Accumulation of Polycyclic Aromatic Hydrocarbons by Lobsters *(Homarus americanus)* Held in a Tidal Pound

J. F. Uthe, D. W. McLeese, G. R. Sirota and
L. E. Burridge

Biological Station,
St. Andrews, N. B., EOG 2X0

April 1984

Canadian Technical Report of Fisheries and Aquatic Sciences No. 1059

Fisheries and Oceans   Pêches et Océans

Canada

Cat. No. Fs 97-6/1059 ISSN 0706-6457

Correct citation for this publication:

Uthe, J. F., D. W. McLeese, G. R. Sirota, and L. E. Burridge. 1984. Accumulation of polycyclic aromatic hydrocarbons by lobsters (Homarus americanus) held in a tidal pound. Can. Tech. Rep. Fish. Aquat. Sci. 1059: iii + 10 p.

ABSTRACT

Uthe, J. F., D. W. McLeese, G. R. Sirota, and L. E. Burridge. 1984. Accumulation of polycyclic aromatic hydrocarbons by lobsters (Homarus americanus) held in a tidal pound. Can. Tech. Rep. Fish. Aquat. Sci. 1059: iii + 10 p.

The levels of polycyclic aromatic hydrocarbons (PAH) in lobsters increased during 3-mo storage in a tidal pound constructed from creosoted lumber. For example, the concentrations of pyrene and benzo(a)pyrene in hepatopancreas of freshly landed lobsters were 59 and 6 ng/g (wet wt) respectively and increased to 4150 and 47 ng/g following 3-mo storage in winter and to 23 550 and 545 ng/g (wet wt) respectively following 3-mo storage in summer. The levels of these two PAH in tail muscle were 0.4 to 1.7% of the levels in hepatopancreas. Transfer of the lobsters to a creosote-free tidal pound resulted in decreases in pyrene and benzo(a)pyrene levels in hepatopancreas of 50 and 40% respectively over 5 wk in winter. Over 2 wk in summer, pyrene level decreased by 80% and change in benzo(a)pyrene ranged from -60 to +35%.

Key words: Lobster, creosote, polycyclic aromatic hydrocarbons, uptake, excretion, tidal pound

RÉSUMÉ

Uthe, J. F., D. W. McLeese, G. R. Sirota, and L. E. Burridge. 1984. Accumulation of polycyclic aromatic hydrocarbons by lobsters (Homarus americanus) held in a tidal pound. Can. Tech. Rep. Fish. Aquat. Sci. 1059: iii + 10 p.

Les concentrations d'hydrocarbures aromatiques polycycliques (HAP) dans des homards ont augmenté au cours d'un stockage d'une durée de trois mois dans un enceinte en bois créosoté. Par exemple, les concentrations de pyrène et de benzo(a)pyrène dans l'hépatopancréas d'homards fraîchement débarqués étaient de 59 ng/g et 6 ng/g (masse humide) respectivement et augmentaient à 4150 ng/g et 47 ng/g après un stockage d'une durée de trois mois en hiver, et à 23 550 ng/g et 545 ng/g (masse humide) respectivement après un stockage d'une durée de trois mois en été. Les concentrations de ces deux HAP dans le muscle de la queue correspondaient à 0,4 p. 100 et 1,7 p. 100 des concentrations dans l'hépatopancréas. Après transfert des homards dans une enceinte exempte de créosote, les concentrations de pyrène et de benzo(a) pyrène dans l'hépatopancréas ont diminué de 50 p. 100 et 40 p. 100 respectivement sur une période de cinq semaines en hiver. Sur une période de deux semaines en été, la concentration de pyrène a diminué de 80 p. 100, tandis que la concentration de benzo(a)pyrène a varié -60p. 100 à +35 p. 100.

INTRODUCTION

Polycyclic aromatic hydrocarbons (PAH) are compounds with three or more fused aromatic rings. A complex mixture of PAH is present in fossil fuels and also is formed during combustion of carbonaceous fuels; the amount formed increases as the combustion efficiency decreases (National Academy of Sciences 1972). Concern over human exposure to PAH dates back to the eighteenth century when Pott (1775) associated an increased cancer incidence with chimney cleaning and soot handling. Volkman (1875) also found an association between the incidence of cancer and work in coal tar plants.

Coal tar, produced by the destructive distillation of bituminous coal, is redistilled to yield a number of fractions, including creosote, which is used in combination with napthalene and coal tar to pressure-treat wood for preservation. In the marine environment, creosote is believed to be the best treatment available for preventing or delaying wood rot and wood-borer attack (Page 1977). Creosote must contain more than 98% aromatic components to be effective as a wood preservative in the marine environment (Baechler and Roth 1961). Both creosote and coal tar contain PAH at high levels (Colley 1974).

