sampling was conducted in the TBRE between 2002–2011 for the purpose of updating the FCG (EPS, 2011).

In 2011, another consulting group—EPS—began fish sampling on behalf of Honeywell (EPS, 2011). EPS most recently collected fish samples in the TBRE in 2017, and resulting data were used to update the FCG for the TBRE in 2018 (EPS, 2018).

Current fishing advisories in the TBRE

In Georgia, the EPD conducts fish monitoring to update all state advisories except for the TBRE in which EPS conducts fish sampling on behalf of Honeywell and provides data to the EPD (L. Booth, personal communication, April 29, 2019). In the TBRE, the FCG recommend which species to avoid or limit consuming throughout four advisory zones (Figure 4.1)— the Upper Turtle and Buffalo Rivers (Zone 1), the Middle Turtle River (Zone 2), the Lower Turtle and South Brunswick Rivers (Zone 3), and Purvis and Gibson Creeks (Zone 4) (EPS, 2018; GDNR, 2021). Advisory guidance varies by location and species and includes four recommendations based on degree of contamination: No Restrictions, 1 meal/week, 1 meal/month, or Do Not Eat (GDNR, 2021).

The FCG also advise filleting fish—removing skin, fat, dark meat, and guts—to minimize ingestion of contaminants like PCBs (GDNR, 2021); PCBs are lipophilic and store in fatty tissues (ATSDR, 2000). Removing fatty tissues, however, does not minimize ingestion of methylmercury—the type of mercury found most often in fish—which predominates in muscle tissue (McAuley et al., 2018).

As FCGs are based on contaminant concentrations in filleted fish samples, this preparation of fish may not represent the actual consumption of all anglers fishing from the TBRE. As such, FCGs may not adequately protect fishers consuming whole fish in the TBRE. Furthermore, we have found absolutely no signage regarding the advisories in any public fishing spots throughout the TBRE so it is likely that many fishers are unaware of the existence of the advisories. Though the area surrounding the LCP site is mainly industrial, the ATSDR noted residential areas approximately 300 yards north and 600 yards southeast of the LCP site in their 2014 health assessment (ATSDR, 2014). Marsh access is limited from the site uplands, but the Turtle River and marsh creeks can be accessed via watercraft (EPS, 2011), and there are anecdotal reports of residents of a mobile home community located adjacent to Purvis Creek fishing in the marsh (D. Parshley, personal communication, 2017).

Our Fish Sampling and Analysis of Consumption in Brunswick

From 2019–2020, we sampled two species of fish popular with recreational anglers—southern kingfish (*Menticirrhus americanus*) and Atlantic croaker (*Micropogonias undulatus*)—for PCBs and mercury. We chose these species based on McElwee's findings (2015) demonstrating their popularity with local recreational anglers in surveys of coastal fishing spots from Brunswick to Sapelo Island, GA in 2013–2014. These species-preference results were supported by DNR's Marine Recreational Information Program (MRIP) data (McElwee, 2015). Additionally, we decided to sample whole-fish tissues based on his finding that approximately 50% of surveyed anglers "always or sometimes" consume whole fish (McElwee, 2015).

Of note, McElwee found that a considerable portion of anglers consumed more fish than advisories recommended with just over half of respondents reporting they consumed 12 oz. or more in a fish meal; troublingly, those who consumed fish meals with greatest frequency also consumed the largest portions (McElwee, 2015). More than a quarter of participants reported annual household incomes of less than $25,000 (29.2%), though 31% of respondents elected not to share their income. Finally, 49.5% of respondents reported consuming one fish meal or more weekly, 52% had children in their homes who consumed their catch, and 55% of respondents

