2004 Final Report: Comparison of Environmental Contaminants on Georges Bank and Stellwagen Bank Contract # 02-574

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Abstract

Cod fishermen's concerns about the potential for contaminant induced effects on reproduction or development in both nearshore and offshore cod formed the basis for this project. Addressing these concerns we measured heavy metals, PCBs and organochlorine pesiticides in cod livers and gonads and sediments from Stellwagen Bank (SB); Georges Bank (GB); and Wilkinson Basin (WB). In general, concentrations of most contaminants were found to be near or below detection limits in cod gonads. Several contaminants were detected in the liver including PCBs (A1254 ranging from 0.3-1.5 ppm) and DDTs (ranging from 0.16-0.66 ppm). However, concentrations from Georges Bank (GB) were drastically lower than those reported earlier by Harvey et al. (1973), and below concentrations linked with reproductive or developmental toxicity in fish. Our analysis of heavy metals suggest that the concentrations of metals measured in this study are within range of those previously reported in cod except for cadmium which ranged from <0.5-22 ppm. The vast majority of PAHs and metals detected in sediments were below the Threshold Effects Levels (TLV) summarized in NOAA's Screening and Quick Reference Tables and PCBs and chlorinated pesticides were below detection limits in the sediments. No one chemical was consistently detected at concentrations suspected of causing adverse effects in cod or their offspring, although we are unable to comment on the potential effects of chronic exposure to low levels of chemical mixtures. Based on the present state of knowledge, it would appear that levels of exposure to the chemical contaminants measured in this study, are unlikely to have had a considerable impact on the near shore or off shore cod fishery.

Introduction and Background

This research was initiated by fishermen concerned with the potential contamination of their fishing grounds and fishing stocks. Their concern was for both surface contamination and for contaminants that could bioaccumulate in fish tissues such as persistent organochlorine chemicals including polychlorinated biphenyls (PCBs), pesticides (including DDTs) and some heavy metals. Several studies over the past decade have established that these chemicals and others can impact reproduction and development in wildlife (Sorenson 1991, Colborn and Clement 1992, Collier et al., 1998; Monosson 2000). In recent years scientists from the Environmental Conservation Division (ECD) of the Northwest Fisheries Science Center (NWFS) have demonstrated reduced reproductive success in bottom fish living in contaminated areas of the United States (US) (Collier et al., 1998). Additionally the National Marine Fisheries Service (NMFS) has reported poor recruitment in Georges Bank, even though the biomass has increased.

Cod landings in the 2003-2004 fishing year totaled nearly 20 million pounds. The Georges Bank area contributed about 60% of the landings and the remainder of the cod came from the Gulf of Maine. This represents more than one third of all Groundfish landed in New England during the period. Because cod are such an important fishery we chose to focus our studies on chemical contaminants in Atlantic cod.

Early studies on fishes of Georges Bank indicated surprisingly high concentrations of PCBs in cod livers (ranging up to 22 parts-per-million (ppm)) compared with much lower concentrations in the flesh (0.04 ppm) (Harvey et al., 1974). They also reported up to 3 ppm of DDT in the liver, and 0.01 ppm of DDT in the flesh. More recently much lower concentrations of these and other chemicals have been reported for cod collected from north of Newfoundland (Hellou et al., 1993; Hellou et al., 1992). However, there are no recent data on chemical concentrations in cod from either the coastal region of the Northeastern US or from Georges Bank.

Although there are several chemical surveillance and monitoring programs in the US, such as the NOAA Status and Trends (NOAA 2004a), the USGS National Water-Quality Assessment Program (USGS, 2004), these studies focus on coastal species and near coastal sites. As noted by the Stellwagen Bank National Marine Sanctuary (NOAA, 2004b) “few studies have measured contaminant concentrations in Stellwagen Bank organisms.” We were interested in exploring chemical contamination from offshore sites and specifically in cod, since it is such an important Western Atlantic fishery.

The goal of this project was to evaluate chemical contamination in cod collected from Georges Bank and from near shore stocks. The results of this survey were primarily intended to provide baseline information for chemical contamination in cod stocks that may then be compared with 1) earlier studies of chemical contamination in cod and current surveys of chemical contamination in cod and other fish species 2) provide data that may be interpreted based on our current knowledge of adverse reproductive and developmental effects in fish and 3) provide a comparison of chemical contaminants in sediments and fish tissues.

This project addressed several of the research funding priority areas for the Northeast Consortium. Specifically, the inclusion of industry based information for essential fish habitat designations, species sampling to analyze life history, behavior and dispersal and oceanographic monitoring. It was an especially good example of the use of commercial fishing vessels as platforms for coastal monitoring, modeling and prediction.

Because our primary interests were to provide a baseline that may be evaluated in terms of reproductive and developmental effects of contaminants in cod, we selected the liver and gonad as our target organs for analysis, rather than edible flesh. However, in light of the recent interest in contaminants in edible fish tissues, particularly of PCBs in farmed salmon (Hites et al., 2004), we provide a brief interpretation of our results in terms of human exposure to chemical contaminants from cod.

Project objectives and hypothesis:

The objectives of this project were to:

1) Measure the concentrations and evaluate the potential for adverse effects of several classes of contaminants that have been either shown to cause, or have been associated with adverse reproductive and developmental effects, or other adverse health effects, in cod from Georges and Stellwagen Banks.
2) Provide baseline concentrations for selected sites and cod stocks for future comparisons.
3) Investigate potential for sediments to serve as a source of these contaminant classes by measuring sediment concentrations.
4) Generate a truly collaborative relationship between fishermen and scientists.
5) Present and discuss data with fishermen through several workshops and generate a peer-reviewed publication.

Participants

This project involved fifteen Gloucester fishermen who participated in workshops and sample collection (see Appendix A).

