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DARBAKER PRIZE PAPER

A MICROSCOPIC EXAMINATION OF WHITEFLY (HOMOPTERA: ALEYRODIDAE) EGG PEDICEL INSERTION INTO HOST PLANT TISSUES[1]

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ABSTRACT

The egg pedicels of three species of whitefly (Insecta, Homoptera: Aleyrodidae); *Aleurodicus dispersus* Russell, *Bemisia argentifolii* Bellows & Perring, and *Trialeurodes vaporariorum* (Westwood) were examined to determine the method of insertion into host plant tissues. The pedicel of each species was examined externally with a scanning electron microscope. Internal structures were examined by sectioning specimens and examining them with a compound light microscope. The pedicel of *B. argentifolii* was always inserted into a leaf stoma. The egg pedicels of *T. vaporariorum* and *A. dispersus* were inserted either directly into the leaf tissues or into the stomata.
[J PA Acad Sci 71 (3) 99-103, 1998]

INTRODUCTION

Whitefly eggs bear a hollow extension of the chorion called the pedicel. The pedicel serves as an anchor to secure the egg to a leaf surface and is also the primary conduit through which the embryo secures moisture which is essential for normal development (Byrne, et al. 1990). Poinar (1965) discovered that the pedicel of *Aleurocybotus occiduus*, a whitefly found on grasses and sedges, was inserted directly into the stomata of its host plant. He concluded that this may have been an adaptive response to facilitate oviposition on plants that contain high amounts of silica and lignin in their epidermal cells. Paulson and Beardsley (1985) found that stomatal oviposition was much more common in whiteflies than Poinar believed and did not seem linked to host plant morphology, but rather was an adaptation to secure moisture from the leaf. The work of Byrne et al. (1990) supported this conclusion by showing experimentally that the egg pedicel did indeed absorb water from the host plant. The purpose of this study was to further explore the egg pedicel-host plant relationship by examining the egg pedicel's insertion into host plant tissues.

MATERIALS AND METHODS

Specimens of *Aleurodicus dispersus* Russell, the spiraling whitefly; *Trialeurodes vaporariorum* (Westwood), the greenhouse whitefly; and *Bemisia argentifolii* Bellows & Perring were collected in Hawaii from greenhouse grown greenbean and pepper plants (identifications provided by Mr. B. Kumashiro, Hawaii Dept. of Agric.). Leaf sections with whitefly eggs were excised from leaf samples. Specimens were prepared for examination with a scanning electron microscope (SEM) by gradual dehydration in ethyl alcohol, critical point drying, and sputter coating with gold (Paulson & Beardsley 1985). Specimens were then examined with the SEM to determine if the egg pedicel was inserted through a stoma or directly into leaf tissues.

Specimens for sectioning were embedded in paraffin using standard procedures, cut into 8 micron sections using a rotary microtome, and stained with fast green and safranin. The point of insertion of egg pedicels into leaf tissues in the prepared slides were examined with a compound light microscope.

[1]Received for publication 15 May 1997; accepted 23 September 1997
[2]Corresponding author

RESULTS AND DISCUSSION

Sixty pedicels of *B. argentifolii* were examined with the SEM. All pedicels appeared to be inserted directly into host plant tissue (Figure 1, A). Stomatal insertion was not observed in a single case. In many instances, stomata were seen in such proximity to the site of insertion that there was no question that the pedicel was inserted directly into the host plant tissue. Non-stomatal oviposition was also clearly seen in sectioned material (Figure 1, B).

A. dispersus and *T. vaporariorum* exhibited both stomatal and nonstomatal pedicel placements. Seventy-five pedicels of *A. dispersus* were examined. Of these specimens 28 (37%) had stomatal pedicel insertion (Figure 2, A) and 30 (40%) had the pedicel inserted directly into host plant tissue (Figure 3, A). The pedicels could not be clearly seen in the remaining specimens. Stomatal (Figure 2,B) and non-stomatal (Figure 3, B)

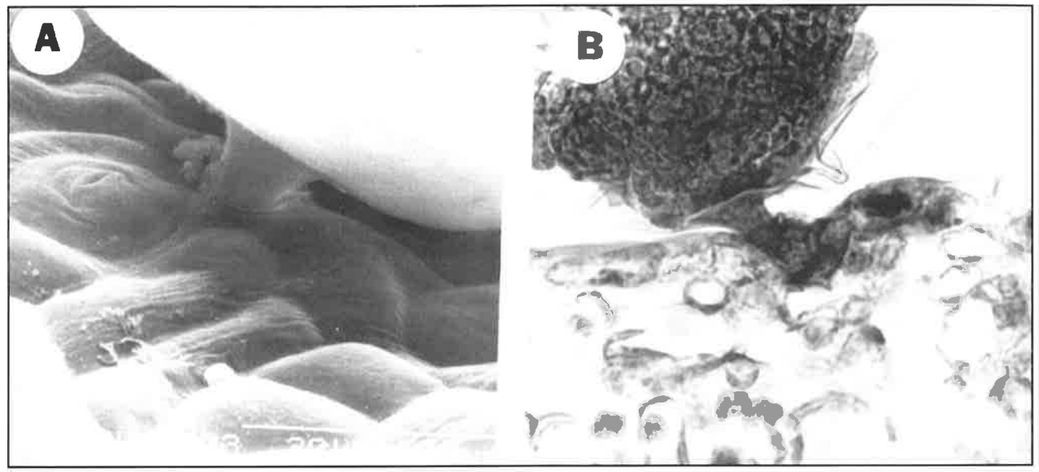

FIGURE 1. A. Electron micrograph of an egg pedicel of *Bemisia argentifolii*, showing insertion directly into host plant tissue. Note the stoma in very close proximity to the place of insertion. Scale bar equals 20 microns. B. Light micrograph of a transverse section showing egg and pedicel of *B. argentifolii*, pedicel inserted directly into host plant tissue.

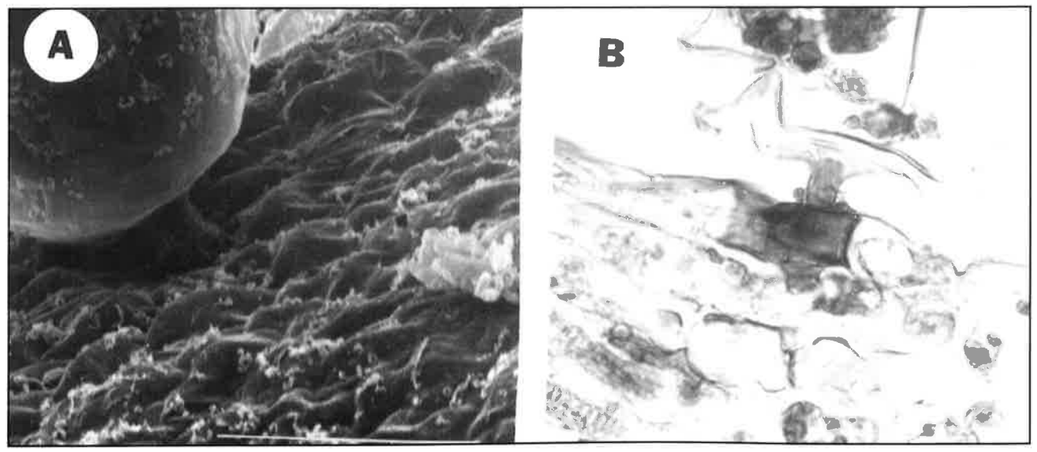

FIGURE 2. A. Electron micrograph of an egg pedicel of *Aleurodicus dispersus* showing insertion directly into a host plant stoma. Scale bar equals 20 microns. B. Light micrograph of a transverse section showing egg and pedicel of *A. dispersus*, pedicel insertion is stomatal. Guard cells are on both sides of the pedicel.

oviposition was also observed in sectioned specimens. Over 60 *T. vaporariorum* pedicels were examined. Examination of the point of insertion into the leaf was problematic in this species because the pedicels are very short and are inserted in such a manner that the eggs stand very erect on the leaf obscuring the view of the pedicel. However, stomatal pedicel insertion (Figure 4, A) was clearly seen 7 times and nonstomatal (Figure 5, A) was observed in 15 specimens. The pedicel was easier to observe in sectioned specimens. Both stomatal (Figure 4, B) and non-stomatal (Figure 5, B) pedicel insertions were seen in sectioned specimens.

