Lead and Mercury Burden of Urban Woody Plants

Abstract. *For six New Haven woody plant species, the mean lead concentrations for tissue produced in the preceding growing season exceeded most lead concentrations determined for trees in areas with geologic lead deposits or adjacent to primary highways. Preliminary estimates indicate that some New Haven plants have slightly higher than natural amounts of mercury. The burden of lead and the difficulty in removing it by washing suggest a potential for pathological significance.*

The lead contamination of trees has been studied primarily in rural areas with geologic deposits of lead or other metals (*1–4*) and at rural roadside locations (*5*) or other nonurban sites (*6*), but rarely in urban environments (*7*). Data for the mercury concentrations of trees are available for only a few nonurban areas (*8, 9*). I have attempted to determine the lead burden of city trees and the location of the lead in or on the trees and to make preliminary estimates of mercury contamination of plants growing in the city.

Branch samples were collected from September through November 1970 throughout the city of New Haven, Connecticut (*10*). New Haven has a population of 137,700 and, on an average day, has more than 100,000 vehicles entering the center of the city. Lead in urban atmospheres comes from the use of lead for many purposes, but it is assumed to be derived

Table 1. Lead burden of trees growing in the city of New Haven. Branch samples were collected during the fall of 1970, approximately 2 m above the ground from trees located within 8 m of streets. Average distances to the nearest streets are given below. The mean and range are given in parts per million on both a dry weight and an ash weight basis. The tissue analyzed represented the growth of the preceding growing season. The washing procedures are described in (*14*).

Total trees (No.)	Street distance (m)	Tissue: Organ	Tissue: Trees (No.)	Lead (μg/g) Unwashed: Dry weight	Lead (μg/g) Unwashed: Ash weight	Lead (μg/g) Washed: Dry weight	Lead (μg/g) Washed: Ash weight
		Pin oak, Quercus palustris *Muenchh.*					
24	1.4	Intact shoots*	12	170 ± 26 (40–345)	3050 ± 391† (973–5070)‡	121 ± 20 (15–250)	2588 ± 322 (855–3956)
		Leaves	12	140 ± 15 (70–220)	2375 ± 250 (1345–4186)	121 ± 14 (55–220)	2081 ± 200 (1125–3235)
		Twigs	12	60 ± 9 (25–110)	1840 ± 280 (532–3909)	67 ±10 (25–125)	1667 ± 292 (417–3571)
		Sugar maple, Acer saccharum *Marsh.*					
14	1.8	Intact shoots	7	164 ± 52 (60–465)	1903 ± 500 (596–4491)	158 ± 35 (60–340)	1931 ± 372 (653–3598)
		Leaves	7	101 ± 19 (25–165)	832 ± 142 (217–1433)	64 ± 12 (35–120)	473 ± 53 (243–613)
		Twigs	7	149 ± 34 (21–315)	4766 ± 2784 (35–21,164)	113 ± 20 (38–195)	1629 ± 366 (313–3220)
		Norway maple, Acer platanoides *L.*					
64	2.0	Intact shoots	32	164 ± 12 (64–305)	1583 ± 121 (540–3195)	164 ± 11 (65–340)	1605 ± 107 (713–3115)
		Leaves	32	156 ± 19 (20–515)	1103 ± 115 (143–2954)	146 ± 18 (45–485)	1096 ± 119 (375–2906)
		Twigs	32	103 ± 11 (25–290)	1872 ± 184 (524–4451)	101 ± 10 (10–300)	1866 ± 157 (251–3750)
		Eastern hemlock, Tsuga canadensis *(L.) Carr.*					
16	3.7	Intact shoots	8	203 ± 30 (85–350)	4866 ± 682 (2179–7634)	184 ± 34 (70–385)	4555 ± 825 (1774–9069)
		Leaves	8	111 ± 21 (40–203)	2116 ± 380 (773–3766)	91 ± 18 (25–180)	1878 ± 360 (538–3704)
		Twigs	8	295 ± 61 (97–510)	10,343 ± 2089 (3448–20,774)	315 ± 75 (155–760)	10,726 ± 2727 (3529–27,839)
		Yew, Taxus *spp.*					
20	3.8	Intact shoots	10	190 ± 33 (105–395)	3086 ± 529 (1535–6381)	131 ± 21 (50–250)	2250 ± 382 (1124–3817)
		Leaves	10	159 ± 21 (50–260)	2478 ± 286 (907–4006)	139 ± 20 (40–240)	2270 ± 293 (732–3514)
		Twigs	10	160 ± 29 (50–318)	3239 ± 543 (1145–5590)	177 ± 29 (70–371)	3641 ± 540 (1673–7156)
		Norway spruce, Picea abies *(L.) Karst.*					
8	4.8	Intact shoots	4	91 ± 14 (50–115)	2004 ± 130 (1701–2331)	65 ± 5 (60–80)	1535 ± 258 (1123–2286)
		Leaves	4	80 ± 18 (45–105)	1328 ± 205 (974–1685)	75 ± 16 (45–100)	1382 ± 251 (946–1817)
		Twigs	4	258 ± 85 (100–390)	6914 ± 1861 (3328–9571)	163 ± 41 (100–240)	5277 ± 1159 (3257–7273)