PAH contamination of marine shellfish living near marinas, harbors, or areas of oil spills has been known for many years (Cahnmann and Kuratsume 1957; Andelman and Suess 1970). Dunn and Stich (1975) found elevated levels of benzo(a)pyrene (BaP) in mussels (Mytilus edulis) taken from creosoted pilings. BaP is a carcinogenic PAH (National Academy of Sciences 1972). Zitko (1975) showed that mussels (Mytilus edulis), periwinkles (Littorina littorea) and various species of whelks had tissue PAH compositions closely resembling that of creosote. Sirota and Uthe (1981) showed the similarity of PAH patterns in creosote and lobster (Homarus americanus) digestive gland.

Dunn and Fee (1979) reported that lobsters held for approximately 3 mo in a commercial lobster storage tidal pound had high PAH levels in the hepatopancreas and tail muscle. PAH levels in hepatopancreas were 7-11 times higher than in tail muscle. They also found BaP in samples of other invertebrates such as clams, cockles, mussels, oysters and crabs, at levels between 1 and 10 ng/g. Levels of BaP greater than 1-10 ng/g are of concern to health officials since the usual level of BaP in most foodstuffs is less than 1 ng/g (Howard et al. 1968; Lo and Sandi 1978).

The purpose of this study was to follow changes in levels of PAH in lobsters held under typical summer and winter storage conditions in the same commercial tidal pound sampled previously by Dunn and Fee (1979). In part, the objective was to determine if conditions within the pound contributed to the accumulation of PAH within the lobsters. In addition, the ability of lobsters to eliminate accumulated PAH was assessed by transferring them to another holding facility where there was no creosote. Freshly caught lobsters from four sites in Nova Scotia were sampled to provide an estimate of background PAH levels in coastal stocks of lobsters.

MATERIALS AND METHODS

DETERMINATION OF PAH

Eleven non-alkylated PAH were measured: phenanthrene, fluoranthene, pyrene, triphenylene, benz(a)anthracene, chrysene, benzo(e)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, and benzo(ghi)perylene. In the summer experiment, indeno(1,2,3-cd)pyrene (o-phenylene pyrene) levels also were determined.

PAH were determined by the method of Dunn and Armour (1980), with slight modifications. All solvents used were HPLC grade. Tissue homogenates were prepared and frozen in solvent-washed glass jars. Following KOH saponification, the residual lipids and PAH were extracted with iso-octane, then transferred to toluene for column chromatography on 30 g of 5% H_2O deactivated Florisil. PAH were eluted with 200 mL of toluene, transferred to 5 mL of dimethyl sulfoxide (DMSO), and extracted into iso-octane from 66% aqueous DMSO, washed with water and then finally prepared for HPLC in 100 μL DMSO. HPLC was carried out on a Vydac 201 TP reverse phase column (10 μ, 3.2 mm id, 25 cm L), using a linear gradient (70-94% acetonitrile/water [v/v] over 20 min). Instrumentation included two Waters M-6000 A pumps, a Waters WISP Model 710B sample processor, and Model 720 system controller. Column temperature was controlled at 25.0°C by an LC-22 column temperature controller (Bioanalytical Systems Inc.). Schoeffel variable wavelength detectors, Models SF770 (UV) and FS970 (fluorescence) were used in series and with separate chart recorders. Wavelengths used were as follows: UV = 265 and 254 nm; fluorescence ex = 280 nm; em = >389 nm. Both internal and external standardizations were used and peaks were identified by retention times, co-chromatography of reference compounds and, if necessary, by response ratios between UV and fluorescence detectors. In a few cases where the fluoranthene and pyrene peaks overlapped, pyrene was quantified by UV.

Recoveries of PAH added to tissue prior to saponification ranged from 83% for benzo(k)-fluoranthene to 109% for fluoranthene. Analytical variance (relative standard deviation) averaged 7.5%, ranging from 1.8% for benzo(e)pyrene to 13.6% for benz(a)anthracene. N equaled 3 for each PAH.

LOBSTER EXPOSURE

Ten lobsters were sampled from the same commercial tidal pound in Charlotte Co., New Brunswick, after approximately 1-, 2-, and 3-mo storage in winter (mid November-mid February) and after about 1-, 2-, 3, and 3.5-mo storage in summer (mid June-early September). At the times of the last samplings, 60 lobsters were transferred to a creosote-free holding facility in Shelburne Co., Nova Scotia. Samples of 10 lobsters were taken 1, 3, and 5 wk after transfer in winter, and at 18 h and at 4, 8, and 13 d after transfer in summer to follow excretion or depuration of the PAH. Length, weight, and sex of each lobster were recorded. The hepatopancreas and tail muscle were removed, weighed, and stored frozen in solvent-washed glass jars, each jar having an aluminum foil lid liner.

For analysis, equal weights of homogenized hepatopancreas from each of five animals were combined to yield two pooled samples from the 10 animals. Similarly, two samples of tail muscle were prepared. Animal-to-animal variation was determined by analyzing samples of hepatopancreas and tail muscle from each of 10 other lobsters taken on the last day of depuration in the summer experiment.