The results of this study indicate that placement of the pedicel during oviposition in whiteflies is more variable than previously believed. We have observed both stomatal and non-stomatal pedicel placements within a species of whitefly. Previous work (Paulson and Beardsley 1985, Lloyd 1922) seemed to indicate that, within a species, whitefly's oviposited either stomatally or non-stomatally. Interestingly, sections showed the

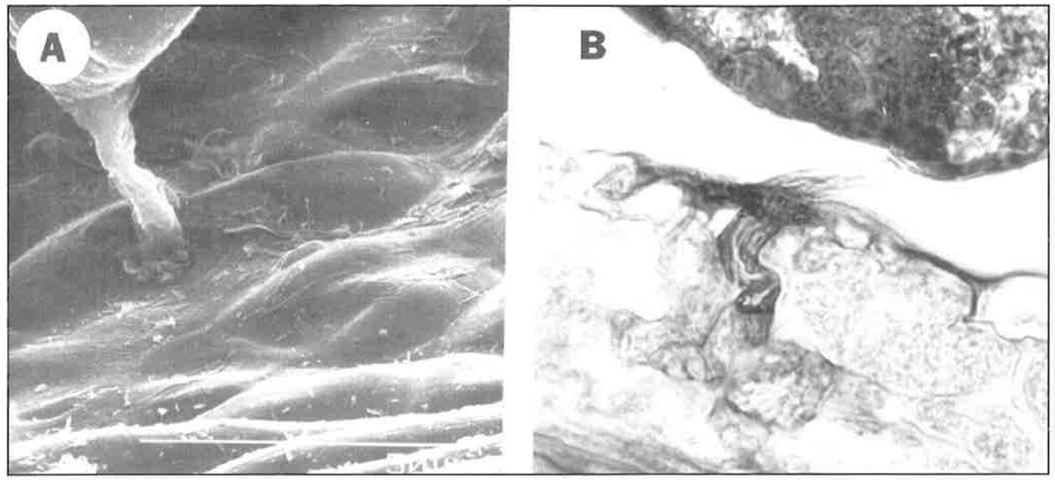

FIGURE 3. A. Electron micrograph of an egg pedicel of *Aleurodicus dispersus* showing insertion directly into a host plants tissue. Scale bar equals 50 microns. B. Light micrograph of a transverse section showing egg and pedicel of *A. dispersus*, pedicel insertion is nonstomatal.

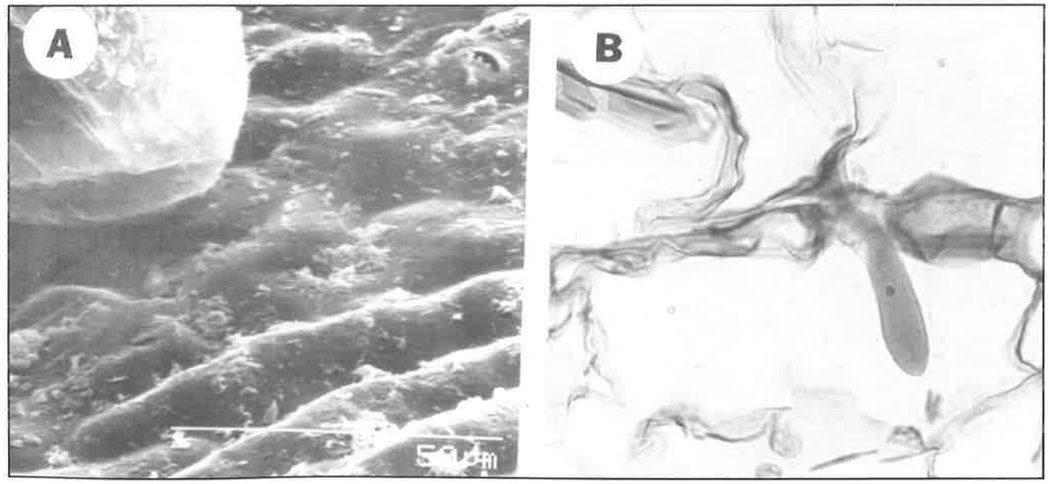

FIGURE 4. A. Electron micrograph of an egg pedicel of *Trialeurodes vaporariorum* showing insertion directly into a host plant stoma. Scale bar equals 50 microns. B. Light micrograph of a transverse section showing egg and pedicel of *T. vaporariorum*, pedicel insertion is stomatal. Note the substomatal chamber in which the end of the pedicel is located.

distal end of the pedicel, where the micropyles are located, was usually located in the spongy mesophyll of the leaf which is where the highest concentration of water vapor would be found in a leaf. Placing the egg pedicel into a stoma usually placed the distal end directly into a substomatal chamber of the spongy mesophyll (Figure 4, B). These sections show how well adapted the egg pedicel is for obtaining moisture for the egg.

An interesting observation was made of the *A. dispersus* pedicels during examination with the SEM. Those that were inserted non-stomatally (Figure 3, A) had more of the pedicel visible outside of the leaf, than those inserted directly into the stomata (Figure 2, A). Sectioned specimens revealed that the pedicels were straighter and projected deeper into the leaf when stomatally inserted (Figure 2, B) as compared to the non-stomatally inserted pedicels that were bent and barely reached the spongy mesophyll of the leaf (Figure 3, B). Because of the role of the pedicel in water absorption necessary for egg development, it would be interesting to study those eggs with non-stomatal pedicel insertion to determine if they would develop at the same rate as those with stomatal pedicel insertion. Furthermore, differences in pedicel morphology in stomatal versus non-stomatal eggs may indicate that it was more difficult for *A. dispersus* to oviposit directly into leaf tissues. Similar observations were made in *T. vaporariorum* egg pedicels inserted stomatally vs. non-stomatally (Figures 4 & 5) however the differences were not as pronounced.

If it is true that direct insertion of the pedicel into host tissues is more difficult than stomatal placement of the pedicel our results may provide a relatively simple partial explanation of several aspects of whitefly oviposition behavior. While factors such as nutrient and water stress have been shown to affect host plant selection by adult whiteflies (Skinner 1996, Skinner and Cohen 1994, Mor and Marani 1984) and host plant mediated fecundity is well documented (e.g. Ihaegwam 1980, van Boxtel, et al. 1978), previous studies have not considered the role that host species (and cultivar) specific morphological characteristics of a leaf, such as the thickness of cuticular wax, the nature and density of trichomes and leaf hairs, the pattern of distribution of the stomata on the leaf surface, the shape of the stomata and guard cells, and the number of stomata on a leaf, may play in oviposition behavior. Certainly any of these factors could affect the ease of oviposition for a female whitefly and, thus, the number of eggs laid on a particular host. Similarly, nutrient and water stress could influence the physical attributes of the epidermal cell wall (i.e., cell "toughness") which could also affect oviposition behavior. Our hypothesis also helps explain whitefly preference for the underside of leaves as oviposition sites since most of the stomata on a plant are on the lower leaf surface and the upper leaf surface often has a relatively thick waxy layer on the leaf surface. It would also be difficult for the pedicel to reach the spongy mesophyll if it was inserted into the upper leaf surface because the palisade parenchyma is found just below the leaf epidermis on the upper surface.

The results of our study have revealed some new information on the nature of whitefly oviposition behavior and the relationship between whiteflies and their host plants. We hope our work will stimulate further study in this field.