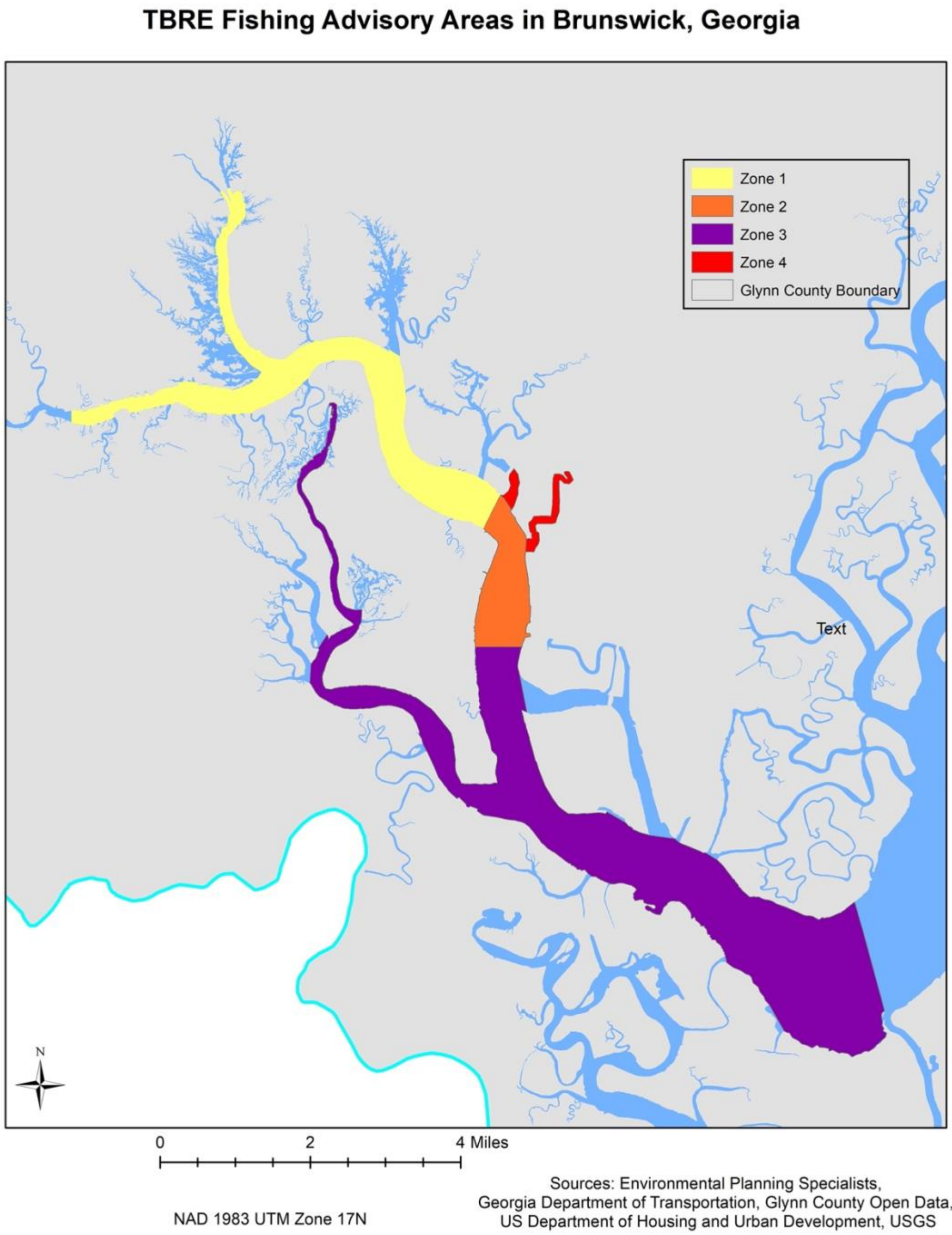

Figure 4.1: The four advisory zones of the Turtle-Brunswick River Estuary (TBRE).

said they had caught and consumed fish from Brunswick-area estuaries for 20 or more years (McElwee, 2015).

These consumption patterns suggested that anglers could be exposed to .074 µg/kg/day of PCB as compared to the ATSDR's Minimum Risk Level (MRL) of .02 µg/kg/day, above which sensitive populations might experience adverse health effects (ATSDR, 2018; McElwee 2015). Conversely, consumption of a whole fish, as opposed to a fillet, may reduce the average mercury exposure concentration (McAuley et al., 2018). It follows, however, that fishers consuming *more* fish than advisories suggest might also be ingesting larger quantities of mercury than assumed.

These results are supported by other regional studies assessing fish consumption along the Savannah River. Burger et al. explored how fishing and fish consumption habits differed by ethnicity, income, education, age, and employment in a group of 258 anglers intercepted on the Savannah River (Burger et al., 1999). Of note, study authors canvassed three sections of the Savannah River for 54 days, with only 10 of the 268 fishers they engaged declining interviews. This population was intended to describe not only those fishing on the Savannah River, but also fishing in similar areas in the region (Burger et al., 1999).