RESULTS AND DISCUSSION

BETWEEN ANIMAL VARIATION

For the 10 individual lobsters, the coefficients of variation (relative standard deviations) for the PAH ranged from 48-86% for hepatopancreas and from 21-70% for tail muscle (Table 1), and the coefficient for each PAH was greater for hepatopancreas than for tail muscle. The large variation among animals may be related to differences in the animals prior to capture, to exposure conditions within the tidal pound, and to metabolic differences among the animals.

The 10 animals ranged in weight from 429-1054 g, the mean weight being 577 $\pm$ 184 g (mean $\pm$ SD). Linear regression analysis did not reveal a significant ($p = 0.05$) correlation between the concentration of PAH in tissue and the total weight of the animal.

The PAH levels in hepatopancreas averaged 35 times higher than those in tail muscle (Table 2). This is because the hepatopancreas, a digestive organ, has a higher fat level than tail muscle (Stewart et al. 1972) and may contain gut contents (van Weel 1979). Obviously, phenanthrene is distributed differently between tail and hepatopancreas since its mean ratio of 7.7 (Table 2) is lower than the mean ratios for the other 11 PAH which range from 29-52. Phenanthrene was the only tricyclic PAH measured and the low values for the ratio may be related to its relatively high water solubility (Neff 1979). Finally, it appears that there are substantial differences in the ratios between animals.

UPTAKE AND DEPURATION OF PAH BY LOBSTERS

The concentrations of PAH in hepatopancreas and in tail muscle increased during storage, more PAH accumulating when the lobsters were at higher (summer) than at lower (winter) temperatures (Table 3, 4). For example, the summer to winter ratios of the PAH levels after 3-mo storage ranged from 2:1 to 19:1 for hepatopancreas and from 1:1 to 33:1 for tail muscle (Table 5).

PAH levels in tail muscle tended to increase for some time after the animals were moved to clean water (Table 3, 4), presumably because excretion was initiated and PAH was transported by blood from hepatopancreas to tail muscle and other tissues. However, holding the animals in clean water for longer periods resulted in lowering the PAH levels. Losses during 5 wk in winter ranged from 31-77% (mean 53%) in hepatopancreas and from 0-81% (mean 44%) in tail muscle. In summer, the results for excretion were variable. By 13 d, there were losses for only 4 of the 12 PAH in hepatopancreas (i.e. gains for 8 PAH) and losses for only 3 PAH in tail muscle. When transferred to clean water, lobsters had higher levels of PAH in summer than in winter, and the excretion period for the summer lobsters was much shorter. From a total of 60 lobsters transferred, 50 had been sampled by 13 d. Mortality, in part caused by cannabalism, did not leave enough lobsters for a later sampling. Cannibalism during the summer excretion period was a factor that could alter the apparent excretion, assuming that PAH could be accumulated from food.

It was shown that PAH from creosote can accumulate rapidly in hepatopancreas of lobsters (McLeese and Metcalfe 1979). Lobsters were not sampled until 1 mo after they were placed in the tidal pound. Therefore, it is impossible to know whether, or how much, the conditions within the tidal pound contributed to the concentrations of PAH measured then. The mean PAH level after 1-mo storage was higher in winter than in summer in 17 of 22 comparisons. This could indicate that the winter stock of lobsters was more heavily contaminated initially. In support of this suggestion, there were decreases in the level of 7 of 11 PAH in hepatopancreas and in 8 of 11 PAH in tail muscle between the 1- and 2-mo periods in winter. In contrast, between 1- and 2-mo storage in summer there were increases in 23 of 24 PAH. Between 2- and 3-mo storage there were increases for each PAH for each tissue and season, indicating contribution of PAH from sediment or water in the tidal pound.

The ratios of the concentrations of a PAH to those of another PAH, for example pyrene/fluoranthene, can be used to show whether there are changes in the uptake or excretion of one PAH relative to the other. Also, the ratios can show whether uptake of PAH is proportional to its concentration in the environment.

Ratios of the concentration of some PAH (pyrene, benz(a)anthracene, and benzo(a)pyrene) to the concentration of fluoranthene were calculated for hepatopancreas and tail muscle data (Table 3, 4) and for sediment (Table 7). The mean ratios are summarized in Table 8.

Three outliers were eliminated from the calculation of the mean ratios for benzo(a)pyrene/fluoranthene for hepatopancreas in summer data (1- and 2-mo data) and from the corresponding data for tail muscle (Table 4). The outliers were more than three times the standard deviation for the mean ratio, with a maximum of two calculations of the mean ratio. Elimination of these values changed the mean ratio from 0.05 to 0.06 for hepatopancreas and from 0.06 to 0.07 for tail muscle.

There were no trends with time for any of the PAH ratios for hepatopancreas or tail muscle (Table 3, 4). Therefore, the concentrations of pyrene, benz(a)anthracene, and benzo(a)pyrene within the lobster tissues maintained the same proportional relationships with the concentration of fluoranthene throughout the uptake and excretion phases of the tests.