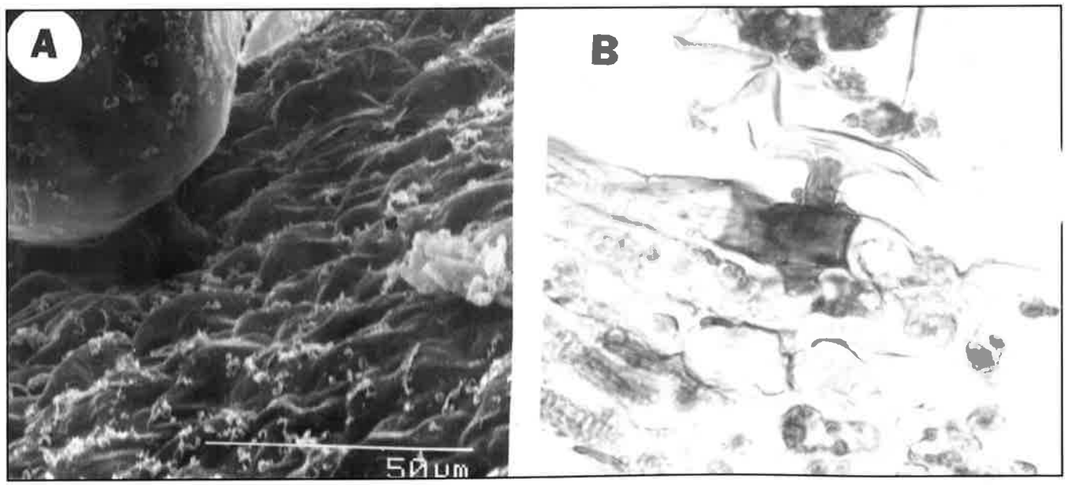

FIGURE 5. A. Electron micrograph of an egg pedicel of *Trialeurodes vaporariorum* showing insertion directly into a host plants tissue. Scale bar equals 50 microns. B. Light micrograph of a transverse section showing egg and pedicel of *T. vaporariorum*, pedicel insertion is nonstomatal.

ACKNOWLEDGEMENTS

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Journal of the Pennsylvania Academy of Science 71(3):104-108, 1998

BUTTERFLY AND SKIPPER USE OF NECTAR SOURCES IN FORESTED AND AGRICULTURAL LANDSCAPES OF PENNSYLVANIA[1]

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ABSTRACT

Use of native and exotic flowering plants as nectar sources by butterfly and skipper communities was examined in forested and agricultural landscapes of central Pennsylvania from May-September, 1994-96. Of the 129 species of flowering plants observed during the study, 60 (47%) were exotic to the United States. Of the flowering plant species, 52 were used as nectar sources by 21 species of butterflies and skippers in both landscapes combined. Twelve species of nectar sources were used by at least four species of butterflies and skippers; only three of these 12 principal nectar sources were native species. Cabbage whites (*Pieris rapae*) used 22 different nectar sources, and 13 other butterfly and skipper species each used at least nine different nectar sources. Logging roads and herbaceous openings (i.e., food plots) in forested landscapes and wooded edges characterized by borders of herbaceous vegetation (2- to 5-m wide) in agricultural landscapes should be protected and maintained (e.g., not mowed, sprayed with herbicides, or grazed by livestock) as critical habitat for the conservation of butterfly and skipper communities.
[J PA Acad Sci 71 (3) 104-108, 1998]

INTRODUCTION

The conservation of butterflies and skippers is of considerable interest because these organisms are major pollinators of flowering plants, indicators of healthy ecosystems, barometers of environmental perturbations, and aesthetically pleasing to outdoor enthusiasts (e.g., Kim 1993, Kremen et al. 1993). Butterfly and skipper populations have declined over the past few decades as a consequence of habitat fragmentation and loss, pesticide use, and loss of host and nectar plants (Iftner et al. 1992, Cushman and Murphy 1993, Britten et al. 1994, Wagner and Miller (1995). As part of a long-term study on the conservation of butterfly and skipper communities of central Pennsylvania (Yahner 1995, 1996, 1997), use of flowering plants as nectar sources was monitored. My objective was to document relative availability and use of both native and exotic plants as nectar sources by butterfly and skipper species in forested and agricultural landscapes. Based on these findings, recommendations for the management of habitat for nectar sources were formulated for the conservation of butterfly and skipper communities in these landscapes.

[1]Received for publication 18 September 1997; accepted 5 December 1997.

STUDY AREAS

The study was conducted on forested and agricultural landscapes on public lands throughout Centre County, Pennsylvania, from May-September in 1994-96. The forested landscape was located at the Barrens Grouse Habitat Management Area (HMA) on state Game Lands 176 (Yahner 1995, 1997); the agricultural landscape included the Toftrees sector of State Game Lands 176 and properties owned by Penn State University (Yahner 1996). The forested landscape at the Barrens Grouse HMA consisted of an uncut sector and a sector managed via an even-aged system of forest clearcutting (extensive details of the Barrens Grouse HMA are provided in Yahner 1993, 1997). Principal overstory trees (>7.5 cm dbh and 1.5 m tall) at the Barrems Grouse HMA included quaking aspen (Populus tremuloides), bigtooth aspen (*P. grandidentata*), pitch pine (*Pinus rigida*), red maple (*Acer rubrum*), and white (*Quercus alba*), northern red (*Q. rubra*), scarlet (*Q. coccinea*), and chestnut oaks (*Q. prinus*) (Yahner 1993). Overstory trees in both uncut and managed sectors were about 75-80 years old; the last cutting cycle on the managed sector occurred in winters 1985-87.

METHODS

In the forested landscape at the Barrens Grouse HMA, 44, 25-m transects were established at survey plots used for inventorying and monitoring butterfly and skipper communities during 1994 and 1995 (Yahner 1995, 1997). These transects were located in representative uncut and clearcut forest stands and along both trails (each 3-4 m wide) and herbaceous habitats (logging roads and herbaceous openings, i.e., food plots). Species and relative abundance of flowering plants were noted within a 1-m lateral distance to each side of the transect during three time periods (mid-June, early July, and late July) in 1995.

Non-wooded habitats in the agricultural landscape were row crops (e.g., corn, alfalfa, soybeans) and pasture. Twenty 250-m transects were established in this landscape to inventory and monitor butterflies and skippers during 1996 (Yahner 1996). Transects were placed at five representative forest, woodlot, hedgerow, and unimproved road edges. Each transect was arbitrarily divided into 50-m segments, and species and relative abundance of flowering plants were recorded within a 5-m lateral distance to each side of the transect during seven time periods (approximately 2- to 3-week intervals from mid-May to early September) in 1996. In both landscapes, the relative abundance was estimated along each transect as the number of individual plants or clumps of plants; a species was recorded during a given time period only if it was flowering and, hence, available as a nectar source for butterflies and skippers at that time (Yahner 1995, 1996).

Use of native and exotic flowering plants by butterflies and skippers was noted during five surveys of butterfly and skipper communities in the forested landscape in 1995 and seven surveys in the agricultural landscape in 1996. A flowering plant was defined as a nectar source whenever a butterfly or skipper landed on the flower and remained for at least 3 seconds, presumably feeding on the nectar. Because different sampling effort and techniques were required for inventorying and monitoring butterfly/skipper and flowering plant communities in the two landscapes (Yahner 1995, 1996, 1997), use of nectar sources was not statistically compared between landscapes. However, the several comparisons of the data presented herein gave some important insights into use of nectar sources by butterflies and skippers in the two landscapes. Common and scientific names of flowering plants were contained in Peterson and McKenny (1968) and Rhoads and Klein (1993); the status (native versus exotic) of flowering plants were from Peterson and McKenny (1968); common and scientific names of butterflies and skippers were obtained from Cassie et al. (1995).