The primary participants involved in design and execution of this project were:

Study Design, sampling and workshop coordinator:
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and

Study Design, chemical analysis and interpretation:
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Methods

The goals of this project were addressed through sampling of both cod tissue and local sediments. Although logistically the sampling for both cod and sediment were conducted separately fishermen strived to sample from the same location using station coordinates.

<u>Site Selecction</u>

Sites were selected by participants representing the fishing community.

Originally 5 sites were selected to compare the conditions of cod stocks in two primary US fishing grounds (one inshore and one offshore) with historical reports of contaminants on the Canadian side of Georges Bank. Two sites were selected on Georges Bank and two sites on Stellwagen Bank. This permitted each of the fishing grounds to be sampled both on top of the banks and on the edges where the sediment types and current patterns are different.

At the request of the Consortium, a reference area in Wilkinson Basin (WB) was added. This proved interesting since for some contaminants, cod collected from WB actually had higher concentrations than cod from the subject fishing grounds.

Although we encountered difficulties in sampling certain locations as a result of required permitting processes (which added one year to the project completion date) we did not stray from the original project as proposed, except for the one year extension.

The selection of sites and the need to collect a representative sample of spawning female cod became the major challenge for this project. Initially much time was wasted trying to obtain permits and clearance from the US and Canada in order to resample historical areas with reportedly high contaminant levels. Neither the Coast Guard, NMFS, the State Department or DFO had sole authority to authorize US commercial fishing vessels to catch cod in Canadian waters. Ultimately, it became clear that the easiest way to overcome these obstacles was to simply contract a Canadian vessel and captain to collect sediments and cod. After numerous contacts and logistical delays, we successfully obtained the samples from Canada.

The permitting situation proved just as formidable on the US side of the Hague Line. Both Georges Bank and Stellwagen Bank were subject to closures with some areas closed for six months during the year. Our plan was to utilize dedicated research trips and hook and line collection when the areas were closed. However, delays in obtaining permits for short sample windows further complicated the situation. Unfortunately, due to stock migration across the sampling stations bad weather and variations in species abundance, (most notably dogfish) this method had to be abandoned.

Ultimately we were forced to combine some fishing trips with sampling to control costs. In one case, this was partly responsible for inadequate sample preparation for shipment and the samples were lost. The station had to be resampled months later at additional cost.

Fortunately in the end, all stations and samples were acquired according to plan and within the original budget. However, sample logistics added more than a year to the project timeline.

Sampling sites for both cod and sediment collections and participating vessels are listed in Tables 1 and 2.

Table 1. Location and Participating Vessel for Cod Sampling

Station to date	Location	Date sampled	Vessel	Latitude	Longitude
Station 1	Stellwagen Sanctuary (SB1)	6/7/04	3 Nina's	42 ^{o} 25'N	70 ^{o} 25'W
Station 2	Stellwagen Sanctuary (SB2)	6/8/04	3 Nina's	42 ^{o} 15'N	70 ^{o} 25'W
Station 3	Georges Bank area (GB1)	6/24/03	Padre Pio	42 ^{o} 10'N	67 ^{o} 14'W
Station 4	Georges Bank area (GB2)	6/24/03	Caterina G	42 ^{o} 10'N	67 ^{o} 29'W
Station 5	Wilkinson Basin (WB)	5/29/03	Caterina G	42 ^{o} 35'N	69 ^{o} 50'W
Station 6	Georges/ Canadian side (GBC)	7/4/03	Vinna and Shane	42 ^{o} 00'N	66 ^{o} 30'W

Table 2. Sampling Sites and Participating Vessels for Sediment Collection.

Station to date	Location	Date sampled	Vessel	Latitude	Longitude	Comments
Station 1	Stellwagen Sanctuary (SB1)	5/28/02	Angela and Rose	42° 25.8’	70 ° 25.17’	Sandy
Station 2	Stellwagen Sanctuary (SB2)	6/21/02	Giovanna	42 ° 15.6’	70 ° 24.04’	Muddy
Station 3	Georges Bank area (GB1)	7/06/02	Jessica D	42 ° 10.0’	67 ° 14.0’	Gravel
Station 4	Georges Bank area (GB2)	7/06/02	Jessica D	42 ° 0.9’	67 ° 29.5’	Sand and Clay
Station 5	Wilkinson Basin (WB)	6/28/02	Padre Pio	42 ° 35.0’	69 ° 50.0’	Mostly mud
Station 6	Georges/ Canadian side (GBC)	7/3/03	Vinna and Shane	42 ° 00	66 ° 30’	Muddy?

<u>Cod sampling</u>

Cod livers and gonads were collected from six sites: Two sites on Stellwagen Bank (SB1 and SB2), one site in WB, two sites on the U.S. side of Georges Bank (GB1, GB2), and one from the northern edge of the bank (GBC) (Table 1). Five to ten samples of each tissue was collected depending on availability of fish. Female fish were targeted where a sufficient number of females could be collected otherwise males were included in the collection. Ideally we would have liked to collect cod during their peak spawn, which generally occurs during late winter or early spring (NOAA 1999). Our samples were collected in May and June.

Tissue samples were collected taking care not to contaminate samples, using procedures set forth at sampling workshops during which fishermen were instructed on ‘clean sampling’ procedure.

Briefly, cod were placed on a clean surface on board ship, covered with laboratory grade bench-coating. After recording the length, stainless steel knives and scissors were used to dissect the liver and gonad from the fish. Tissues were placed in chemically clean jars provided by Severn Trent Laboratory, Vermont (STL) and placed on ice until returning to dock, where they were kept frozen or shipped immediately, overnight to STL for analysis. Analysis included both chemical analysis and analysis of lipid content in livers and gonads from selected sites. Cod tissues were analyzed for metals, PCBs and in some cases organochlorine pesticides.