Respondents were white (70%), African American (28%) or other (2%), primarily male (89%), and had an average annual income of $21,490 (Burger et al., 1999). Researchers found that African Americans consumed fish more frequently and ate larger portions of fish than Caucasians, but quantity per serving and fish meals per month were positively correlated for both African Americans and Caucasians. They also found that some anglers exceeded total consumption values used to represent recreational (19 kg/year) and subsistence (50 kg/year) fishers. Further, 85% ± 2 of fishers reported consuming whole fish, and many respondents noted that their children and wives ate the fish they caught, with children beginning to eat fish between the ages of 3–5 (Burger et al., 1999).

Fish sampling results

Our results provide compelling evidence that the recommendations of some TBRE advisories warrant amendment to reduce exposure and that an expansion of the advisory zone should be considered. McElwee used the average ounces of fish consumed by surveyed fishers from Brunswick to Sapelo and the average PCB concentration of skin-on filets (gutted) found by Wirth et al. in the TBRE to calculate PCB daily intake (DI) (per the EPA's formula). This DI was 0.074 µg/kg/day as compared to the ATSDR's MRL of 0.02 µg/kg/day for chronic duration exposure exceeding 365 days (ATSDR, 2000; McElwee, 2015). Further, as exposure assessments incorporate duration of exposure as part of calculating risk, anglers ingesting fish for a period of 20 years, as some indicated to McElwee, are being exposed for a chronic duration (365 days and beyond) according to the ATSDR (ATSDR, 2000).

Using mean concentration of whiting from fish sampled in an area outside of the advisory zones, the St. Simons Sound (76.33 ng/g ww), we calculated a DI of 0.04 µg/kg/day. This value is twice that of the ATSDR MRL and is based on average PCB concentration in whole fish whiting in a non-advisory area. Mean PCB levels in whiting in the St. Simons Sound exceeded those in Zone 3. Croaker did not exceed the PCB MRL for St. Simons Sound, but it did in Offshore samples with a DI of 0.027 µg/kg/day.

Additionally, we found higher mean PCB levels in Zone 1 whiting than in Zone 4 samples. Our Zone 4 PCB findings were lower than reported in some studies; subsequently we are not advocating for a reduction in the "Do Not Eat" advisory for whiting in this Zone. Our Zone 1 PCB levels, however, indicated that a "1 meal/month" advisory might be more appropriate for whiting than the current “1 meal/week” classification. We calculated these advisories based on the tissue concentrations that bind consumption recommendations as reported in a 2004 memo by former state toxicologist, Randy Manning (Manning, 2004).

Our finding of higher levels of ∑PCBs in whiting in a non-advisory area compared to an advisory area (Zone 3) is suggestive of the need for advisory boundary extension. This decision should be made as part of a wider monitoring effort involving sampling of prey species in non-advisory areas proximal to the TBRE to better capture contaminant concentrations in those frequently consumed by recreational anglers. Additionally, more extensive social surveying in Brunswick, with efforts to capture those anglers who have not been well represented in past efforts, is necessary to understand whether whole-fish consumption and/or subsistence fishing is common in this area, and to confirm species and preparations most-preferred by these anglers (Backer et al, 2019; Pulster et al, 2005; Wirth et al., 2014).

A recent study documented similarity in contaminant profiles in humans, dolphins, and prey fish in three coastal communities, including Sapelo Island. Study authors noted that their results suggested that marine mammal contaminant presence and concentrations are useful in indicating a need for further research in human populations, particularly where human data is lacking (Backer et al., 2019). To our knowledge, no studies of Brunswick fishers to date have documented ∑PCB concentrations in humans or longer-term measures of mercury ingestion. These biological markers are essential to understanding whether humans in Brunswick also carry body burdens of contaminants from the estuaries from which they feed, and this research should be prioritized.

Fishing Advisory Communication: Observations

As part of this study, we fished at many local piers within and outside of the advisory areas, and we launched boats from docks within advisory areas. Of tremendous concern, absolutely no advisory signs were present at any of the sites, docks, piers, or bridges within the advisory areas, even though such postings are the most obvious means of communicating this risk to the public, many of whom might not use internet resources where this information is available, though not prominent.

We also reviewed sources of available fishing advisory information in Brunswick. Though fishing advisories are available on GDNR's website, they are not prominently displayed. Additionally, advisories are not included on the interactive fishing map featured on GDNR's website. Advisory guidelines may be found in the section of the site where a fisher may purchase a fishing license online, but again, this information is not prominently displayed.