RESULTS AND DISCUSSION

Relative Availability of Nectar Sources

During this study, 129 species of flowering plants (woody and herbaceous) were noted, including 40 and 108 species in the forested and the agricultural landscapes, respectively. Because only 19 (15%) species were common to both landscapes, I considered these landscapes distinct from each other in terms of species richness of flowering plants. Similarly, each landscape had relatively distinct butterfly and skipper communities (Yahner 1995, 1996, 1997). For example, great spangled fritillaries (*Speyeria cybele*) and spicebush swallowtails (*Papilio troilus*) tended to predominate in the forested landscape, whereas cabbage whites (*Pieris rapae*) and orange sulfurs (*Colias eurytheme*) tended to be the most abundant species in the agricultural landscapes.

Of the 129 total species of flowering plants, 60 (47%) were exotic (Peterson and McKenny 1968), including 15 (38%) of 40 species in the forested landscape compared to 56 (52%) of 108 species in the agricultural landscape. I expected more exotic species to occur in the agricultural landscape because it was relatively more disturbed than the forested landscape; the proportion of exotic organisms tends to increase with extent of disturbance (after Soule 1990).

The most abundant species of nectar sources in the forested landscape were hop clover (scientific names are given in Table 1), white clover, birdsfoot trefoil, basil, and yellow wood-sorrel; these species were found almost exclusively in herbaceous habitats (i.e., logging roads and herbaceous openings) (Yahner 1995). The most common agricultural species were dandelion, common fleabane, white clover, smaller hop clover, and thistle; each of these occurred in forest, woodlot, hedgerow, and road edges (Yahner 1996). Of these nine most abundant species, only fleabane and wood-sorrel were native (Peterson and McKenny 1968). Recent studies have shown that habitat disturbances, such as those caused by logging roads and agriculture, facilitate the invasion of exotic plant species into otherwise undisturbed landscapes (e.g., Brothers and Spingarn 1992, Tyser and Worley 1992).

Relative Use of Nectar Sources

Fifty-two species of flowering plants were used as nectar sources by 21 species of butterflies and skippers in the two landscapes combined (Table 1). More species and a higher percentage of available species of flowering plants were used in the agricultural landscape (n = 37,71%) than in the forested landscape (n = 24, 46%); nine of the 54 species (17%) were used by lepidopterans in both landscapes. A greater variety of nectar sources used by butterfly and skipper species in the agricultural landscape was in part attributed to a greater species

TABLE 1. Use of flowering plants as nectar sources by butterflies and skippers in forested (FO) and agricultural (AG) landscapes of central Pennsylvania, 1994-96 .

Nectar source	Landscape: butterfly /skipper species[1]
Alfalfa (*Medicago sativa*)[2]	AG: CAW, EUS, ORS
Barrens strawberry (*Waldsteinia fragariodes*)	AG: HOS, DRD
Basil (*Satureja vulgaris*)	FO: ETB, ORS, PES
Bicknell's cranesbill (*Geranium bicknellii*)	AG: CAW
Birdsfoot trefoil (*Lotus corniculatus*)[2]	FO: CLS, DRD,DUS,ETB,EUS,GSF,HOS,JUD,LOD,ORS,PES,SSS
Blueberry (*Vaccinium* spp.)	FO: DRD
Buckthorn (*Rhamnus davurica*)	AG: SPA,RSP
Buckwheat (*Fagopyrum sagittatum*)[2]	AG: CAW,JUD
Bush clover (*Lespedeza hirta*)	FO: ETB
Butterfly weed (*Asclepias tuberosa*)	AG:MON
Catnip (*Nepeta cataria*)[2]	AG: CAW
Chickory (*Cichorium intybus*)[2]	AG: ORS
Chinese mustard (*Brassica juncea*)[2]	AG: CAW
Common burdock (*Arctium minus*)[2]	AG: BLS,CAW,ORS
Common fleabane (*Erigeron strigosus*)	FO: ETB, SPS AG: BLS,EUS,ORS,SPA
Common St. Johnswort (*Hypericum perforatum*)[2]	FO: ORS
Crown vetch (*Coronilla varia*)[2]	FO: AMC,DUS,EUS,ETB,GSF,LOD AG: CAW
Dame's rocket (*Hesperis matronalis*)[2]	AG: ETS,MON
Dandelion (*Taraxacum officinale*)[2]	FO: ORS AG: CAW,EUS,HOS,MON,ORS
Deptford pink (*Dianthus armeria*)[2]	AG: CAW
Dewberry (*Rubus recurvicaulis*)	AG: HOS
Foxglove beardtongue (*Penstemon digitalis*)	AG: SPS
Garlic mustard (*Alliaria officinalis*)[2]	AG: SPA
Goldenrod (*Solidago* spp.)	FO: CAW,GSF,MON,PES AG:MON
Heal-all (*Prunella vulgaris*)[2]	FO: DUS,ORS AG; CAW,DUS,EUS,ORS,PES
Hedge mustard (*Sisymbrium officinale*)[2]	AG: CAW
Hop clover (*Trifolium agrarium*)[2]	FO: EUS
Horseweed (*Conyza canadensis*)	AG: BLS,MON
Indian-pipe (*Monotropa uniflora*)	FO: GSF
Lady's thumb (*Polygonum persicaria*)[2]	AG: CAW,ORS
Mayweed (*Anthemis cotula*)[2]	AG: CAW,EUS,JUD,MON,MOC,SSS,SPA
Orange hawkweed (*Hieracium aurantiacum*)[2]	AG: MEF
Ox-eye daisy (*Crysanthemum leucanthemum*)[2]	FO: CLS,COH
Queen Anne's lace (*Daucus carota*)[2]	AG: MEF, MON
Raspberry (*Rubus occidentalis*)	AG: CAW,SPA
Red clover (*Trifolium pratense*)[2]	AG: BLS,MON,ORS
Rough cinquefoil (*Potentilla norvegia*)	AG: CAW,EUS
Rough hawkweed (*Hieracium scabrum*)	AG: EUS
Round-headed bush-clover (*Lespedeza capitata*)	FO: ETB
Smaller hop clover (*Trifolium campestre*)[2]	FO: ETB AG: CAW
Spotted knapweed (*Centaurea maculosa*)[2]	FO: CAW,CLS,DUS,GSF,ORS,PES,SPS,SSS
Spreading dogbane (*Apocynum androsaemifolium*)	FO: GSF
Swamp dewberry (*Rubus hispidus*)	FO: PES,SPS
Tatarian honeysuckle (*Lonicera tatarica*)[2]	AG: APF,ETS,HOS,SSS
Thistle (*Cirsium* spp.)2	FO: BLS,ETS,GSF,MON,SPS,VIC AG: APF,BLS,CAW,ETS,EUS,GSF,MEF,MON,ORS,SSS,SPS
White clover (*Trifolium repens*)[2]	FO: ETB,EUS,HOS AG: CAW,ETB,EUS
Wild bergamot (*Monarda fistulosa*)	FO: ETS,GSF,SPS,SSS
Wild geranium (*Geranium maculatum*)	FO: CAW,LOD
Winter cress (*Barbarea vulgaris*)[2]	AG: EUS,JUD
Wood lily (*Lilium philadelphicum*)	FO: COH
Yarrow (*Achillea millefolium*)[2]	FO: COH ,EUS,GSF,ORS AG: APF,EUS
Yellow wood-sorrel (*Oxalis stricta*)	AG: CAW,COS

[1]APF= aphrodite fritillary (*Speyeris aphrodite*), AMC = American copper (*Lycaena phlaeas*), BLS = black swallowtail (*Papilio polyxenes*), CAW = cabbage white (*Pieris rapae*), CLS = clouded sulfur (*Colias philodice*), COH = coral hairstreak (*Satyrium titus*), COS = common sootywing (*Pholisora catullus*), DRD = dreamy duskywing (Erynnis icelus), DUS = dun skipper (Eyphyes vestris), ETB = eastern tailed-blue (*Everes comyntas*), ETS = eastern tiger swallowtail (*Papilio glaucus*), GSF = great spangled fritillary (Speyeria cybele), EUS = European skipper (*Thymelicus lineola*), HOS = hobomok skipper (*Poanes hobomok*), JUD = juvenal's duskywing (Erynnis juvenalis), LOD = long dash (*Polites mystic*), MEF = meadow fritillary (Boloria bellona), MOC = mourning cloak (*Nymphalis antiopa*), MON = monarch (*Danaus plexippus*), ORS = orange sulfur (*Colias eurytheme*), PES = Peck's skipper (*Polites peckius*), RSP = red-spotted purple (*Limenitis arthemis*), SPA = spring azure (*Celastrina ladon*), SPS = spicebush swallowtail (*Papilio troilus*), SSS = silver-spotted skipper (*Epargyreus clarus*), VIC = viceroy (*Limenitis archippus*).