The mean ratios for pyrene/fluoranthene (4.1) and for benz(a)anthracene/fluoranthene (3.1) for hepatopancreas in winter are greater than the mean ratios for sediment, 1.1 and 1.3, respectively (Table 8). Presumably in winter, accumulation of these two PAH in heptopancreas was enhanced relative to the accumulation of fluoranthene. With these exceptions, the general similarity of the ratios for PAH concentrations in lobster tissues and in sediment indicates uptake of these four PAH was proportional to their concentrations in the sediment.

The levels of PAH were low for lobsters captured at four sites around Nova Scotia (Table 6) and, as expected, the levels in tail muscle often were immeasurable and lower than in hepatopancreas. Compared with data for New Harbour lobsters, the PAH levels in lobsters after 3-mo storage in the tidal pound were 2-60 times higher in winter (Table 3) and 13-170 times higher in summer (Table 4).

Dunn and Fee (1979) reported the range of tail muscle levels of the carcinogen BaP to be 0.4-0.9 ng/g wet wt for lobsters prior to storage. After storage in the tidal pound for approximately 3 mo, BaP levels in tail muscle ranged from 7.4-281 ng/g. In our study, levels of BaP in tail muscle ranged from trace amounts to 1.5 ng/g in control lobsters (Table 6). The mean value after storage in the tidal pound was 0.2 ng/g after 3 mo in winter and was 6.5 and 7.5 ng/g after 3 and 3½ mo respectively in summer. None of these values approached the maximum value of 281 ng/g found by Dunn and Fee (1979). In hepatopancreas the BaP levels ranged from 0.8-22 ng/g for control lobsters (Table 6) and the mean value was 46.5 ng/g after 3 mo in winter and was 507 and 361 ng/g after 3 and 3½ mo respectively in summer (Table 3, 4).

Sediments from the tidal pound were analyzed for PAH (Table 7). Values for phenanthrene, fluoranthene, and pyrene in the tidal pound sediments, ranged from 650-3100 ng/g (Table 7) and were higher than those in a 215-m deep sediment from the Gulf of Maine (43-120 ng/g, wet weight) (Laflamme and Hites 1978), or for those in a sediment 45 km seaward from Boston, Mass., at 90 m deep (250-360 ng/g). However, the tidal pound sediment values were similar to or lower than values for Boston harbor or Charles River sediments which ranged from 670-13,000 ng/g (Windsor and Hites 1979). Levels similar to or slightly higher than those in the tidal pound sediments were reported for several PAH by John et al. (1979) for sediments from the Severn Estuary, Great Britain, an area characterized by high tides and receiving industrial effluents. The elevated PAH levels in the sediment of the tidal pound probably resulted from the creosoted lumber used in the construction of the pound.

The uptake of PAH by impounded lobster may be enhanced because lobsters tend to burrow into sediments (McLeese and Wilder 1964), eat each other, and a few may gnaw at the wooden parts of the enclosures. Because of the possibility of tainting, pound owners have been warned against storage of lobster in freshly creosoted pounds (McLeese and Wilder 1964). However, there is no evidence that lobsters are tainted after being held in creosoted structures which have been exposed to sea water for extended periods. Most of the creosote loss from creosoted wood to sea water occurs during the first year (Gibb 1978). Creosoted timbers in current tidal pounds are likely to be several years old, particularly since it is reported that recent repairs are made with timbers pressure-treated with a non-creosote preservative. The relative roles of old creosote timbers and of contaminated sediment as they affect uptake of PAH by lobsters in storage are not fully understood. Assuming contaminated sediment may be a continuing major source of PAH, the extent and distribution (area and depth) of the PAH-contaminated sediments in and around each tidal pound will require assessment before sediment removal can be recommended.

There are 18 tidal pounds in New Brunswick (Bay of Fundy area) and three in southwestern Nova Scotia (total 21). According to a recent survey conducted by questionnaires, four tidal pounds had minor amounts of creosoted materials and 17 were reported to be constructed with untreated wood (no creosote) (McLeese 1983). An earlier survey indicated that six pounds had minor amounts of creosoted materials, two had been constructed many years ago with creosoted material and that 13 were constructed with untreated material (McLeese 1983). The potential for lobsters in tidal pounds to become contaminated with PAH probably is limited to a few of the 21 tidal pounds.

ACKNOWLEDGMENTS

Drs. V. Zitko, K. Haya, and A. Campbell provided helpful comments on the text. Mrs. J. Hurley and Mrs. B. Fawkes typed the manuscript. Ms. R. Garnett provided editorial and proofreading assistance.

REFERENCES

Andelman, J. B., and M. J. Suess. 1970. Polynuclear aromatic hydrocarbons in the water environment. Bull. Wld. Hlth. Org. 43: 479-509.

Baechler, R. H., and L. Roth. 1961. Further data on the extraction of creosote from marine piles. Proc. Am. Wood Preservers' Assoc. 56: 124-129.

Cahnmann, H. J., and M. Kuratsume. 1957. Determination of polycyclic aromatic hydrocarbons in oysters collected in polluted water. Anal. Chem. 29: 1312-1317.