In Brunswick, the Glynn Environmental Coalition (GEC)—a local non-profit tasked with communicating Superfund-related information to Glynn County residents—offers advisory communication and outreach to anglers through their "Safe Seafood" program. GEC partnered with other local agencies to produce a two-page pamphlet aimed at simplifying and streamlining advisory information, while highlighting advisories specific to women and children, and prominently featuring preparation methods. Though GEC distributes this flyer throughout the community and aims to target at-risk populations, their funding is limited. Consistent and prominent notice of advisories across stakeholder websites and relevant print materials, would ensure increased awareness of advisories.

For fishing advisories to be effective in protecting public health, anglers and those consuming recreationally caught fish must be able to access, understand, and follow posted advisories. Further, advisories must acknowledge exposures from multiple sources that are often found in environmental justice communities (Gochfeld & Burger, 2011).

Given the fish consumption habits identified in Brunswick, including the consumption of whole fish, and the high contaminant levels (particularly Aroclor 1268) within and outside of the TBRE advisory areas, we recommend the following to better protect the health of humans feeding from the TBRE. Agencies who would likely be involved in each action are indicated in parentheses. We have grounded these recommendations in findings from fishing advisory communication literature.

1. ***Modify fish-sampling protocol and advisory boundaries. (ATSDR, EPD, EPA, GDNR Honeywell)***

   Expand fish-sampling protocol to include St. Simons Sound (at a minimum), focusing on popular fishing spots currently unrepresented in contaminant fish-monitoring efforts (e.g., Jekyll Pier, F.J. Torras Causeway, St. Simons Island Pier) to determine whether advisory boundaries should be extended beyond the TBRE. Continue extended monitoring protocol throughout site remediation efforts to ensure appropriate clean-up levels are achieved for wildlife and humans as site contaminants have been documented migrating offsite.

2. ***Update and conduct more comprehensive surveying of fish consumption habits in Brunswick recreational fishers. Focus on capturing responses from the "outliers." (ATSDR, GEC, Honeywell)***

   Update surveying of anglers in the vicinity of the LCP site, ensuring those demonstrated as high-consumers (e.g., African Americans) or especially vulnerable to the risks of contaminants (e.g. women of child-bearing age, children) are adequately represented in sampled population. Training long-time Brunswick residents to conduct interviews with fishers (J. Burger, personal communication) and share fishing spots popular with local anglers may be helpful in uncovering consumption patterns in previously under-represented demographics.

Gochfeld and Burger (2011) argued that risk assessment traditionally excludes or transforms outlier data, but that in fact these are the members of a population that require more attention. They also noted that some populations (including children, minorities, and rural and urban poor) may be subject to the underestimation of risk in traditional assessment practices and that fish-consumption data for minority, low-income, and recreational consumers of fish demonstrate the importance of site-specific data for those consuming large quantities of fish, whether high-end consumers or outliers (Gochfeld & Burger, 2011).

3. ***Post advisory information prominently at fishing sites within the TBRE as well as at all docks, piers, and bridges within the advisory areas. Include in the signage information about the role that fileting fish plays in reducing PCBs. Develop signs and content that the public can clearly read and understand and post it in all popular fishing spots. Tailor recommendations for increased understanding by different subpopulations. Provide culturally tailored messages. (ATSDR, GEC, Honeywell)***

Focus groups should be held with community residents, and versions of communication materials tested prior to selecting language and messaging for signs and other flyers/resources. Additionally, signs should be bilingual to ensure language is not a barrier in accessing information.

In a study of anglers at a North Carolina lake, LePrevost et al. (2013) found significant differences in initial awareness of the term "fish consumption advisory" between groups of anglers who fished from land (shore anglers) versus from a boat. Though participants of both groups experienced significant increases in knowledge of a specific fishing advisory following introduction of an advisory sign, another subsample of fishers—those who shared their catch with women and children— did not (LePrevost et al., 2013). This highlighted the importance of addressing subgroups within populations in creating fishing advisory messaging.

In another North Carolina study, a group of stakeholders conducted focus groups with 38 anglers to discuss knowledge of fishing advisories and reactions to sample advisory signs (Gray et al., 2020). Participants were confused by the text referring to the number of servings of fish allowed by advisories and the variability of advisories for subgroups and suggested streamlined messages, graphics (such as realistic fish pictures), non-technical language, and multiple languages would be beneficial in understanding advisory information from a sign (Gray et al., 2020).

Similarly, Tan et al. (2011) assessed issues in advisory understanding and subsequently developed recommendations for effective advisory communication. They found consumption frequency to be a more "realistically adjustable" behavior than portion size as many participants struggled to identify ounces of fish consumed—though visual models helped in estimation— and reported that determinants other than recommended portions led to their consumption decisions. Frequency of consuming specific species, in terms of more or less often, or not consuming, was better understood (Tan et al., 2011).