[2]Exotic species.

richness of both butterfly/skipper and flowering plant communities in the agricultural compared to the forested landscape (Yahner 1995, 1996).

Principal nectar sources, i.e., arbitrarily defined as those used by at least four butterfly and skipper species, used in the forested landscape were birdsfoot trefoil, crown vetch, goldenrod, spotted knapweed, thistle, wild bergamot, and yarrow (Table 1). Principal nectar sources used in the agricultural landscape included dandelion, heal-all, mayweed, tatarian honeysuckle, and thistle. Of these 12 nectar sources, three species (common fleabane, goldenrod, wild bergamot) were native and nine were exotic (Peterson and McKenny, 1968). Furthermore, only six of the 12 principal nectar sources used in this study (spotted knapweed, wild bergamot, yarrow, heal-all, mayweed, and tatarian honeysuckle) have previously been reported as nectar sources for butterflies and skippers (Audubon Society 1992, Iftner et al. 1992, Opler 1992).

Cabbage whites (scientific names are given in Table 1) were observed using 22 different species of nectar sources (Table 1). This finding was perhaps not unexpected because the cabbage white comprised nearly 63% of the total individual butterflies and skippers noted in the agricultural landscape during 1996 (Yahner 1996). The cabbage white has been reported elsewhere as using an extensive variety of nectar sources and, thus, may be considered a generalist in terms of use of nectar sources (e.g., Iftner et al. 1992). Two other generalists in use of nectar sources were European skippers (n = 16 species used) and orange sulfurs (n = 16 species). Eleven other butterfly and skipper species used at least four nectar sources, including monarchs (n = 11 species used), great spangled fritillaries (n = 10 species), eastern tailed-blues (n = 9 species), spicebush swallowtails (n = 7 species), black swallowtails (n = 6 species), hobomok skippers (n = 6 species), Peck's skippers (n = 6 species), silver-spotted skippers (n = 6 species), spring azures (n = 5 species), dun skippers (n = 5 species), and juvenal's duskywings (n = 4 species).

CONSERVATION IMPLICATIONS

Logging roads and herbaceous openings in the forested landscape and wooded edges characterized by a 2- to 5-m border of herbaceous vegetation in the agricultural landscape are valuable habitat for flowering plants, as well as for butterfly and skipper communities in my study (Yahner 1995, 1996, 1997). Hence, in forested landscapes, herbaceous vegetation should remain unmowed until at least early September. A delay of mowing until late summer would be of direct benefit to the butterfly and skipper communities by providing habitat for flowering plants as nectar sources throughout spring and summer (Yahner 1995). Similarly, herbaceous borders along forest or woodlot edges in agricultural landscapes should not be mowed or sprayed with herbicides until at least late summer. Moreover, grazing of herbaceous vegetation by livestock along wooded edges should be avoided to ensure protection and maintenance of critical habitat for flowering plant, butterfly, and skipper communities (Yahner 1996). In summary, the conservation of butterflies and skippers will be largely contingent on the conservation and management of habitat for native and exotic nectar sources in both forested and agricultural landscapes.

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REMOVAL OF IRON FROM SYNTHETIC COAL MINE DRAINAGE USING RUBBER[1]

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ABSTRACT

The removal of iron from acid mine drainage (AMD) discharges by passive treatment systems is becoming an increasingly popular and inexpensive treatment alternative. Passive treatment, which requires little or no maintenance, usually involves passing AMD water through a bed of limestone, compost material, or other media in order to remove iron oxyhydroxides by sorption and/or precipitation. This laboratory equilibration study was undertaken to evaluate the feasibility of using rubber stoppers (a surrogate for automobile tires) as a potential medium for removing iron (by sorption) from synthetic AMDs typical of the anthracite mining region of northeastern Pennsylvania (pH = 6, Fe = 50 mg/L). For the experimental conditions tested, rubber can sorb up to 6 µg/cm² of particulate iron before the surface becomes saturated. Extrapolating this result to the scale of automobile tires indicates that it would take over 5,300 standard-size tires to remove only one pound (0.45 kg) of iron from AMD. Therefore, using old automobile tires as an iron sorption medium would be impractical for treating AMDs typical of northeastern Pennsylvania.
[J PA Acad Sci 71 (3) 109-112, 1998]

INTRODUCTION

The removal of iron from acid mine drainage (AMD) has historically been accomplished using a combination of physical and chemical processes to raise pH and/or aerate the water in order to accelerate the oxidation of ferrous iron and the subsequent precipitation of iron oxyhydroxides. The rate of ferrous iron oxidation has been shown to be independent of pH at values less than 5.5 and is mediated by acidophilic iron-oxidizing bacteria, such as *Thiobacillus ferrooxidans*. At pH values greater than 5.5, however, iron oxidation is chiefly an abiotic process and is second-order with respect to hydroxide ion concentration (Stumm and Morgan, 1981). In northeastern Pennsylvania, AMDs from anthracite coal mines are typically greater than pH 5.5 (Tarutis et al., 1994; Klemow et al., 1995; Price et al., 1996).

Only relatively recently have alternative "passive" technologies, such as wetlands, been used to treat AMD discharges. Wetlands remove iron primarily by decreasing the velocity of water, allowing oxidized iron to precipitate from solution, and providing sufficient time and surface area for particle formation and settling (Tarutis and Unz, 1996).

It is possible that certain materials, such as rubber, may be more efficient at removing iron than a wetland. If true, then perhaps old automobile tires could be used for the treatment of AMD. The purpose of this laboratory study was to determine the capacity of rubber for removing iron from a synthetic AMD solution and to assess the feasibility of using automobile tires in an AMD treatment process.

MATERIALS AND METHODS

All experiments were carried out in 50-mL polypropylene centrifuge tubes. Experimental tubes containing two black rubber stoppers (No. 1 size) were

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prepared by adding 1 mL of a concentrated iron solution (as $FeSO_4 \cdot 7\ H_2O$) to 20 mL of an oxygenated buffered calcium carbonate solution which had been previously adjusted to pH 6.0 with 6 N sulfuric acid, giving a final iron concentration of 50 mg/L. Each stopper had a surface area of 13.9 cm^2 calculated using the dimensions of the stopper given in the 1994 *Fisher Scientific Catalog* and the formula for the surface area of a frustum of a right circular cone (Beyer, 1991). Control tubes contained the same synthetic AMD solution volume, but without rubber stoppers.

Prepared tubes were agitated for 15, 30, 60, 120, 240, 480, 720 or 1440 minutes using a wrist-action shaker. After each agitiation period, one control tube and one experimental tube were sacrificed. Solution (about 20 mL) was withdrawn from each tube by syringe. Half of the solution volume was injected into a small plastic vial and preserved with concentrated nitric acid and later analyzed for total iron using flame atomic absorption spectrophotometry. The remaining volume was filtered through a 0.22-µm syringe filter, preserved as above, and analyzed for dissolved iron. Particulate iron was calculated as the difference between total iron and dissolved iron.

The amount and form (dissolved and particulate) of iron removed over time were determined from the difference between measured iron in the control tubes and the experimental tubes using the equation:

$$\text{Fe Removed } (\mu g/cm^2) = 1000 \cdot (Fe_c - Fe_r) \cdot V/A \qquad (1)$$

where Fe_c is iron content in control tubes (mg/L), Fe_r is iron content in experimental tubes (mg/L), V is solution volume (0.021 L), and A is rubber surface area (27.8 cm^2).