The lack of clearly anomalous data suggests that the participating fishermen, when properly trained in sampling protocol, can successfully conduct collection of biological samples for scientific analysis.

Sediment Samples:

Sediment samples were collected at sites used for fish sampling (Table 2). Samples were collected using a Ted Young benthic grab sampler. Two samples were collected from each station (and two sub samples were removed from each grab, allowing for archiving of duplicate samples). All sediment samples were returned to the Gloucester Fishermen's Wives Association; two samples from each site were packaged and sent to STL, Burlington, VT and analyzed for metals and PCBs. Additionally, polyaromatic hydrocarbons (PAH) and organochlorine pesticides were measured in samples from SB and WB. Archived samples are currently in storage at the Gloucester Fishermen's Wives Association.

Chemical Analysis:

Analysis was conducted at STL laboratories in Burlington Vermont according to the methods listed in Table 3. Since a complete set of chemical analysis was not conducted for all samples Table 3 also lists which type of chemical analysis was applied to tissue and sediment samples. All data on fish tissues are reported as fresh weight or wet weight. Sediment data are reported in dry weight.

Table 3. Analytical methods employed by Severn-Trent Laboratories for cod tissue and sediment analysis.

Analysis	Analytical Method	Comments
Metals	Method 6010B	All tissues and sediments
PCBs	Method 8082	All tissues and sediments
Pesticides	Method 8081A	Tissue and sediment from SB, WB and GBC
PAHs	NOAA S&T PAH SIM Method	Sediment from SB, GBC and WB.

Statistical Analysis: Statistics were conducted using the Statitica package, where appropriate Tukey's HSD was applied to evaluate differences in contaminant concentrations amongst different sites.

Data

The results of our collections and chemical analysis are provided in data Tables (4-10) below. These data are currently being formatted for inclusion in the NEC Fisheries and Oceans Database, and will be submitted by December 2005, once we have submitted our work for peer review publication.

Cod

Table 4. Cod length and lipid content of livers and gonads

Site	Sex	N	Length (cm)	Liver % lipids	Gonad % lipid
GB1	Females	5	62.5 ± 6.1	NA	NA
GB2	Females	6	68.3 ± 4.4	55.8 ± 12.7	0.7 ± 0.3
WB	Females Males	3 2	85.0 ± 2.5 75.0 ± 3.5	68.3 ± 13.4 43.3 ± 3.5	1.5 ± 1.2 NA
GBC	Females Males	4 4	68.0 ± 3.9 82.5 ± 12.4	22.5 ± 15.3 55.3 ± 2.8	0.5 ± 0.1 NA
SB 1	Females	6	70.0± 8.2	49.2± 12.5	1.0±0.2
SB 2	Females	6	73.8± 6.1	58.4± 7.8	0.8± 0.3

Table 5. Mean (± SD); range [in brackets]; and numbers of detectable samples for selected metals[a] in cod liver tissue. Data are reported for wet weight as parts-per-million.

Site	Arsenic	Cadmium	Copper	Mercury	Selenium	Silver	Zinc
GB1	8.2±6.3 [3.7-19.1] 5/5	3.4±3.8 [1.1-7.7] 3/5	21.4±15.3 [6.2-42.4] 4/5	0.11±0.0 [0.06-0.1] 4/5	3.7±1.4 [2.3-5.8] 5/5	3.3±1.4 [1.7-4.2] 3/5	38.4±26.0 [12.6-71.1] 5/5
GB2	6.0±5.5 [3.4-17.2] 6/6	5.5±8.0 [0.8-21.6] 6/6	19.9±19.9 [5.8-21.2] 6/6	0.09±0.1 [0.05-0.21] 3/6	3.5±1.6 [2.0-6.6] 6/6	--------[c] [2.3,11.4] 2/6	36.9±29.4 [13.6-95.2] 6/6
GBC[b]	5.7±4.2 [2.2-15.7] 8/8	3.4±2.7 [1-6.6] 4/8	11.8±5.2 [4.2-20.3] 8/8	0.05±0.01 [0.04-0.06] 7/8	1.9±0.4 [1.3-2.5] 8/8	1.8±0.8 [1.0-2.8] 4/8	24.9±8.8 [26.6-38.1] 8/8

WB[b]	5.9±1.9 [4.2-9.2] 5/5	ND[d] ------- 0/5	7.7±3.3 [3.0-11.0] 5/5	ND[d] ----- 0/5	1.7±0.7 [1.1-2.8] 5/5	ND[d] ----- 0/5	27.1±8.5 [16.7-37.4] 0/5
SB1	1.9±0.5 [1.4-2.6] 4/6	ND[d] ------- 0/6	4.8±1.8 [3.2-7.2] 4/6	------- [c] [0.05] 1/6	0.6±0.2 [0.2-0.8] 6/6	----- [c] [1.6] 1/6	13.0±4.7 [5.9-19.8] 6/6
SB2	3.2±1.1 [2.0-4.1] 6/6	ND[d] ------- 0/6	5.4±1.9 [3.8-8.7] 6/6	------ [c] [0.04] 1/6	0.5±0.2(6) [0.3-0.7] 6/6	----- [c] [1.1] 1/6	12.9±3.6 [8.2-19.3] 6/6

[a]Metals were assayed using Method 6010B; a total of 24 metals were analyzed (in addition to those reported above analysis included: aluminum, chromium, cobalt, iron, manganese, magnesium, nickel, lead, molybdenum, thallium, calcium, potassium, vanadium, barium, beryllium, antimony and sodium). Means were calculated for samples with consistently detectable concentrations.
[b]Data for GBC include data from 4 female and 4 male fish combined; data for WB include data from 3 female and 2 male fish combined.
[c]Mean was not calculated since there were only one or two data points.
[d]Metal was below detection limits for all fish. Cadmium detection limits ranged from 0.46-0.49 ppm for both SB sites. The detection limits for mercury and silver at WB from 0.03-0.07 and 0.9-1.8 respectively.