* Twig plus leaves. † Mean and standard error. ‡ Range.

Table 2. Mercury burden of single samples from trees growing in the city of New Haven. Branch samples were collected during the fall of 1970 approximately 2 m above the ground. The trees were located within 8 m of streets, except the first, which was situated in a natural forest. Mean and standard error are given in parts per million on both a dry weight and an ash weight basis. The tissue analyzed represented the preceding season's growth.

Species	Tissue	Mercury (μg/g)	
		Dry weight	Ash weight
Sugar maple, *Acer saccharum* Marsh.*	Leaves	0.81 ± 0.16	6.34 ± 1.22†
Ailanthus, *Ailanthus altissima* Mill.	Leaves	0.61 ± 0.02	2.42 ± 0.08
London plane, *Platanus xacerifolia* (Art.) Willd.	Leaves	0.71 ± 0.14	6.11 ± 1.23
	Twigs	0.13 ± 0.04	3.39 ± 0.99
Norway spruce, *Picea abies* (L.) Karst.	Intact shoots‡	0.22 ± 0.01	6.00 ± 0.21
Austrian pine, *Pinus nigra* Arnold	Leaves	0.17 ± 0.05	5.43 ± 1.58
	Twigs	0.08 ± 0.01	2.11 ± 0.14
Pin oak, *Quercus palustris* Muenchh.	Leaves	0.76 ± 0.13	12.20 ± 2.06
Taxus, *Taxus* spp.	Intact shoots	0.85 ± 0.23	10.97 ± 2.94
Little-leaf linden, *Tilia cordata* Mill.	Leaves	1.10 ± 0.12	5.34 ± 0.56

* Lake Gaillard, North Branford, 14.4 km east of New Haven. † Mean and standard error of replicate analyses. ‡ Twig plus leaves.

mainly from the combustion of lead alkyl additives in motor vehicle fuels (*11*). The average lead content of the soil 1 to 2 cm deep at the perimeter of the New Haven Green (an open space 9 hectares in area in the center of the city) was 478 parts per million. The lead content of soil from rural (nonroadside) areas is usually similar to that of the earth's crust, 10 to 15 ppm (*12*). The average lead content of New Haven air was 2.60 $\mu g/m^3$ in 1970 (*13*). Portions of the samples collected for lead analysis were subjected to various washing procedures (*14*). All samples were then dried at 80°C, ground, and ashed at 450°C (*15*). The lead content was determined by atomic absorption spectrophotometry. Mercury determinations were made with unwashed specimens by means of a flameless adaptation of atomic absorption spectrophotometry after wet digestion (*16*).

The lead content of plants growing in natural, relatively unpolluted environments is approximately 1.0 ppm (dry weight basis) (*2, 3*). Table 1 shows that New Haven trees are carrying a high lead burden. The average values in Table 1 exceed most lead concentrations reported for trees, and the maximum values exceed all previously reported lead concentrations, even for trees in areas with geologic lead deposits (*1–4*). The values in Table 1 are generally comparable with or slightly higher than those reported for herbaceous plants growing along heavily traveled primary roadways (*17*).