Tan et al. also found that certain words or phrases, such as “women of childbearing age,” “anglers,” “meal,” “uncooked,” and, “Omega-3 fatty acids,” were confusing to study participants, as were advisory categories labeled by recommendation, such as “one meal a week.” Participants liked graphics of mercury levels in a round “speedometer” with low, medium, and high contaminant levels, as they related this to stopping at a higher level of danger (Tan et al., 2011). Of note, presenting mercury information for specific species, rather than as an advisory, also helped participants overcome pre-existing beliefs they had about specific species (Tan et al., 2011). Consistent with findings from other studies demonstrating a lack of information about both degree of contamination and health effects of contaminants, study participants preferred comparing mercury levels between species through use of the mercury meter (Tan et al., 2011).

Additionally, categorizing advisories by high, medium, and low levels of contaminants facilitated better understanding of guidance, and explicit description of sensitive populations was better understood—such as “Women over 45” rather than “Women beyond childbearing age—than phrases requiring interpretation (Tan et al., 2011). Importantly, study authors highlighted the importance of field-testing material designs among their intended audience to determine whether specific audiences are receiving the intended messages.

Ellis et al. (2014) found misperception in fishing advisories and catch restrictions among Gullah/Geechee residents in two coastal South Carolina counties (Ellis et al., 2014). Similarly, Chess et al. (2005) reviewed studies demonstrating minority audiences’ understanding of culturally relevant risk communications, as opposed to more generic "government-speak" strategies (Chess et al., 2005).

4. ***Add advisory information to GDNR fishing maps and display more prominently during fishing license purchase. (GDNR)***

   Georgia Fish Consumption Guidelines are available in a variety of locations on the GDNR website, their "Go Outdoors GA" app, and on the GDNR EPD's Integrated Report Map but they are not displayed prominently. To access guidelines in these locations, one must navigate to the proper area of the site. Neither advisory information nor a list of species not to keep or consume is included on the interactive fishing map on GDNR's website. As there are currently no advisory signs at fishing sites, it is particularly important that this map prominently feature advisory information to help anglers select safe fishing locations.

   Participants in Gray et al.'s study (2020) noted that it would be beneficial to post advisory information where anglers apply for fishing licenses. Though the pdf of fish consumption guidelines is available for download when purchasing a fishing license from the GDNR's website, more prominently displayed advisory information would allow easier access to this information.

5. ***Encourage interagency collaboration and seek agency input. Distribute fishing advisory guidelines to organizations that interact with vulnerable populations in the community.***

   Share advisory resources with local organizations (religious organizations, community groups, NGOs), health providers (GCHD, Southeast Georgia Health Systems, OBGYNs, etc.), health and nutritional programs (e.g., WIC), schools (PTAs, daycares and "Mom's

Morning Out", Pre-Ks and kindergarten programs, science and health teachers), and other organizations/groups that interact with women of child-bearing age, young children and their parents, and/or low-income residents, particularly African American residents.

Love et al. (2013) examined the two primary ways in which recreational fishing is regulated—catch regulations to protect fishing stocks and fishing advisories—in all 50 states and found that these were frequently issued by different state agencies. They also noted the limitations of regulatory safeguards to protect consumers of recreationally-caught fish—though the United States Food and Drug Administration (FDA) is tasked with inspecting commercial seafood for environmental pollutants, the only national guidance on self-caught seafood is for mercury, and this is issued by the EPA (Love et al., 2013).

Study authors noted that Georgia was one of three states where consumption advisories and catch regulations were produced in concert, a positive sign for intra-agency collaboration, but they suggested that collating results by waterbody, such as done in Arkansas, would allow users to access all relevant information on the same page (Love et al., 2013). Further, study authors noted the benefits of interagency collaboration, such as a natural resource agency working with a public health department to emphasize the interdependence of human and environmental health, diet, and food supply (Love et al., 2013).

Burger et al. (2003) also identified the importance of interagency collaboration in development of two different material formats—a brochure and a classroom presentation—developed in collaboration with the New Jersey State and local town Woman, Infants, and Children (WIC) program staffs. Both formats were successful in educating Latina women of child-bearing age—in both English and Spanish— at a New Jersey WIC center about fishing advisories, though more participants of presentations remembered unsafe locations from which to avoid seafood (Burger et al., 2003). Study authors noted the importance of involving agencies at the state and local levels in development of these materials; for example, this collaboration led to regional locations of New Jersey WIC centers incorporating developed materials into their curriculum post-study (Burger et al., 2003).