Table 6. Means (± SD); range, in [brackets]; number of detects per sample for PCBs[a] 1254 and 1260 in cod liver tissues in parts-per-billion wet weight.

Site	PCB 1254	PCB 1260
GB1	309.6±222.96 [98-620] 5/5	153.3±25.17 [130-180] 3/5
GB2	327.0±89.92 [230-460] 6/6	73.2±48.7 [25-150] 6/6
GBC [b]	318.6±253.6 [65-830] 8/8	149.7±108.4 [28-350] 7/8
WB [b]	676.0±229.9 [470-1000[c]] 5/5	398.0±76.0 [330-490] 5/5
SB1	1,456.7±670.93 [760-2500] 6/6	655.0±443.8 [180-1200] 6/6

SB2	1,483.3±292.7 [1200-2000] 6/6	576.7±97.7 500-760 6/6

[a]PCBs were assayed using method 8082. PCB patterns for both Aroclors 1254 and 1260 were altered suggesting weathering.
[b] Data for GBC include data from 4 female and 4 male fish combined; data for WB include data from 3 female and 2 male fish combined.
[c] The two highest concentrations, 830 and 1000 ppb were detected in the two male fish of the sample.

Table 7. Means (± SD); range, in [brackets]; number of detects per sample for selected DDT and metabolites[a], in parts-per-billion, wet weight detected in cod liver tissue;

Site	4,4'-DDE	4,4'-DDD	4,4'-DDT	Total DDTs
GBC	120.8±92.08 [16-130] 8/8	25.0±15.4 [6-24] 7/8	54.5±35.4 [12-120] 6/8	165.5±147.4 [16-447]
WB	262.0±75.0 [140-320] 5/5	94.6±45.1 [33-130] 5/5	304.2±211.4 [31-540] 5/5	660.8±324.9 [204-970]
SB1	146.6±84.8 [66-240] 6/6	48.5±14.7 [28-63] 4/6	41.2±12.9 [22-59] 6/6	220.2±120.4 [44-303]
SB2	151.7±39.7 [100-200] 6/6	40.6±7.0 [29-48] 5/6	30.4±4.6 [26-38] 5/6	210.8±39.7 [165-256]

[a]Total DDTs are the sum of the two 4,4'-DDT metabolites and 4,4'-DDT. For those sites where DDT was not detected a concentration of zero was used in the summation.

Table 8. Means (± SD); range, in [brackets]; number of detects per sample for selected organochlorine pesticides[a], in parts-per-billion, wet weight detected in cod liver tissue;

Site	HCH/BHCs[c]	AldrinC	Heptaclor epoxide	Dieldrin	Endrin	α–Chlordane
GBC[b]	23.5±11.4 [8.5-41.0] 6/8	8.5±5.0 [5.4-16.0] 5/8	6.8±1.1 [5.2-7.8] 4/8	16.0±8.1 [11. -28.] 4/8	16.6±9.8 [4.6-33.] 6/8	14.9±9.8 [4.7-33] 7/8

WB [b]	ND[d] ND 0/5	ND ND 0/5	16.8±6.8 [7.2-22.0] 4/5	NA [15,21] 2/5	41.0±14.6 [18.-56.] 5/5	29.2±6.7 [22. -38] 5/5
SB1	ND ND 0/6	ND ND 0/6	NA 22,20 2/6	NA 160,27 2/6	ND ND 0/6	30.0±2.9 [27-34] 4/6
SB2	ND ND 0/6	ND ND 0/6	17.2±2.3 [15-21] 5/6	27.0±2.0 [26-30] 4/6	NA [28] 1/6	24.8±4.5 [17-28] 5/6

[a]Pesticides were analyzed using method 8081A.
[b] Data for GBC include data from 4 female and 4 male fish combined; data for WB include data from 3 female and 2 male fish combined.
[c]HCH/BHCs include α, β, γ and δ-BHC (hexachlorocyclohexane). Detection limits were 15 and 10 for each metabolite at SB1 and SB2 respectively.
[d]ND:mean not calculated due to lack of data.

Sediment

Table 9. Concentrations of PAHs in sediments from Stellwagen Sanctuary and Wilkinson Basin.

PAH Analysis Using SIM Analysis (parts per billion; ug/Kg)		
Site	Stellwagen Sanctuary (Sample 2 a, c)	Wilkinson Basin (Sample 5 a, b)
Naphthalene	6.9, 8.5	4.6, 6.5
2-methylnapthalene	4.0, 5.1	3.4J, 3.5J
1-methylnapthalene	3.0J[a], 3.8J	2.6J, 2.4J
Biphenyl	1.7J, 2.0J	U[b], U
2,6 Dimethylnapthalene	2.9J, 3.7J	U, U
Acenaphthylene	3.6, 4.3	U, U
Acenaphthene	3.2J, 4.0	U, U
2,3,5 Trimethylnaphthal	2.0J, 2.6J	U, U
Fluorene	6.7, 8.2	2.5J, 3.8J
Dibenzothiophene	3.7, 4.7	U, U
Phenanthrene	56, 69	16, 21
Antharacene	9.8, 12	2.1J, 4.2
1-Methylphenanthrene	14, 19	3.4J, 2.8J
Fluoranthene	**120, 120[c]**	32, 25
Pyrene	98, 120	26, 22
Benzo(a)anthracene	50, 68	12, 11

Chrysene	58, 74	18, 15
Benzo(b)fluoranthene	68, 99	28, 14
Benzo(k)fluoranthene	58, 80	18, 15
Benzo(e)pyrene	50, 70	18, 13
Benzo(a)pyrene	60, 82	16, 14
Perylene	15, 20	5.8, 6.5
Indeno(1,2,3-cd)pyrene	43, 64	17, 11
Dibenz(a,h)anthracene	**16, 24**	5.6, 3.6J
Benzo(g,h,I)perylene	47, 69	20, 32
Total	801, 1037	251, 212

[a]J indicates estimated value, where result is less than reporting limit but greater than ½ the reporting limit.
[b]U indicates that the compound was not detected.
[c]Bold indicates above NOAA Screening Quick Reference Table Threshold Effects Level for marine sediment which is 112.8 ppm for fluoranthene and 6.2 ppm for dibenz(a,h)anthracene.