The highest lead concentrations were associated with twigs in sugar maple, eastern hemlock, yew, and Norway spruce and with leaves in pin oak and Norway maple. The maximum lead concentration observed was 760 ppm (dry weight basis) in a washed hemlock twig. The importance of twigs in lead accumulation has been stressed previously (*2, 4*).

There was no significant difference ($P = .95$) in the amount of lead found between samples subjected to the various washing procedures and unwashed samples. Either the washing procedures were inadequate to remove surficial deposits, or a large portion of the lead was located inside the tissues. The latter possibility and the high concentrations involved indicate a potential for pathological importance. Lead is a biologically nonessential element (*18*) and capable of interfering with the activity of several enzymes (*19*).

Mercury is introduced into the atmosphere by the combustion of fossil fuels, by industrial processes, and through other activities of man (*20*). Although there have been relatively few studies of the amount of mercury in plants, about 0.5 ppm (dry weight basis) has been suggested as the general background concentration of mercury in unmineralized areas (*9*). Information concerning the biologic effects of mercury is very sparse (*21*). Ten unwashed samples of tree and shrub tissues collected in New Haven during the fall of 1970 were analyzed for mercury. The mercury contents of six of these samples slightly exceeded 0.5 ppm (Table 2). Only one sample, however, contained more than 1.0 ppm mercury. The sugar maple leaves, which had 0.81 ppm mercury, were collected from a natural area 14.4 km east of New Haven. The small number of samples and the fact that all the specimens were unwashed preclude an estimation of the pathological potential of the mercury.

Irrespective of whether the metals are located inside or outside the plant tissues, it is apparent, especially in the instance of lead, that woody plants may play an important role in heavy metal cycling in urban areas by acting as a short- and long-term repository. Lead associated with leaves and other deciduous tissue may be returned to the soil or atmosphere in relatively short order. Lead associated with twigs and other perennial tissue, however, may be removed from circulation for extended periods.

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References and Notes

1. H. L. Cannon, *U.S. Geol. Surv. Bull. 1000-D* (1955); J. W. Harbaugh, *Econ. Geol.* **45**, 548 (1950); H. V. Warren, R. E. Delavault, C. H. Croos, *West. Miner* (1966).
2. H. V. Warren and R. E. Delavault, *Trans. Roy. Soc. Can. Sect. 4* **54**, 11 (1960).
3. J. S. Webb and A. P. Millman, *Inst. Mining Met. Trans.* **60**, 473 (1951); J. E. Worthington, *Econ. Geol.* **50**, 420 (1955).
4. J. Lounamaa, *Ann. Bot. Soc. Zool. Bot. Fenn. Vanamo* **29**, 1 (1956).
5. T. Keller and H. Preis, *Schweiz. Z. Forstwes.* **118**, 143 (1967); A. Rühling and G. Tyler, *Bot. Notis.* **121**, 321 (1968); W. H. Smith, *Forest Sci.* **17**, 195 (1971).
6. W. U. Ault, R. G. Senechal, W. E. Erlebach, *Environ. Sci. Technol.* **4**, 305 (1970); R. B. Holtzman, *ibid.*, p. 314; H. A. Schroeder and J. J. Balassa, *J. Chronic Dis.* **14**, 408 (1961); H. V. Warren, *J. Coll. Gen. Pract. Res. Newsl.* **11**, 135 (1966).
7. H. V. Warren and R. E. Delavault, *J. Sci. Food Agr.* **13**, 96 (1962).
8. V. A. Stock and F. Cucuel, *Naturwissenschaften* **22**, 390 (1934); H. V. Warren, R. E. Delavault, J. Barakso, *Econ. Geol.* **61**, 1010 (1966).
9. H. T. Shacklette, *U.S. Geol. Surv. Prof. Pap. 713* (1970), p. 35.
10. Duplicate samples of intact shoots (leaf plus twig) encompassing the growth of the previous growing season were collected from over 300 trees at the sides of streets. Sampling was restricted to branches that could be reached from the ground. Samples were collected with plastic gloves and placed in individual polyethylene bags. At each collection site, the horizontal distance from the base of the tree to the nearest street and the vertical height of the sample above the ground were determined. Samples were stored in a cold room until analyzed.
11. T. J. Chow and J. L. Earl, *Science* **169**, 577 (1970).