6. ***Discuss benefits and drawbacks of local seafood consumption. Help local residents reliant upon fishing for livelihood (such as fishing charter services) to become safe-seafood experts. (GDNR, GEC, UGA Marine Extension)***

Advisory materials should include information on health benefits of seafood consumption as well as risks of contaminant ingestion. Additionally, materials should offer a list of safer options, particularly for those most vulnerable to risk of contaminant effects.

Recognizing that some residents of Brunswick who rely upon local fishing and tourism for their livelihood may fear increased awareness of contaminated fish, help them become part of the solution. Educate them on safest fishing choices/locations for their clients to fish.

7. ***Host "fish-cleaning" workshops. (GDNR, GEC, UGA Marine Extension)***

Offer demos, or workshops, on how to properly fillet fish. During demos, share best practices for reducing contaminant ingestion from local seafood. Annual events, such as DNR's "Coastfest," are ideal opportunities to raise awareness of local advisories among a large local audience.

Conclusion

The EPA's website currently lists the LCP site's status as uncontrolled for human exposure. Per the EPA, this means unsafe contaminant levels exist at the site and there is a "reasonable expectation" of human exposure (EPA, n.d.-f). Conducting updated social surveying, extended fish sampling, and human biomonitoring for PCB and mercury contamination to better understand the extent of risky fish consumption in Brunswick will better protect all residents, particularly those minority groups who tend to be disproportionately affected by Superfund sites. Further, field testing communication strategies with target populations, increased interagency collaboration, and more prominent and frequent display of advisory information will increase advisory awareness, understanding, and adherence.

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CHAPTER 5

CONCLUSIONS

In Brunswick, Georgia, contaminant releases resulting from past industrial operations at the Linden Chemicals and Plastics (LCP) Superfund site have altered the Turtle-Brunswick River Estuary (TBRE) and mobilized contaminants into the food web. Past ecotoxicology research has documented dolphins' high PCB body burdens (Pulster & Maruya, 2008; Pulster et al., 2009; Balmer et al., 2011) and markers of impaired health (Schwacke et al., 2012). Distinct genetic differences in the Southern Georgia Estuarine System Stock (SGES) combined with photo-identification research further support this stock's long-term site fidelity to, and contaminant exposure in, this area (Balmer et al., 2011). As such, the SGES are a sentinel species for human residents feeding from the TBRE and surrounding waters.

McElwee's research indicated that croaker and whiting were two of the species most frequently consumed by recreational fishers, and also two of the species subject to most stringent fishing advisories in the TBRE (McElwee, 2015). Further, consumption surveying indicated that Brunswick fishers may be consuming whole fish and larger quantities of fish (McElwee, 2015) than accounted for in the previous Glynn County Health Department (GCHD) fish consumption study. Dolphins and humans overlap on some preferred prey items and depart on others. Dietary analysis of stranded dolphins in South Carolina revealed star drum and croaker as popular dolphin prey items (Pate & McFee, 2012).

Thus, we sampled whiting, croaker, and star drum, to understand sources of potential exposure to humans and dolphins in four sampling zones inside the TBRE and three outside the

TBRE. Our goals were to quantify PCB and mercury concentrations in whole-fish samples of selected species throughout the four advisory zones of the TBRE, to test whether advisory boundaries are adequate to protect public health, and, depending upon results, to provide state and federal agencies new data to consider in making management and research decisions relevant to the LCP site. Our results indicated that revisiting of institutional controls may be an essential step in protecting public health at the LCP site.

Institutional controls are "non-engineered instruments," for example administrative or legal controls, that help manage potential exposure to contaminants at a Superfund site (EPA, 2012). States, territories, and tribes are responsible for setting advisories (EPA, n.d.-d), and in Georgia, the Georgia Department of Natural Resources (GDNR) Environmental Protection Division (EPD) issues fish consumption guidelines (FCG) recommending which species to avoid or limit consuming throughout four advisory zones in the TBRE (GDNR, 2021). They also advise filleting fish—removing skin, fat, dark meat, and guts—to minimize ingestion of contaminants like PCBs (GDNR, 2021).