Table 10. Concentrations of metals in sediments collected from Georges Bank, Stellwagen Sanctuary and Wilkinson Basin. Concentrations shown for duplicate samples from each site (a,c). Metals Analysis Using Method 6010B (reported as parts per million (mg/kg), dry weight)

Site	SB1	SB2	GB1	GB 2	GBC	WB
Mercury	<0.037, <0.038	0.081, 0.12	<0.046, <0.045	0.060, <0.047	<0.034, <0.037	<0.064, <0.062
Aluminum	348, 428	8560, 11200	3510, 3430	6160, 6100	852, 1510	16700, 17700
Arsenic	1.7, 1.9	**10.0, 10.0** [a]	6.5, 6.9	3.7, 3.8	3.2, 3.7	4.0, 4.9
Cadmium	<0.59, <0.57	<0.82, <0.96	<0.65, <0.65	<0.67, <0.72	<0.52, <0.52	<0.92, <0.94
Chromium	1.9, 2.4	35.2, 45.7	17.1, 16.5	21.2, 20.2	3.3, 5.4	37.3, 40.5
Cobalt	<5.9, <5.7	<8.2, <9.6	<6.5, <6.5	<6.7, <7.2	<5.2,<5.2	14.3, 15.5
Copper	<3.0, <2.9	9.6, 15.2	<3.3, <3.3	6.8, 6.9	<2.6, <2.6	17.7, 17.2
Iron	1350, 1690	16400, 20000	16400, 15800	15700, 15500	3330, 5760	30900, 34700
Magnesium	<584, <563	5370, 6710	2400, 2326	4320, 4310	1040, 1270	10900, 11700
Manganese	19.4, 34.9	228, 272	111, 79.7	168, 171	85.6, 65.7	486, 962
Nickel	<4.7, <4.6	13.3**, 17.3**	<5.2, <5.2	11.6, 11.5	<4.2, <4.2	**32.0, 33.4**
Lead	1.2, 1.7	18.2, 23.1	4.6, 4.3	9.2, 9.4	2.4, 2.4	19.1, 15.7
Silver	<1.2, <1.2	<1.7, <2.0	<1.3, <1.3	<1.4, <1.5	<1.0, <1.0	<1.9, <1.9
Selenium	<0.59, <0.57	<0.82, <0.96	<0.65, <0.65	<0.67, 0.73	<0.52, <0.52	<0.92, 1.2
Molybdenum	<1.2, <1.2	<1.7, <2..0	<1.3, <1.3	<1.4, <1.5	NR[b]	<1.9, <1.9
Thallium	<1.2, <1.2	<1.7, <2.0	<1.3, <1.3	<1.4, <1.5	<1.0, <1.0	<1.9, <1.9
Zinc	3.0, 3.6	44.9, 55.8	21.0, 19.0	32.7, 32.4	5.7, 8.9	84.7, 87.1

Vanadium	<5.9, <5.7	30.0, 39.4	26.8, 26.2	24.7, 24.2	10.3	55.2, 56.4
Barium	<23.4, <22.6	<32.5, 38.8	<26.0, <026.0	<26.8, <28.5	<20.8	69.8, 74.7
Beryllium	<0.59, <0.57	<0.82, <0.96	<0.65, <0.65	<0.67, <0.72	<0.52	1.0, 1.1
Antimony	<7.1, <6.8	<9.8, <11.5	<7.8, <7.8	<8.1, <8.6	<6.2	<11.0, <11.3

[a]Concentrations in bold exceed NOAA's Screening Quick Reference values for Threshold Effects Level (TEL) in marine sediments. TELs (in ppm) were available only for the following metals: Arsenic (7.2), cadmium (0.7), chromium (52.3), copper(18.7), lead (30.2), mercury (0.1), nickel(15.9), silver(0.7), and zinc(124.0).
[b]Not reported

Polychlorinated biphenyls and organochlorine pesticides were below detection limits for all sediment samples.

Results and Conclusion

<u>Cod</u>

Because we were interested in the effects of chemical contaminants on reproduction and development in cod we targeted female fish. However at sites where collection of sufficient numbers of female fish was difficult (e.g. WB and GBC), male fish were collected as well (Table 4). Because of the small numbers collected for each sex, data for both sexes were combined for statistical analysis.

Metals

The heavy metals As, Cu, Se, Zn, were detected in most fish at all sites (Table 5), while Hg, Cd, and Ag were detected primarily in cod from the three GB sites. Several metals including Al, Cr, Mn, Tl, and V were detected in only a few fish across all sites or not at all. These metals were dropped from the analysis. Statistical analysis of the four metals detected in all sites reveals a trend in which the concentrations are consistently lower in the SB cod compared to the GB cod. This is interesting, since the sediment trends suggest slightly higher concentrations of metals in SB and WB, compared to GB, although as noted earlier, the sediment data are limited to only two samples and thus can only be considered as a very limited data set. Comparing our results for metals to those of Hellou et al., (1992) who measured trace metals in cod livers collected off the coast of Newfoundland, the mean concentration of Cd in fish from GB was roughly 8-10 fold higher than those concentrations reported by Hellou (Table 11) and Cu is up to 3-fold higher. We were unable to compare our data with concentrations recently reported by the USGS National Water Quality Assessment Program, because they report concentrations in fillet rather than in liver (USGS 2002).