12. T. J. Chow and C. C. Patterson, *Geochim. Cosmochim. Acta* **26**, 263 (1962).
13. Mean of quarterly figures (from one sampling station) provided by the Connecticut State Department of Health, Hartford.
14. The washing procedures were: (1 and 2) 30 seconds vigorous agitation in metal-free water; (3) 60 seconds vigorous agitation in 1.0 percent hexadecyltrimethylammonium bromide, followed by rinse in metal-free water; (4) 60 seconds vigorous agitation in 0.1 percent hexadecyltrimethylammonium bromide, followed by rinse in metal-free water; (5) 30 seconds vigorous agitation in 0.05 percent hexadecyltrimethylammonium bromide and 0.05 percent *N*-(hydroxyethyl)ethylenediaminetriacetic acid, followed by rinse in metal-free water; (6) 30 seconds vigorous agitation in 0.05 percent hexadecyltrimethylammonium bromide and 0.05 percent diethylenetriaminepentaacetic acid followed by rinse in metal-free water.
15. G. E. Likens and F. H. Bormann, *Yale School of Forestry Bulletin 79* (Yale School of Forestry, Yale University, New Haven, Conn., 1970).

→ W. R. Hatch and W. L. Ott, *Anal. Chem.* **40**, 2085 (1968).
17. H. L. Cannon and J. M. Bowles, *Science* **137**, 765 (1962); T. J. Chow, *Nature* **225**, 295 (1970); J. V. Lagerwerff and A. W. Specht, *Environ. Sci. Technol.* **4**, 583 (1970); H. L. Motto, R. H. Daines, D. M. Chilko, C. K. Motto, *ibid.*, p. 231; E. A. Schuck and J. K. Locke, *ibid.*, p. 324.
18. R. A. Kehoe, *Roy. Inst. Pub. Health Hyg. J.* **24**, 81 (1961).
19. J. Chisolm, *Sci. Amer.* **224**, 15 (Feb. 1971); D. E. Koeppe and R. J. Miller, *Science* **167**, 1376 (1970); S. Selander and K. Cramer, *Brit. J. Ind. Med.* **27**, 28 (1970).
20. H. V. Weiss, M. Koide, E. D. Goldberg, *Science* **174**, 692 (1971).

→ R. C. Harriss, D. B. White, R. B. Macfarlane, *ibid.* **170**, 736 (1970).

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Free-Floating Mucus Webs: A Novel Feeding Adaptation for the Open Ocean

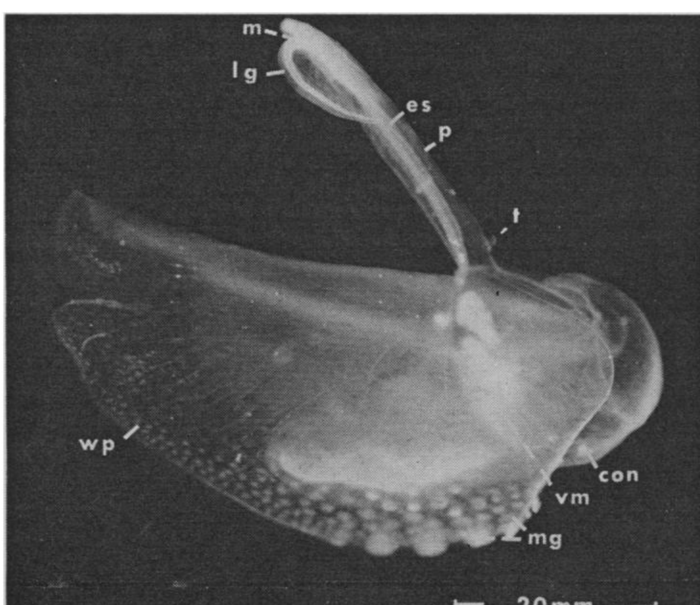
Abstract. *Observations by means of conventional scuba techniques have revealed that highly modified planktonic gastropods, in the order Thecosomata, utilize a free and unsupported mucus web for collecting food particles. Their delicate bodies, quick reactions, and apparent abundance suggest that traditional plankton-sampling methods may be inadequate to assess their importance in the blue-water plankton communities.*