The FCG were written using a risk-based approach incorporating EPA's carcinogen potency factors and noncarcinogen reference doses (GCHD, 1999). Prior to 1995, advisories were based on FDA action levels (ATSDR, 1996). Recommendations are derived from contaminant concentrations in fish fillets with skin, fat, and organs removed (EPS, 2018), and TBRE monitoring informing advisories is conducted by a consulting group on behalf of site owner, Honeywell (EPS, 2018).

Institutional controls, such as fishing advisories, are employed at Superfund sites to help mitigate human health risks of contaminant consumption, but Brunswick consumption advisories may not be adequate to protect all fishers. Further, some assumptions informing health assessments at the LCP site may not represent all Brunswick anglers' fish consumption behaviors.

Environmental Planning Specialists (EPS) prepared the *Human Health Baseline Risk Assessment for the Estuary, Operable Unit 1* (HHRA), an assessment requested by the United States Environmental Protection Agency (EPA) in part to evaluate any potential human health risks associated with fish consumption from the LCP marsh (EPS, 2011). As part of this assessment, EPS evaluated risks to "hypothetical high quantity consumers" in response to two fishers identifying themselves as subsistence fishers during Glynn County Health Department's (GCHD) 1999 fish consumption study. Data from the study's target group respondents—those who had ingested seafood from the Turtle River and associated tributaries—were used, in addition to data from other sources, to evaluate high quantity consumers (EPS, 2011). Of note, though frequencies of consumption identified in the GCHD study—2 meals/month, 4 meals/month, and 7 meals/month—were used as part of this simulation, information on quantity came from the U.S. Department of Agriculture's Continuing Survey of Food Intake by Individuals (EPS, 2011), not from local or regional data.

The GCHD study under-represented African Americans (GCHD, 1999)—a demographic that has been identified as consuming more total ounces of fish than Caucasian fishers (Burger et al., 1999; McElwee, 2015), and authors stated that results of this study may not apply to the Brunswick African American population (GCHD, 1999). Only 4% of participants were African American (Environmental Planning Specialists [EPS], 2011; Glynn County Health Department [GCHD], 1999), and Brunswick's population is currently 55.1 % Black or African American alone (USCB, 2021). Also, though the GCHD study tested urine mercury concentrations, it did not address lipophilic contaminants like PCBs that accumulate in fatty tissues and organs of fish, and that are reduced by filleting fish. In surveys of Brunswick anglers, around 50% of participants reported "always or sometimes" ingesting whole fish (McElwee, 2015). These fishers are being exposed to larger quantities of PCBs than accounted for in filleted fish estimates.

McElwee also found that 49.5% of respondents consumed 1 fish meal or more weekly, 52% had children in their homes who consumed their catch, and 55% of respondents said they had caught and consumed fish from Brunswick-area estuaries for 20 or more years (McElwee, 2015). Children are more sensitive to the effects of PCBs and mercury than adults; their possible consumption of whole fish from the TBRE is especially concerning.

Whiting and croaker are subject to some of the most stringent advisories in the TBRE including "Do Not Eat" status in Zone 4, "1 meal/month" for croaker and "1 meal/week" for whiting in Zone 1, "1 meal/month" for both species in Zone 2, and "1 meal/week" for both species in Zone 3. Of further concern, our results indicated that whiting had higher mean levels of mercury in Zone 1 (333.66 ± 130.95 ng/g ww) where the advisory is "1 meal/week" than in Zone 4 (208.97 ± 76.40 ng/g ww) where it is "Do Not Eat." Though mean ∑PCB concentrations were somewhat lower in Zone 1 (317.40 ± 114.01 ng/g ww) than in Zone 4 (346.67 ± 31.80), they were still far higher than the rest of sampled zones, suggesting a more stringent advisory should be in place for whiting in Zone 1.

Further, as exposure assessments incorporate duration of exposure as part of calculating risk, anglers ingesting fish for a period of 20 years, as some indicated to McElwee, are being exposed for a chronic duration (365 days and beyond) according to the ATSDR (ATSDR, 2000). Though this work was unpublished, other peer reviewed studies in this region have found similar fish consumption trends (Burger at al., 1999), indicating that some Brunswick fishers may be exceeding advisory consumption guidance, potentially exposing children—a population vulnerable to the effect of mercury and PCBs—to unsafe levels of contaminants, and exposing themselves to estuary contaminants for a chronic duration.