Interestingly, the concentrations of Cd in GB cod livers from our study were within the range of concentrations found in fresh water fish (measured as whole-bodies) collected from a lake contaminated by an electroplating plant, and are comparable to some of the higher mean concentrations of cadmium (which ranged from 0.1-19.6) in NOAA's 1987 Status and Trends report (NOAA 1987). The Cd concentrations measured in the GB cod are also within range of cadmium concentrations reported in tilefish livers from several deep sea canyons located in the Middle Atlantic Bight, including one location (Lydonia Canyon) on Georges Bank (Steimle et al., 1996; Steimle et al., 1990).

Cadmium and copper are known reproductive and developmental toxicants in fish (reviewed in Sorensen 1991; Jarvinen and Ankley 1999). However, the potential for adverse reproductive or developmental effects in cod caused by Cd at the concentrations measured in this study remain unclear, because the majority of toxicity data relate either exposure concentrations to toxicity, rather than tissue concentrations, or were designed to evaluate life stages and endpoints other than those of interest in this current study.

In the gonads, the only metals consistently detected were Fe, Na, Se, K and Zn. Both selenium and Zn were higher in gonads compared to livers, which is in agreement with an earlier study by Hellou et al. (1992), who noted their importance for the normal functioning of certain enzymes.

Table 11. Comparison of mean concentrations of selected metals in female cod livers from present study and Hellou et al. 1992. Data are reported as ppm wet weight.

Site	Year	Arsenic	Cadmium	Copper	Mercury	Zinc
GBC[a]	2003	5.7	3.4	11.8	0.05	24.9
GB1[a]	2002	8.2	3.4	21.4	0.11	38.4
GB2[a]	2002	6.0	5.5	19.9	0.09	36.9
WB[a]	2002	5.9	ND	7.7	ND	27.1
SB1[a]	2004	1.9	ND	4.8	ND	13.0
SB2[a]	2004	3.2	ND	5.4	ND	12.9
North of Newfoundland Canada (site 3Ps)[b]	1991	3.2	0.40	6	<0.05	19
North of Newfoundland Canada (site2J)[b]	1990	3.9	0.40	3	<0.05	13

[a]This study (mecury was only above detection limits in one fish from each SB site).
[b]Hellou et al., 1992.

PCBs and Chlorinated Pesticides

The PCBs Aroclor 1254 and 1260 were detectable in the majority of cod livers from all sites (Table 6) with the highest concentrations in fish from SB. The concentration of Aroclor 1254 in these fish was approximately 5-fold greater than in fish from the GB sites, and 2-fold greater than in fish from WB. PCB concentrations detected in cod livers from the present study are below those reported to cause adverse effects on reproductive or development (Monosson 1999/2000; Reiser et al., 2004).

Interestingly, PCB concentrations were below detection limits (<50ppb) in gonads from all sites.

Of the several organochlorine pesticides and their metabolites analyzed in this study, only DDT and its metabolites (DDD and DDE), a-chlordane, endrin and heptachlor were detected in more than 50% of the samples across all sites. Concentrations of these pesticides are reported in Tables 7 and 8.

Besides those pesticides (and pesticide breakdown products) detected in liver and reported in Tables 7-8, analysis included: heptachlor; endosulfan I; endosulfan II; endosulfan sulfate; methoxychlor; endrin ketone; endrin aldehyde; toxaphene. These pesticides were generally below detection limits in cod livers.

Cod livers from WB had almost three-fold higher concentrations of total DDT than fish from all of the other sites for which DDTs were measured. Interestingly, WB fish also had similar concentrations of the long-lived DDE metabolite and the more rapidly metabolized DDT parent compound, unlike cod from SB and GB, suggesting a newer source of DDT exposure for Wilkinson Basin cod. A study of contaminants in tilefish collected from several deep sea canyons in the Northwest Atlantic showed a similar occurrence where DDE concentrations in tilefish from Lydonia Canyon (on GB) was detected at concentrations similar to the parent DDT compound. In contrast DDT concentrations were roughly half the concentration of DDE metabolite in tile fish from the remaining canyon sites (Steimle et al. 1996).

Notably, PCB and DDT concentrations in cod from GBC are drastically lower than those reported earlier by Harvey et al. (1973). Additionally concentrations for both organochlorines in cod from GBC tend to be lower than concentrations reported historically for cod collected from various locations in the 1970's and 1980's (Table 13). Concentrations of PCBs in fish from Stellwagen Bank, however are higher compared to other sites and other years (excepting the high concentrations reported in the Southern Baltic and on Georges Bank in the 1970s (Table 12)), as are the concentrations of DDTs found in fish from Wilkenson Basin.

Table 12. Summary of PCBs and DDTs in cod livers from other studies and sites. Data are for ppm wet weight. (*modified from Hellou et al., 1993*).

Site	Year	Length	PCB	DDTs
GBC[a]	2003	68	0.47	0.17
WB[a]	2002	85	1.07	0.66
SB1[a]	2004	70	2.11	0.22
North of Newfoundland Canada[b]	1991	91	0.15	0.16
N. Baltic[c]	1988	31-35	1.1	0.33
S. Baltic[d]	1983	61-70	27	6.0
GBC[e]	1971	?	22.0	2.7

[a]This study – data are combined means for A1254 and A1260 for PCBs; DDTs indicates 4,4'-DDT and metabolites combined.
[b]Hellou et al., 1993.
[c]Haati and Pertilla, 1988 as reported by Hellou et al., 1993.
[d]Falandysz, 1984, as reported by Hellou et al., 1993.
[e]Harvey et al., 1973

Unfortunately, there are no consensus guidelines allowing for the evaluation of contaminant concentration in marine fish livers or gonads with health risk to fish. As noted earlier the majority of toxicity studies for metals relate concentrations in water to toxicity, rather than concentrations in tissues like liver or fillet. Although there is one often quoted contaminant guideline for protection of fish-eating wildlife, the NAS/NAE Guideline, this document was produced in 1973, over 30 years ago and its relevance today is unclear given the advances in our understanding of the reproductive, developmental and neurological effects of many of these chemicals.