Colley, R. H. 1974. Comparison of gas chromatogram patterns with standard Al flash distillations and with 5-ball column distillations. Original oils and extracted residuals from three creosotes used in marine post and panel exposure tests. 1958 Cooperative Creosote Project VIII. Proc. Am. Wood Preservers' Assoc. 70: 278-299.

Dunn, B. P., and R. J. Armour. 1980. Sample extraction and purification for determination of polycyclic aromatic hydrocarbons by reversed-phase chromatography. Anal. Chem. 52: 2027-2031.

Dunn, B. P., and J. Fee. 1979. Polycyclic aromatic hydrocarbon carcinogens in commercial seafoods. J. Fish. Res. Board Can. 36: 1469-1476.

Dunn, B. P., and H. F. Stich. 1975. The use of mussels in estimating benzo(a)pyrene contamination of the marine environment. Proc. Soc. Exp. Biol. Med. 150: 49-51.

Gibb, H. 1978. Coal tar, creosote and coal tar neutral oil. Fed. Regist. 43: 202, Oct. 18, v + 14 p.

Howard, J. W., T. Faxio, R. H. White, and B. A. Klimeck. 1968. Extraction and estimation of polycyclic aromatic hydrocarbons in total diet composites. J. Assoc. Off. Anal. Chem. 49: 595-610.

John, E. D., M. Cooke, and G. Nickless. 1979. Polycyclic aromatic hydrocarbons in sediments taken from the Severn Estuary drainage system. Bull. Environm. Contam. Toxicol. 22: 653-659.

LaFlamme, R. E., and R. A. Hites. 1978. The global distribution of polycyclic aromatic hydrocarbons in recent sediments. Ceochim. Cosmochim. Acta. 42: 289-303.

Lo, M. T., and E. Sandi. 1978. Polycyclic aromatic hydrocarbons (polynuclears) in foods. Residue Rev. 69: 35-86.

McLeese, D. W. 1983. The potential for exposure of lobster to creosote during commercial storage in the Maritime Provinces of Canada. Can. Tech. Rep. Fish. Aquat. Sci. 1203: iv + 28 p.

McLeese, D. W., and C. D. Metcalfe. 1979. Toxicity of creosote to larval and adult lobster and *Crangon* and its accumulation in lobster hepatopancreas. Bull. Environm. Contam. Toxicol. 22: 796-799.

McLeese, D. W., and D. G. Wilder. 1964. Lobster storage and shipment. Fish. Res. Board Can. Bull. 147: 69 p.

National Academy of Sciences. 1972. Particulate polycyclic organic matter. Washington, D.C., 361 p.

Neff, J. M. 1979. Polycyclic aromatic hydrocarbons in the aquatic environment. Applied Science, London, p. 62.

Page, R. Z. 1977. Discussion on: Biodegradation of creosote/naphthalene treated wood in the marine environment by Seesman et al. Proc. Am. Wood Preservers' Assoc. 73: 60.

Pott, P. 1775. *Cancer scroti*, p. 63-68. *In* Chirurgical Observations. Hawes, Clarke and Collins, London.

Sirota, G. R., and J. F. Uthe. 1981. Polynuclear aromatic hydrocarbon contamination in marine shellfish, p. 329-341. *In* M. Cook and A. J. Dennis (eds.) Polynuclear Aromatic Hydrocarbons. Batelle Press, Columbus, Ohio.

Stewart, J. E., G. W. Horner, and B. Arie. 1972. Effects of temperature, food and starvation on several physiological parameters of the lobster, *Homarus americanus*. J. Fish. Res. Board Can. 29: 439-442.

van Weel, P. B. 1979. "Hepatopancreas"? Comp. Biochem. Physiol. 47A: 1-9.

Volkman, R. 1875. Uber Theer and Russkrebs. Klin. Wochenchr. 11: 218-220.

Windsor, J. G., and R. A. Hites. 1979. Polycyclic aromatic hydrocarbons in Gulf of Maine sediments and Nova Scotia soils. Geochim. Cosmochim. Acta. 43: 27-33.

Zitko, V. 1975. Aromatic hydrocarbons in aquatic fauna. Bull. Environm. Contam. Toxicol. 14: 621-631.

Table 1. PAH concentrations (ng/g wet weight) in hepatopancreas and tail muscle of 10 individual lobsters following 3 mo summer holding in a creosoted pound, then transferred to clean water for 13 d.