RESULTS AND DISCUSSION

The mechanisms by which iron may be removed by rubber are sorption of dissolved iron and particulate iron by the rubber surface. The concentration of total iron in the experimental tubes was significantly less than that of the control tubes throughout the duration of the experiment, indicating that the presence of rubber did enhance iron removal (Figure 1). Whether this difference can be attributed to a preferential removal of dissolved iron or particulate iron cannot be determined by examination of total iron data alone. A plot of dissolved iron over time (Figure 2) indicated no difference between the control and experimental tubes. Thus, dissolved iron was not adsorbed by the rubber surface to any appreciable extent. A plot of particulate iron over time (Figure 3) reveals that particulate iron was sorbed onto the rubber surface. This was expected since Belzile et al. (1989) have shown that glass, plexiglass, polystyrene, polyvinyl chloride, and teflon all collected iron oxyhydroxides (particulate iron) to some extent.

Equation (1) was used to estimate the amount of particulate iron removed by the rubber surface (Figure 4). Particulate iron sorption was essentially completed within 60 minutes, as indicated by the relatively constant sorption maximum of 6 µg Fe/cm^2. This value is substantially larger than those reported by Belzile et al. (1989) for other materials (Table 1), probably due to differences in the surface properties of these materials and to differences in experimental conditions, as discussed below. Nevertheless, the presence of a sorption maximum indicates that the rubber surfaces became saturated with particulate iron within 60 minutes of exposure to the synthetic AMD solution. It is probable

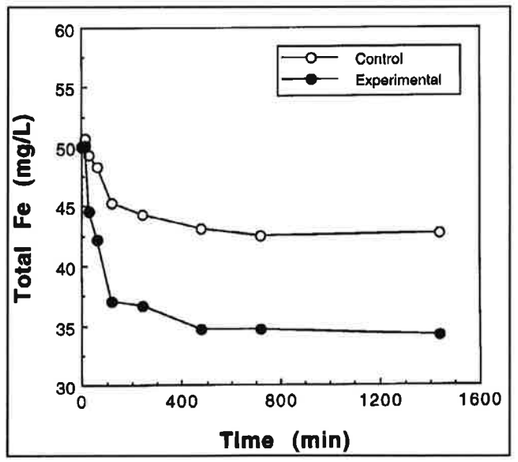

FIGURE 1. Total iron over time for the control (without rubber) and experimental (with rubber) tubes.

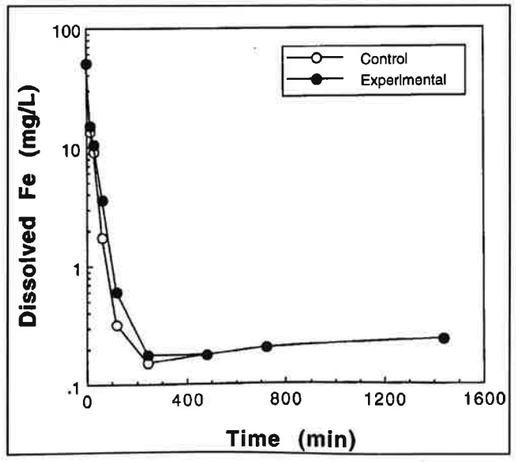

FIGURE 2. Dissolved iron over time for the control (without rubber) and experimental (with rubber) tubes. Note the logarithmic y-axis.

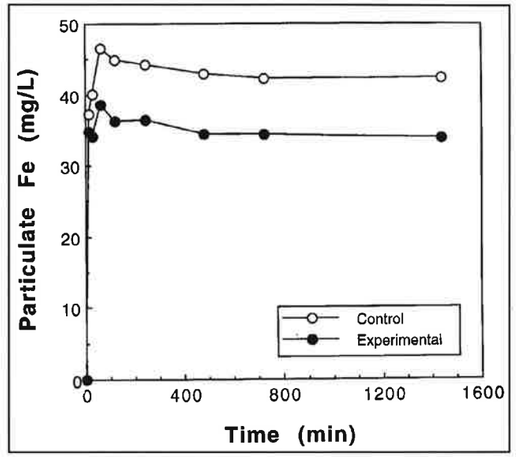

FIGURE 3. Particulate iron over time for the control (without rubber) and experimental (with rubber) tubes.

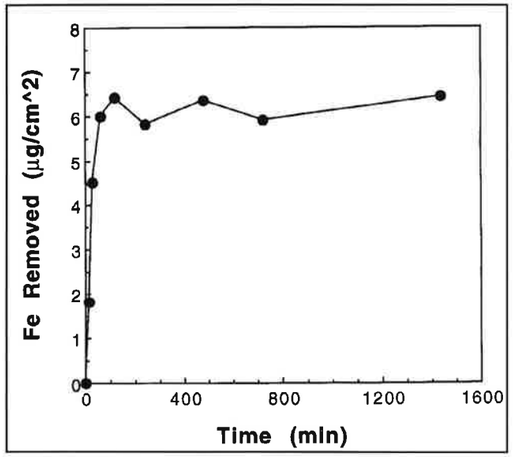

FIGURE 4. Mass of particulate iron removed by the rubber surface over time.

that a change in solution chemistry (e.g., pH or Fe concentration) may influence both the rate and extent of particulate iron sorption. The synthetic AMD solution composition was chosen to mimic the chemistry of typical AMD outfalls in the Wilkes-Barre area to the extent possible (Tarutis et al., 1994; Klemow et al., 1995; Price et al., 1996).

Iron removal by this mechanism will result in the formation of a "monolayer" of particulate iron attached to the tire surface. Such a monolayer will not likely be visible to the naked eye, so the tire will not appear to be discolored. Once the rubber surface is saturated (i.e., coated) with iron, any additional iron removed is due solely to the sorption (or precipitation) of iron onto an iron-coated surface. Thus, any surface properties of rubber that may have enhanced iron removal by sorption are lost once the rubber becomes saturated with particulate iron, which is on the order of 60 minutes for this AMD chemistry (Figure 4). Other AMDs having higher pH values and higher iron concentrations will likely saturate rubber much more quickly.

The feasibility of using old automobile tires in AMD treatment can be estimated by calculating the surface area of a "typical" tire and estimating the amount of iron removed per tire. The information given by Lord (1995) was used to estimate the surface area of a P185/70R13 tire. Larger tires would of course have higher surface areas. A P185/70R13 tire has a rim diameter of 13 inches (33 cm), which corresponds to an area of 855 cm^2. The width of the tire is 185 mm (18.5 cm). The rim-to-road distance is 70% of the width of the tire, or 130 mm (13 cm). Therefore, the area of one sidewall is the area of a circle with radius 29.5 cm less the area of the rim, which equals about 1,880 cm^2. The area of tread is the circumference of the tire times the width, which equals about 3,430 cm^2. Summing the areas of two sidewalls plus the tread gives an estimate of the surface area of the outside of the tire, or about 7,200 cm^2. Assuming the inside area is roughly equal and chemically similar to the outside area, the total surface area of the tire is about 14,400 cm^2. This estimate does not take into account the presence of treads or any tire wear. If the tire has surface properties similar to a black rubber stopper, the maximum amount of iron removed per tire is:

6 µg Fe/cm^2 x 14,400 cm^2/tire x 0.001 mg/µg = 85 mg Fe/tire.

Based on this value, it would take over 5,300 tires to remove one pound (0.45 kg) of particulate iron assuming all of the tire surface area is exposed to AMD (i.e., no tire-to-tire contact). Thus, a bed of used automobile tires may initially enhance iron removal by providing additional surface area to which particulate iron can attach, but once these tires become saturated their usefulness as an iron sorption medium would be extremely limited.

TABLE 1. Particulate iron deposition onto various materials.