While these data suggest that chemical contaminant concentrations are not alarmingly high, the combined impact of small concentrations of many chemicals, such as cadmium, copper, PCBs, and DDTs is currently unknown. This is an area of research that warrants further attention.

Human consumption

Because of the recent interest in the impact of contaminants, particularly PCBs, in fish tissues on human health, we also considered what these concentrations might mean for human health. Since samples were of livers rather than edible tissues, we can only estimate the concentrations that might occur in tissues of cod.

Cod are a species where the ratio of lipid (fat) between the liver and the flesh is extremely large. That is, the percent lipid in the cod liver may be up to 100X greater than the percent in the muscle (Hellou et al. 1993). This means that for chemicals that accumulate in the fat, such as organochlorines, the concentration in the flesh is likely to be much lower than in the liver.

Low (or near or below detection limits) concentrations have previously been reported in cod muscle samples collected North of Newfoundland for PCBs and for Cd (which accumulates preferentially in the liver and kidney in cod) by Hellou et al. (1993). Thus the concentration of PCB and Cd in cod fillets from sites evaluated in the present study are likely to be much lower than concentrations measured in the livers.

Mercury concentrations were also relatively low in the livers of cod. However, unlike PCBs, mercury tends to be higher in fillet compared to liver of cod (Hellou et al. 1992). In their studies mercury concentrations were at least 10X greater in muscle tissue compared to liver tissue. These data suggest that mercury concentrations in cod muscle from these sites may be 10X greater than the concentrations reported in liver.

Current FDA guidelines for mercury, and selected organochlorines in edible tissues are listed below in Table 14.

Table 13. FDA guideline for mercury and organochlorines in edible fish tissue in ppb wet weight.

Chemical	USFDA[a]
Total PCBs	2,000
Total Chordane	300
Total DDTs	5,000
Mercury	1,000

[a]U.S. Food and Drug Administration Tolerance level for PCB in edible fish tissue and action levels for mercury chlordane and DDTs. http://www.cfsan.fda.gov/~comm/haccp4i.html

Sediments

The sediment results represent only a small number of sediment samples (six sites, two samples per site). The sediment survey was intended only for a pilot comparison to tissue samples rather than to provide a general characterization of sediments from Georges and Stellwagen Banks.

PAHs

In general PAHs were detected in sediments from Stellwagen bank at low concentrations except for fluoranthene which was slightly above the Threshold Effects Level (TEL) for marine sediments (NOAA 2004c) and dibenzathracene which was approximately 3X over the TEL (Table 9). The majority of PAHs were at or below detection limits in Wilkinson Basin, and all were below detection limits on the Canadian side of Georges Bank.

Metals

As with PAHs, the majority of metals detected in sediments were below TELs except for arsenic and nickel (Table 10). Concentrations for both metals were slightly above TELs at SB2 and nickel concentrations were approximately 2-fold greater than the TEL at WB. In general metals tended to be higher in SB2 which consisted of muddy sediments compared to SB1, a site consisting mainly of sand, and both Georges Bank sites. The highest concentrations for several metals were found in WB, a mainly muddy site.

The majority of metal concentrations from all sites in this study tended to be at least three times lower than those reported by Chalmers (2002) for the median concentration of the New England Coastal Basins sites, except for As, Cr, Ni from SB2 and Cr and Ni from WB. In these cases the sediment metals concentrations were closer to the median concentrations. Generally the metal concentrations measured in this current study tended towards the lower end of both the Coastal Basin study and in comparison to the NOAA Status and Trends data from 1987 (Table 14).

Table 14. Range of selected metals detected in New England sediments reported by NOAA Status and Trends (NOAA 1987) and USGS (Chalmers 2002) compared with range of metals detected in current study of Wilkinson Basin, Stellwagen and Georges Banks.

Source of data	Arsenic	Cadmium	Copper	Nickel	Mercury
NOAA 1987	7.8-20.9	0.09-9.8	16.3-256.1	22.7-65.2	0.007-1.7
Chalmers 2002	6.6-160	0.44-18	21-360	2-83	0.02-2.8
Current study	1.7-10.0	<0.5-<1.0	<2.6-17.7	<4.2-33.4	<0.03-0.1

PCBs and Chlorinated Pesticides

All PCBs and chlorinated pesticides were below detection limits in sediments. Detection limits for PCBs ranged from 21-33 ppb depending on the moisture content of the sample.

Impact of results on Fisheries Management

The impact of these results on fisheries management is significant, since many have suggested that non-fishing impacts could be equally as severe as fishing impacts. This study shows that contaminant on the fishing grounds may not be great enough to be responsible for the differences in recruitment of the two cod stocks. Furthermore it demonstrates that pollution levels on the banks and in the sediments are unlikely to have any impact on the reproductive success or survivability of the cod stocks.

Limitations for interpretation of results

This study was limited primarily by the funds available. While we successfully tested for toxicants that may act as endocrine disrupting compounds including PCB's, metals and selected pesticides, we were unable to sample directly for hormones, steroids, pthalates and other endocrine disrupting substances which may occur in extremely minute traces (parts per trillion). This limitation is common and is consistent with other reports published by the USGS and NOAA. With more than 25,000 new drugs and chemicals added to the environment each year we must confine our studies to the most prevalent compounds given the limited funds available.

Obviously, since we only sampled the livers and gonads of cod, it is difficult to draw firm conclusions about other species or the possible implications for human health from fish consumption. However, since the contaminant levels were so low in the organs that would normally concentrate them, it seems safe to assume that pollution of the fishing grounds offshore New England is generally not a major problem for Groundfish.