PAH	Lobster no. 1	2	3	4	5	6	7	8	9	10	C V[a]	Mean
Hepatopancreas												
Phenanthrene	1980	2000	720	700	1100	3400	390	1600	3100	3000	66	1799
Fluoranthene	3800	6700	3400	2100	3400	10300	6500	7100	10600	8500	48	6240
Pyrene	1300	3000	1200	420	1400	5500	1800	2400	2700	3500	63	2322
Triphenylene	11500	8200	7800	4100	6700	32800	15200	24700	39000	18700	69	16870
Benz(a)anthracene	6200	8100	4900	2000	4500	20000	9500	17500	19400	1960	64	9406
Chrysene	5600	5300	3600	1800	3100	17800	7200	16100	16700	17600	70	9480
Benzo(e)pyrene	1200	500	360	210	250	1600	780	1200	1400	1200	59	870
Benzo(b)fluoranthene	790	620	440	370	390	2000	950	2100	1800	1800	63	1127
Benzo(k)fluoranthene	200	160	110	100	100	530	250	520	450	440	63	286
Benzo(a)pyrene	220	150	140	100	140	860	270	830	680	740	78	413
Benzo(ghi)perylene	340	240	240	140	240	1600	400	1700	1300	1400	86	760
Indeno (1,2,3-cd)pyrene	1000	690	560	390	500	4300	1300	4300	2900	3300	83	1924
Tail muscle												
Phenanthrene	300	140	280	270	180	210	220	260	310	200	21	237
Fluoranthene	91	97	180	99	67	180	200	210	230	240	40	159
Pyrene	10	35	56	22	29	83	47	57	61	78	47	48
Triphenylene	280	150	430	320	200	650	550	820	320	590	48	431
Benz(a)anthracene	200	210	260	130	100	370	410	560	310	370	56	292
Chrysene	190	130	160	110	60	290	280	430	200	250	50	210
Benzo(e)pyrene	30	14	20	10	10	36	30	45	22	30	45	25
Benzo(b)fluoranthene	30	20	26	27	9	42	46	72	31	35	48	34
Benzo(k)fluoranthene	7	4	7	7	2	11	13	19	9	10	51	9
Benzo(a)pyrene	8	5	10	12	4	21	19	32	15	16	57	14
Benzo(ghi)perylene	15	8	15	17	6	39	29	59	24	25	64	24
Indeno (1,2,3-cd)pyrene	45	21	34	44	12	100	78	170	60	59	70	62

[a]Coefficient of variation.

Table 2. Ratio of PAH concentrations of hepatopancreas to tail muscle in individual lobsters following 3 mo summer holding in creosoted pound, then transferred to clean water for 13 d.

PAH[a]	Lobster no. 1	2	3	4	5	6	7	8	9	10	Mean ratio ± SD
Phenanthrene	6.6	14	2.6	2.6	6.1	16	1.8	6.3	9.9	15	7.7 ± 6.6
Fluoranthene	42	69	20	21	50	58	32	33	45	36	40 ± 16
Pyrene	130	86	21	19	48	67	37	42	44	45	52 ± 29
Triphenylene	42	54	18	13	34	50	28	30	123	32	42 ± 31
<u>Benz(a)anthracene</u>	31	38	19	15	45	54	23	31	62	5.3	37 ± 16
<u>Chrysene</u>	29	41	23	16	52	61	25	37	82	70	44 ± 22
<u>Benzo(e)pyrene</u>	40	36	18	21	25	44	26	28	65	41	35 ± 14
<u>Benzo(b)fluoranthene</u>	26	31	17	14	43	49	20	29	57	52	34 ± 15
<u>Benzo(k)fluoranthene</u>	28	40	17	15	50	48	20	27	50	46	33 ± 14
<u>Benzo(a)pyrene</u>	27	30	14	8	35	42	14	26	37	46	29 ± 14
<u>Benzo(ghi)perylene</u>	23	30	16	8	39	41	14	29	53	57	31 ± 16
<u>Indeno (1,2,3-cd)pyrene</u>	22	33	16	9	43	43	16	25	48	56	31 ± 16
All PAH mean ratio ± SD	36±26	42±19	17±6	14±6	39±13	48±13	21±9	29±9	57±27	45±14	35
Carcinogenic PAH mean ratio ± SD	30±7	35±4	18±3	14±5	41±9	49±7	21±5	30±5	60±13	53±10	

[a]Carcinogenic PAH are underlined.

Table 3. PAH concentrations (ng/g wet weight) in hepatopancreas and tail muscle of lobsters held in a tidal pound in winter, then transferred to a creosote-free storage facility. The two entries under each date are values from analysis of two pooled tissue samples from five animals each.