Material	Fe Deposited (µg/cm^2)	Reference
Rubber	6.0	This study
Glass	0.6	Belzile et al. (1989)
Plexiglass	0.4	Belzile et al. (1989)
Polystyrene	1.3	Belzile et al. (1989)
Polyvinylchloride	0.9	Belzile et al. (1989)
Teflon	3.6	Belzile et al. (1989)

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AN UPDATED TORNADO CLIMATOLOGY OF PENNSYLVANIA: METHODOLOGY AND UNCERTAINTIES[1]

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ABSTRACT

An up-to-date Pennsylvania county tornado climatology is presented. Tornado occurrences are converted to density values by dividing by the area of the county. Further, because weak tornadoes rarely pose a fatality threat, mappings of the risk of tornadic wind speeds in excess of about 50 m/s are also presented. The analyses primarily use data from 1950 to 1996. Because the frequency of tornadoes, especially weak ones, has increased during that period - presumably due to increased public awareness - it would be desirable to use a shorter period of record. However, for rare events like tornadoes even a 47-year period can sometimes be too short to obtain a valid sample on a county basis. In fact, to reduce this problem we have introduced a hybrid statistical approach that includes tornadoes on record from 1916-1949 whenever the use of this period increases the tornado risk for a county (despite the overall tendency for fewer tornadoes statewide in earlier decades). The paper documents other factors that must be considered in risk assessment and presents a risk mapping that considers variations of tornado winds along and within their damage paths.
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INTRODUCTION

Pennsylvania is far geographically removed from "tornado alley," but tornadic thunderstorms do strike the state with some regularity. Over the last decade, Pennsylvania has averaged 17 tornadoes per year. According to the official tornado archives of the Storm Prediction Center (1997) for the period 1950-1995, Pennsylvania ranks 25th among states in the number of observed tornadoes and 30th in the number of tornadoes per year per unit area. The state ranks 21st nationally in tornado fatalities (with 77), 22nd in injuries from tornadoes (with 1077), and 13th nationally in Consumer Price Index-adjusted dollar damage from tornadoes.

The last assessment of tornado trends in Pennsylvania and analysis of risk from tornadoes for specific Pennsylvania regions and counties was compiled nearly three decades ago by then state-climatologist Paul Dailey Jr. (Dailey, 1970). Since then, new observational and theoretical capabilities have added significantly to our knowledge of tornadoes (sometimes referred to as "twisters"). For example, the Fujita Scale (F-Scale) of tornado wind speed and damage potential, given in Table 1, was introduced in the early 1970s (Fujita, 1971). Tornado F-Scale intensities and maximum wind speeds are now routinely estimated on the basis of the type and extent of the resulting damage. The differences between damage caused by tornadic winds and that resulting from straight-line winds are now better understood (Fujita, 1985). In addition, improved observational resources

TABLE 1. The Fujita Scale of Wind Speed and Damage (Fujita, 1981)

	Wind speed (m/s)	Wind speed (mph)	Damage Class
F0	18-32	40-72	Light
F1	33-50	73-112	Moderate
F2	51-70	113-157	Considerable
F3	71-93	158-206	Severe
F4	94-117	207-260	Devastating
F5	118-143	261-318	Incredible

(such as Doppler radar) have allowed identification of tornadoes that may have eluded detection in previous years. For these reasons, an updated climatology of Pennsylvania tornadoes, including a risk assessment by county, is appropriate at this time.

It is well known that tornado databases contain considerable uncertainty and some inaccuracy, especially prior to the 1970s (e.g., Doswell and Burgess, 1988). Just obtaining the most basic of statistics, an accurate tornado count, is not trivial for several reasons. Many tornadoes have undoubtedly gone unreported, particularly in sparsely populated regions in the pre-Doppler-radar years. Without a post-storm survey of the damage pattern by professionals, straight-line wind damage and tornadic wind damage can be confused. Other known sources of uncertainty include the somewhat subjective nature of assigning F-scales, the relatively short period of official tornado records (which means, for example, that the risk statistics are least stable for the strongest, rarest tornadoes), and the somewhat spotty documentation of path length, path width, and maximum wind speed for those tornadoes that are reported. It should also be noted that there is uncertainty concerning the appropriate wind speeds to attribute to the F-scale damage intensity categories in Table 1, and structural engineers generally view the F4 and F5 wind speeds as overestimates. Any climatology and risk assessment of Pennsylvania tornadoes must be viewed in light of these uncertainties.

The tornado databases used to compile this climatology are described in Section II. The temporal and spatial climatology of Pennsylvania tornadoes is presented in Sections III and IV. A risk assessment that incorporates tornado path width, tornado path length, and the differences in F-scales between tornadoes is given in Section V. In addition, we address the uncertainty involving the relatively short period of "official" tornado information (1950 to present) by advancing a hybrid tornado risk statistic that incorporates relevant tornado information from the period 1916 to 1949. Conclusions and a discussion are presented in Section VI.

DATA SOURCES

In compiling this climatology of Pennsylvania tornadoes, we used three primary data sources: (1) the official archives of the Storm Prediction Center (SPC) for tornadoes in the period 1950-1995 (SPC, 1997), supplemented by preliminary statistics for 1996 - we will call this the SPC database; (2) a database of tornadoes from 1916-1989, compiled by Dr. Theodore Fujita and his colleagues at the University of Chicago - we will call this the Fujita database (e.g., Tecson, Fujita, and Abbey, 1982); (3) the voluminous *Significant Tornadoes* (Grazulis, 1991), which documents (with short descriptions and narratives) all known tornadoes in the period 1680-1991 of F2 or higher intensity (in Grazulis' estimation). These three databases were not compiled completely independently of one another, and all rely heavily on *Storm Data* (e.g., NOAA, 1992), the official listing of severe weather published by the National Oceanic and Atmospheric Administration. The climatology of Pennsylvania tornadoes compiled by Daily (1970) and *Tornadoes of the United States* (Flora, 1958) were also used as secondary sources.

In addition to the date, time, injuries, and fatalities for each tornado, the three primary databases provide an F-scale rating (in nearly all cases) and path length and width information (in most cases). Tornadoes that occurred prior to the introduction of the Fujita Scale were assigned F-scale ratings by the various database authors by using available information about the tornado rather than actually assessing the damage first-hand. All three databases also provide some indication of tornado location. In the SPC database, location is specified by latitude, longitude, and county. Grazulis gives a county and a narrative description that often mentions specific cities. The Fujita database locates tornadoes in a grid of 1/4° latitude by 1/4° longitude boxes; thus, identifying the precise county is, in some cases, not possible using solely the Fujita data.

We use the period 1950-1996 as the primary basis for this climatology. Beginning with 1950 is reasonable considering that this is the first year of the official SPC archives. Although many pre-1950 tornadoes likely went undetected, a considerable number were documented (particularly the stronger ones). From the perspective of risk analysis, this information should not be ignored, particularly if pre-1950 tornadoes occurred in regions that had little or no risk as measured by tornado frequency during the 1950-1996 period. To address this issue, in section V we advance a "hybrid" risk statistic: if including pre-1950 data yields a larger risk for a particular county, we use the longer period 1916-1996 to represent the risk. If including pre-1950 data would not produce a higher risk statistic for a particular county, we used the risk statistic computed from 1950-1996 data. We chose 1916 as our beginning year for this hybrid statistic because it is the earliest year for which two primary databases (Fujita and Grazulis) exist.

We attempted to resolve discrepancies among databases by consulting *Storm Data* and, when necessary, newspaper microfilm. Even then, for the reasons mentioned earlier, some uncertainty remains. In essence, no matter how good the intentions, imperfect databases cannot produce perfect conclusions.

TORNADO DISTRIBUTION IN TIME

Figure 1 shows annual tornado frequency in Pennsylvania since 1950, and annual frequency of tornadoes rated F2 or higher (sometimes called "significant tornadoes"). In this 47-year period, 492 tornadoes have been observed in Pennsylvania, with 147 of them being rated F2 or higher. After an active decade of tornadic activity in the 1950s followed by a lull in the 1960s, total tornado frequency has increased dramatically in the last few decades: the 1987-1996 average of 17 tornadoes/yr is nearly triple the 1950-1959 average. In contrast, there appears to be little, if any, general upward trend in the frequency of significant tornadoes. In fact, the 1987-1996 decadal average of 2.3 significant tornadoes/yr is actually lower than the 1950-1959 decadal average of 3.4. The spike in significant tornadoes in 1985 reflects the 16 F2-F5 tornadoes that touched down on May 31, 1985. Thus, the increase in total tornadoes is almost exclusively the result of an increase in weak (F0 and F1) twisters.