Significance of project in terms of objectives and NEC goals

The primary objectives of this project have been addressed. The anecdotal evidence of widespread pollution on the fishing grounds does not appear to apply to cod and probably groundfish in general. Furthermore, there is clear evidence that the contaminant levels have been improving since the 1970's.

This study is an important contribution to the small data base on contaminants in offshore fish, and demonstrates clear differences in contaminant concentrations for cod collected from different sites (e.g. PCBs in fish from Stellwagen Bank verse Georges Bank; DDTs in fish from Wilkinson Basin verses all other sites; and higher cadmium concentrations in offshore sites compared to nearshore sites). Except for cadmium and perhaps copper, these data indicate relatively low concentrations of chemical contamination in livers and gonads of cod collected from Georges Bank sites. And, as noted above without further analysis linking tissue concentrations of cadmium, copper and other metals with toxicity, it is difficult to interpret the meaning of these data.

Aside from PCBs, contaminant concentrations in inshore cod are either similar or less than offshore cod. This result is somewhat surprising giving the tremendous amount of freshwater dumped from the rivers carrying runoff from the coasts. Apparently oceanographic conditions such as rapid currents and wind conditions prevent widespread transport of contaminants to the principal fishing grounds.

One of the most interesting findings in this study are the relatively low concentrations of PCBs in the Georges Bank fish compared to the earlier studies conducted by Harvey et al., (1974). This leaves us with three possible explanations for the historically high levels of pollutants reported in the literature: 1) the ocean environment has significantly improved since PCB's were banned in the 1970's, 2) the earlier measurements and analysis was faulty 3) the high readings were concentrated in a very small, localized region of Georges Bank. Although measurements of the period were considerably less reliable and precise than today, the extremely high PCB levels were carefully re-examined and every effort was made to confirm the validity of the analysis in those days. This study duplicated the published coordinates of the period, but we cannot rule out that a single wreck or leaking container could have been responsible for the anomalous PCB readings.

It is interesting to note that in the early 1980's, marine PCB contaminant levels in US waters were challenged generally on the basis that hundreds or even thousands of pounds of PCBs would have to be flowing into the oceans to account for the high readings. Of course, we now know that actually thousands of tons of PCBs were indiscriminately and illegally dumped in harbors and at disposal sites offshore New England immediately following the ban.

Only a later phase of coring could fully resolve these different interpretations. However, it would take many long cores to demonstrate conclusively that widespread pollution offshore has improved significantly in the last half century.

Partnership

The collaboration between the fishermen and scientists has been a very positive experience, resulting in highly relevant and useful data set for both partners. In this collaboration, without the fishermen the scientist would not be able to obtain the samples (either economically or logistically) that have been collected by the fishermen. The fishermen involved benefited both economically and educationally by being integrally involved in this project. They have helped to generate a report on contaminants in tissues from cod stocks and sediments that is of direct relevance to them.

Through the combined efforts of the fishermen and the scientists we have developed a database on chemical contaminants in offshore cod, the first of its kind for cod in this location.

This study was truly a collaborative effort. Although there were some stumbling blocks, this project has provided valuable information and experience for all participants by providing the fishermen with the tools for assisting scientists in data collection, and by providing the scientist with tools for working with communities such as the Gloucester fishermen.

Collaboration with other projects

Impacts on end-users: The results of this project continue to be both surprising and reassuring to end users. Since this project was initiated, the US Geological Survey has published their 2004 report on *Water Quality in the New England Coastal Basins - Circular 1226.* The USGS concluded that PCB levels in fish taken from 12 rivers in New England had the highest levels in comparison to 38 other study regions across the nation. Mercury advisories exist for freshwater fish throughout many New England states because levels in fish fillets were greater than the US EPA's health advisory of 0.3 ppm for eating fish. This would be cause for alarm if these levels were measured in common ocean fish such as cod.

Our study recorded mercury levels in the livers to be an order of magnitude less than these advisories, although until further study we cannot confirm low mercury concentrations in cod fillet. Although PCB levels in offshore cod livers exceeded the median concentrations in rivers of total PCBs in the reference basin, it must be remembered that for chemicals such as PCBs concentrations in the livers could well be over 50 times greater than the fillet.

Users should feel relieved that the high levels of Zinc, lead, total PCBs and Total PAHs in streambeds were not found in marine sediments. There is no evidence that the low level of contaminants found in marine sediments are bioaccumulating close to the guidelines for aquatic life protection. However we note that our sediment sampling was of limited design, and that confirmation of the sediment results would require more rigorous sampling.

In short, it does not appear that contaminants from New England urbanized areas are being concentrated offshore on or near the fishing grounds.

Presentations: A poster was presented at the NEC conference in the Fall of 2003, and 2004.

Student Participation: NA

Published reports and papers: The results from this project will be written up for submission to Canadian Journal of Fisheries and Aquatic Sciences.

Images:
We have photos of the workshops and catching and measuring fish which will have to be digitized

Future Research
Research that would build upon these results would include 1) studies of cod fillets in addition to livers to address the question of edible tissues 2) studies of other species that inhabit both offshore and near shore fishing grounds to determine if our results can be extended to a wider range of marine fishes 3) a comprehensive literature review linking tissue concentrations to toxicological effects of selected metals in marine fish.

Appendix A

Participating Fishermen:

Giuseppe Palazzolo
Antonio Randazzo
Paul Vitale
Vincenzo Taormina
Giuseppe Randazzo
Nick Vitale
Nino Giacalone
Vito Giacalone
Michael Buscano
Al Cottone
Joseph Orlando
John Sanfilippo
Angela Sanfilippo
Francesco Groppo
Gaetan Brancaleone

Appendix B: Citations

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