PAH	Uptake						Excretion					
	Dec. 13 (1 mo)		Jan. 14 (2 mo)		Feb. 13 (3 mo)		Feb. 21 (1 wk)		Mar. 6 (3 wk)		Mar. 21 (5 wk)	
						Hepatopancreas						
Phenanthrene	1130	1120	1580	1122	2500	2450	2300	1340	1600	1630	1320	2090
Fluoranthene	450	295	601	583	689	1050	587	633	677	670	464	370
Pyrene	1760	1380	2050	1850	2910	5400	2390	2320	2520	2450	2330	1850
Triphenylene	3560	3650	3040	3320	6570	11300	5760	4930	5630	4800	5340	4790
Benz(a)anthracene	1360	1070	1590	1780	2430	3650	2210	2090	1910	1730	1360	1280
Chrysene	349	400	170	250	626	748	534	426	333	267	344	412
Benzo(e)pyrene	528	723	302	538	1150	2000	1150	785	608	489	497	655
Benzo(b)fluoranthene	108	119	70	98	223	342	213	139	127	92	94	115
Benzo(k)fluoranthene	22	22	14	21	49	66	47	27	23	18	17	22
Benzo(a)pyrene	33	46	9	17	56	37	63	32	23	16	20	36
Benzo(ghi)perylene	117	141	23	58	283	576	333	179	129	100	74	127
Indeno (1,2,3-cd)pyrene[a]	-	-	-	-	-	-	-	-	-	-	-	-
						Ratios						
Pyrene/fluoranthene	3.8	4.8	3.4	3.2	4.2	5.3	4.0	3.7	3.7	3.7	5.0	5.0
Benz(a)anthracene/fluoranthene	3.0	3.6	2.6	3.0	3.6	3.4	3.7	3.3	2.9	2.6	2.9	3.3
Benzo(a)pyrene/fluoranthene	0.07	0.16	0.01	0.03	0.08	0.04	0.1	0.05	0.03	0.02	0.04	0.1
						Tail muscle						
Phenanthrene	20	36	55	35	59	95	108	110	93	77	42	6
Fluoranthene	45	41	15	19	36	48	61	86	31	23	17	22
Pyrene	45	42	54	42	53	87	98	123	66	36	19	8
Triphenylene	86	137	89	165	109	172	278	261	134	70	61	135
Benz(a)anthracene	62	100	49	47	96	133	201	226	80	56	48	60
Chrysene	8	14	5	5	10	16	29	21	10	5	4	9
Benzo(e)pyrene	18	39	13	13	21	35	99	53	29	13	11	26
Benzo(b)fluoranthene	5	9	4	4	7	11	21	16	9	4	4	6
Benzo(k)fluoranthene	0.9	1.6	0.7	0.6	1.2	2.1	4	3	1.5	0.6	0.6	1
Benzo(a)pyrene	0.5	2.8	0.1	0.1	0.2	0.2	1.8	0.4	0.6	0.1	0.1	0.3
Benzo(ghi)perylene	2	8	1.6	1.7	5	6	37	13	9	4	2.5	7
Indeno (1,2,3-cd)pyrene[a]	-	-	-	-	-	-	-	-	-	-	-	-
						Ratios						
Pyrene/fluoranthene	1.0	1.0	3.7	2.7	1.5	1.8	1.6	1.4	2.1	1.5	1.1	0.4
Benz(a)anthracene/fluoranthene	1.4	2.4	3.2	2.5	2.6	2.8	3.3	2.6	2.6	2.4	2.8	2.7
Benzo(a)pyrene/fluoranthene	0.01	0.07	0.006	0.005	0.005	0.004	0.03	0.004	0.2	0.004	0.006	0.01

[a]Not measured in winter experiment.

Table 4. PAH concentrations (ng/g wet weight) in hepatopancreas and tail muscle of lobsters held in a tidal pound in summer, then transferred to a creosote-free storage facility. The two entries under each date are values from analysis of two pooled tissue samples from five animals each.