Comparatively little information has been available on the biology of several important categories of planktonic organisms. Among these obscure groups are pseudothecosomatous pteropods, comprising a highly modified suborder of planktonic opisthobranch gastropods. Because of the extreme fragility and unknown swimming abilities of these organisms, previous expeditions have collected only a few badly damaged specimens (*1–3*).

During October and November 1971, as part of a diving research team from the University of California at Davis, I made field observations of the rare *Gleba cordata* (Forskål) and of *Corolla spectabilis* (Dall), two closely related species, in the surface waters of the Florida current 8 to 16 km west of Bimini, British West Indies, by using scuba. These data constitute the first observations of live members of the Pseudothecosomata. Furthermore, this is the first report of *Gleba* in the Florida current, and the first record of *Gleba* adults in any part of the tropical Atlantic (*1, 3*). Over 500 of these common, but patchily distributed, animals have been observed in the field. After making observations of their feeding habits, I collected some by hand and studied them in the laboratory.

As members of the family Cymbuliidae, *Gleba* and *Corolla* possess a characteristic jellylike, internal conch, seen intact in Figs. 1 and 2. This conch is so fragile that obtaining intact specimens is virtually impossible and taxonomists have been hampered in recognizing distinct variations (*1, 2*).

Gleba cordata feeds from a large, free-floating, and unsupported mucus web spread horizontally in the water



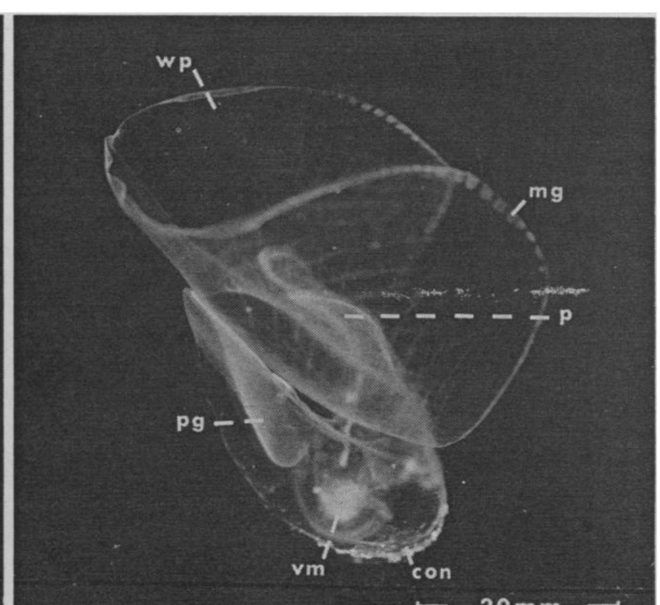


Fig. 1 (left). *Gleba cordata* as it appears while motionless in the water. The numerous mucus glands (*mg*) on the periphery of the wing plate (*wp*) are primarily responsible for the secretion of the web. The other abbreviations are: *con*, conch; *es*, esophagus; *lg*, lateral grooves; *m*, mouth; *p*, proboscis; *t*, tentacles; *vm*, visceral mass. Fig. 2 (right). *Corolla spectabilis* swimming toward the surface of a tank in the laboratory. The mucus glands (*mg*) are conspicuous on the periphery of the wing plate (*wp*). The pallial gland (*pg*) and the visceral mass (*vm*) are enclosed by the internal conch (*con*) below the fins and proboscis (*p*).