Aroclor 1268 has been well documented in fish throughout the TBRE as well as in sounds to the north and south, and fish are likely vectors transporting residues outside the TBRE (Backer et al, 2019; Pulster et al., 2005; Wirth et al., 2014). At the same time, evidence suggests that PCBs and mercury act synergistically (Bemis & Seegal, 1999), and though mercury is analyzed in filleted fish samples informing fishing advisories, it has not been analyzed in other TBRE prey studies.

Trends in our results were generally consistent with other prey studies in the TBRE. These studies have documented intra- and interspecific variability in Aroclor 1268 concentrations and movement of Aroclor 1268 both within and outside of the TBRE (Maruya & Lee, 1998; Pulster et al., 2005; Wirth et al., 2014). Though our sample sizes were small, we observed variability of an order of magnitude in species in some sampling locations, and we detected Aroclor 1268 in samples collected from the St. Simons Sound, as well as in those collected ~5.5km from the mouth of the TBRE in our Offshore location. Our PCB ratio findings, however, were somewhat unexpected with a 1.0 ratio in Offshore and St. Simons Sound samples and less than a 1.0 ratio for some zones closer to the LCP point source, including Zone 1, Zone 2, and Zone 3. As previously discussed, a long history of industry and legacy pollutants at the LCP site may have caused release of other PCB formulations into the TBRE.

Star drum mean ∑PCB concentrations were generally lower than those found in croaker but exceeded those measured in croaker in Zone 1 (100 ng/g ww in star drum versus 80 ng/g ww in croaker). In contrast, mean mercury concentrations were higher in star drum than croaker in all but two zones (Zone 1 and Zone 4). If star drum are as an abundant component of SGES dolphin's diets as those in South Carolina, they could be meaningfully contributing to PCB and mercury contaminant burdens of dolphins feeding in the TBRE.

Of greatest concern, both whiting, and star drum had higher mean ∑PCB concentrations in one or both reference locations than in the Zone 3 advisory area. This strongly suggests a need to revisit advisory boundaries. This result is supported by research on diamondback terrapins in the TBRE area. Bauer (2019) found higher concentrations of PCBs in terrapin livers from dead terrapins sampled around the Downing Musgrove Causeway that leads to Jekyll Island than Kannan et al. (1998) found in terrapin livers from Purvis Creek adjacent to the LCP site in 1995, one year after the plant's closure. Additionally, Bauer detected high Aroclor 1268 concentrations in livers of terrapins both within and outside of advisory areas, and subsequently, he suggested the need to further research the adequacy of advisory boundaries (Bauer, 2019).

These results also highlight an important distinction that exists at Superfund sites in management of ecological health versus human health. Though institutional controls, such as fishing advisories, can help reduce human exposure to contaminants, this is not the case for resident animals. However, expansion of advisory areas would potentially prompt more routine monitoring of areas included within advisories. As migration of contaminants beyond the advisory boundaries has been well documented, dolphins and other animals are being exposed to higher levels of contaminants than anticipated outside this site. Monitoring protocols associated with remediation actions at the site should be designed with this known transmission of Aroclor 1268 in mind to ensure remediation goals and cleanup levels are set at appropriate levels. Additionally, institutional controls are only effective if people are aware of them.

Though our results should be interpreted with caution due to low sample sizes and limited species, our findings of PCB concentrations in reference areas exceeding those in advisory areas suggests the need for further research as well as advisory boundary expansion. Whole fish contain higher PCB levels than filleted fish and whiting in the St. Simons Sound and croaker from Offshore sampling locations exceeded ATSDR's PCB MRL of 0.02 µg/kg/day for chronic duration exposure indicating a potential public health risk. We will provide an executive summary of our findings to the ATSDR and GDNR EPD in hopes that this will prompt additional sampling outside of the advisory areas as well as additional fish consumption surveying.

Burger et al. (1999) stated the importance of understanding how exposure variables are distributed rather than focusing solely on parameters such as averages, as averages do not represent those at highest risk. They noted the need for site-specific information (fisher demographics and consumption) to assess and manage risks at a site (Burger et al., 1999). This is of the utmost importance in Brunswick where unpublished research (McElwee, 2015) identified different, and concerning, fish consumption habits than indicated in GCHD's 1998 study. Future research should focus on increasing sampling of more commonly consumed species outside of advisory boundaries to determine whether boundaries should be extended. Further, the extent to which fishers are consuming whole fish in Brunswick must be quantified using survey methods designed to capture those at higher risk of exposure, such as African American fishers. As Burger advises, the demographics and consumption habits of all fishers must be understood as they are distributed, not just as averages, to ensure they are being protected.

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