PAH	Uptake								Excretion							
	June 17 (1 mo)		July 24 (2 mo)		Aug. 19 (3 mo)		Sept. 4 (3.5 mo)		Sept. 5 (18 h)		Sept. 8 (4 d)		Sept. 13 (8 d)		Sept. 17 (13 d)	
Hepatopancreas																
Phenanthrene	1800	1280	3350	2230	7250	9010	3990	3670	4410	4360	7110	6780	1620	3390	1270	2460
Fluoranthene	406	326	4930	2700	9410	1140	8320	7250	7810	11500	8610	9640	3380	3780	3610	8400
Pyrene	2200	1150	3550	1640	15900	31200	10700	20800	10700	13200	16600	4040	5420	6610	2980	3520
Triphenylene	1370	763	5050	3250	11500	33200	11700	10700	25000	28700	32500	16400	13500	16800	9900	29100
Benz(a)anthracene	323	303	5630	2570	14800	18300	13000	12700	14000	17100	15600	9200	7232	7890	5510	17400
Chrysene	576	347	4060	1670	11700	14900	10600	8350	11200	13200	13100	7100	6480	7920	3950	15500
Benzo(e)pyrene	178	120	1880	369	5160	3570	649	660	998	1190	1130	1190	602	600	372	1230
Benzo(b)fluoranthene	75	37	503	191	1240	1690	1140	1020	1240	1590	1340	841	758	842	564	1760
Benzo(k)fluoranthene	17	8	140	51	341	444	313	258	337	431	348	245	176	186	145	447
Benzo(a)pyrene	0.9	1.8	180	29	407	680	420	303	488	651	572	332	308	336	158	710
Benzo(ghi)perylene	29	18	366	86	898	1180	624	490	827	1120	942	377	474	636	258	1370
Indeno (1,2,3-cd)pyrene	67	39	607	156	1540	2080	1090	769	1360	1860	2260	1110	788	1550	743	3200
Ratios																
Pyrene/fluoranthene	0.515	3.6	0.7	0.6	1.7	2.7	1.3	2.8	1.4	1.1	1.9	0.4	1.6	1.7	0.8	0.4
Benz(a)anthracene/ fluoranthene	0.8	0.9	1.1	1.0	1.5	1.6	1.5	1.7	1.7	1.5	1.8	1.0	2.1	2.1	1.5	2.1
Benzo(a)pyrene/ fluoranthene[b]	0.002	0.005	0.04	0.01	0.04	0.06	0.05	0.04	0.06	0.06	0.07	0.03	0.09	0.09	0.04	0.08
Tail muscle																
Phenanthrene	117	20	62	71	82	104	110	19	129	117	262	100	55	260	184	226
Fluoranthene	31	20	28	44	68	111	160	69	138	147	97	110	189	213	94	200
Pyrene	59	11	81	74	154	167	221	35	510	206	94	182	191	194	42	83
Triphenylene	33	11	64	51	182	239	302	198	311	253	315	423	603	562	311	679
Benz(a)anthracene	43	10	71	51	185	291	334	206	311	323	209	237	389	350	177	424
Chrysene	32	12	67	42	156	226	258	221	204	230	132	210	288	253	116	319
Benzo(e)pyrene	6.8	3	16	8.8	22	29	T[a]	37	26	43	26	38	27	30	13	19
Benzo(b)fluoranthene	4	2	8	7	19	30	35	22	27	35	18	26	41	44	22	47
Benzo(k)fluoranthene	0.9	0.5	1.5	1.8	4	6.4	9	4	7.5	8	4.7	5.8	11	11	5	13
Benzo(a)pyrene	0.1	0.1	0.4	0.2	5	8	10	5	7	6.7	5.7	9.5	20	19	7	24
Benzo(ghi)perylene	1.6	0.8	4.6	2	14	21	20	12	15	19	86	17	33	28	11	41
Indeno(1,2,3-cd)pyrene	3.6	2.5	17	8	43	60	60	37	59	66	28	47	80	72	29	103
Ratios																
Pyrene/fluoranthene	1.9	0.5	2.9	1.7	2.3	1.5	1.4	0.5	3.7	1.4	1.0	1.7	1.0	0.9	0.4	0.4
Benz(a)anthracene/ fluoranthene	1.4	2.0	2.6	1.2	2.7	2.5	2.1	3.0	2.3	2.2	2.2	2.2	2.0	1.6	1.9	2.1
Benzo(a)pyrene/ fluoranthene[b]	0.003	0.005	0.01	0.004	0.07	0.07	0.06	0.07	0.05	0.04	0.06	0.08	0.1	0.09	0.07	0.1

[a]Trace.

[b]Underlined values, outliers eliminated from calculation of mean.

Table 5. Ratio of summer/winter concentrations of PAH in each of two tissues of lobsters after storage in a tidal pound for 3 mo.

PAH[a]	Ratios for hepatopancreas	Ratios for tail muscle
Phenanthrene	3	1
Fluoranthene	12	2
Pyrene	6	2
Triphenylene	3	2
Benz(a)anthracene	5	2
Chrysene	19	15
Benzo(e)pyrene	3	1
Benzo(b)fluoranthene	5	2
Benzo(k)fluoranthene	7	3
Benzo(a)pyrene	12	33
Benzo(ghi)perylene	2	3

[a]Concentrations in Tables 3 and 4.

Table 6. Mean PAH concentrations (ng/g wet weight) in hepatopancreas and tail muscle of freshly captured lobsters from four locations around Nova Scotia; number of lobsters sampled indicated in brackets.

PAH	Port Hood (14)		Cape Sable (10)		New Harbour (10)		East River (10)	
	Hepato-pancreas	Tail muscle	Hepato-pancreas	Tail muscle	Hepato-pancreas	Tail muscle	Hepato-pancreas	Tail muscle
Phenanthrene	100	7	14	nd[a]	94	16	27	T[b]
Fluoranthene	150	5	19	4	400	28	41	7.5
Pyrene	T	nd	95	nd	140	5	T	nd
Triphenylene	55	2	nd	nd	150	7	nd	nd
Benz(a)anthracene	22	T	43	16	600	27	8.5	T
Chrysene	11	nd	36	12	240	2	4	T
Benzo(e)pyrene	20	T	15	4	340	4	12	T
Benzo(b)fluoranthene	6.5	0.4	47	2	45	3.5	16	T
Benzo(k)fluoranthene	1.5	T	7	0.2	13	0.9	1.0	T
Benzo(a)pyrene	0.8	T	1	T	22	1.5	0.8	T
Benzo(ghi)perylene	6.7	0.5	21	0.3	16	1.5	2.5	T
Indeno (1,2,3-cd)pyrene	4.2	0.2	47	3.0	45	1.5	5.0	0.3

[a]Not detected.
[b]Trace.

Port Hood, Inverness Co.; Cape Sable, Shelburne Co.; New Harbour, Guysborough Co.; East River, Lunenburg Co.; lobsters captured in May.