These trends are consistent with those observed nationally (e.g., Ostby, 1993). In the United States, the frequency of F0 and F1 tornadoes has approximately quadrupled since the 1950s, while the number of significant tornadoes has stayed fairly constant or even decreased slightly (e.g., Schaefer et al, 1993). Because statistics on powerful tornadoes are more reliable over the decades (since these twisters leave widespread damage, they are usually documented), and because there is no reason to believe that weather patterns are changing to produce more weak tornadoes while leaving the number of strong ones unchanged, it is reasonable to conclude that the rising number of weak tornadoes simply reflects improved reporting. There are more people now, spread over a wider area (many armed with video cameras), allowing detection and verification of more tornadoes than ever before. Likewise, Doppler radar has made National Weather Service (NWS) forecasters more aware of potentially severe storms because of the radar's ability to detect mesocyclones (counterclockwise-rotating wind patterns in the types of thunderstorms most likely to produce tornadoes). This heightened public awareness of severe weather, coupled with greater efforts on the part of the NWS to seek verifications of severe thunderstorm and tornado warnings, contributes to increased reporting of tornadoes.

Figure 2 shows the time of year of occurrence of Pennsylvania tornadoes for the period 1950-1996, distributed by half-month (Figure 2a) and by month (Figure 2b). Only six tornadoes (approximately 1.2% of the total number) have been observed between December 1 and March 15, testifying to the stabilizing low-level chill of winter. No tornadoes have been observed in December, dating back to at least 1854. Tornado frequency then

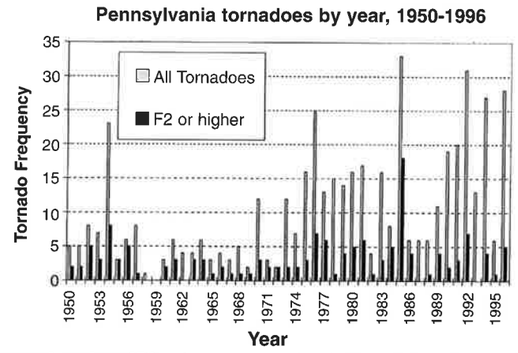

FIGURE 1. Total number of tornadoes and number of F2 and stronger tornadoes in Pennsylvania, by year, from 1950 to 1996. Averages are 10.5 and 3.1, respectively.

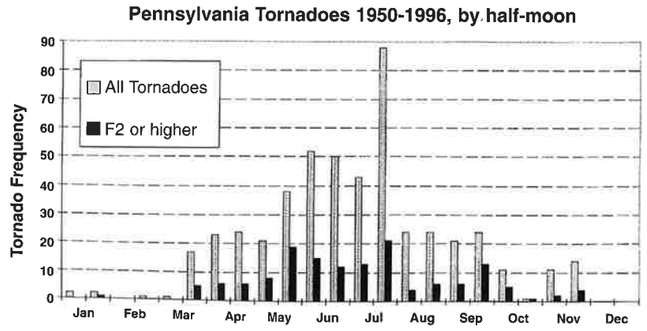

FIGURE 2a. Distribution of Pennsylvania tornadoes during the period 1950-1996 by (a) half-month and (b) month.

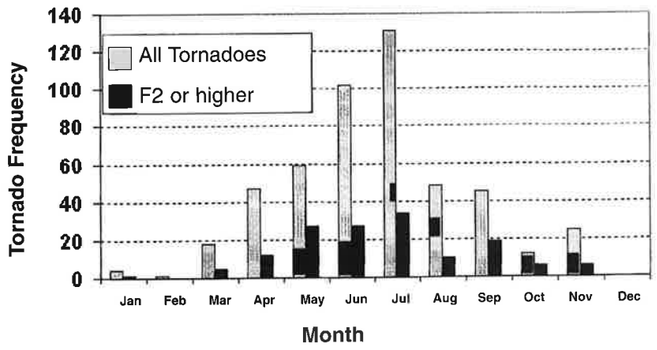

FIGURE 2b.

increases to approximately 20 per half-month from mid-March into mid-May as growing low-level warmth interacts with potent spring storms. The main tornado season begins in late May, culminating in a dominant peak in late July (when thunderstorm frequency also peaks). Tornado frequency then falls sharply, with half-month totals in August and September only about 30% of the late-July maximum. This sharp drop results from the increase in stability that occurs as upper levels reach their maximum warmth late in the summer. The decrease continues into October, with only one tornado observed in the latter half of that month. However, a weak relative maximum appears in November, likely associated with the strong cold fronts and fast winds aloft that accompany the change from autumn to winter in Pennsylvania. The November "mini-peak" in tornadoes is not confined solely to Pennsylvania, but shows up nationally as well (Ostby, 1993).

Figure 2 also shows that, in general, the monthly variation in the frequency of F2-F5 tornadoes mimics that of total-tornado frequency, although the peak in late July is much less dominant. The increase in late May reflects the 16 significant tornadoes on May 31, 1985. Had these tornadoes occurred eight hours later, the peak in significant tornadoes would be in early June. The tendencies for more and stronger tornadoes in early summer than late summer is likely to reflect the role that strong winds aloft play in the development of tornadic thunderstorms, as winds aloft decrease in speed as the summer progresses.

As in other parts of the country, Pennsylvania tornadoes often occur in groups. The 492 Pennsylvania tornadoes in the period 1950-1996 actually occurred on just 295 days. Table 2 lists those days when at least six tornadoes have been observed in Pennsylvania. Note that with just one exception, all of these outbreaks have occurred since 1976, again testifying to the increased

Table 2. Notable Pennsylvania Tornado Outbreaks, 1916-1996

Date	No.	Tornadoes by F-Scale 0 1 2 3 4 5	Deaths/ Injuries	Counties
5-31-85	21	2 3 4 4 7 1	65/526	Beaver. Butler, Cameron, Centre, Clarion, Clearfield,Clinton, Crawford, Elk, Erie, Forest, Indiana, Luzerne, Lycoming, Mckean, Mercer, Monroe, Northumberland, Venango, Union
4-9-91	11	2 9 0 0 0 0	0/7	Bedford, Cambria, Centre, Cumberland, Fayette, Westmoreland
7-19-96	9	2 3 4 0 0 0	0/4	Adams, Bedford, Blair, Cambria, Clarion, Clearfield, Franklin, Fulton, Indiana, Jefferson
7-17-92	8	2 4 2 0 0 0	0/4	Berks, Chester, Dauphin, Lebanon, Montour, Snyder
3-21-76	7	2 3 1 1 0 0	0/0	Adams, Cumberland, Franklin, Lehigh, Monroe, Northampton, York
11-8-96	7	1 5 1 0 0 0	0/2	Bedford, Centre, Clinton, Lycoming, Mifflin, Monroe, Northampton
7-15-92	6	1 4 1 0 0 0	0/2	Clinton, Columbia, Delaware, Northampton, Schuylkill
6-23-44	3	0 0 0 1 2 0	45/300+	Allegheny, Armstrong, Cambria, Fayette, Greene, Indiana, Westmoreland, Washington

reporting in recent years. Although officially listed as a three-tornado day, the June 23, 1944 outbreak is included because it is the second most deadly tornado outbreak in Pennsylvania history, and because one of the F4 tornadoes may have actually been a series of twisters produced from the same parent thunderstorm, called a "tornado family."

By any measure, the May 31, 1985 tornado outbreak was the worst in the recorded weather history of Pennsylvania. During a six-hour period, 21 tornadoes touched down in the state, killing 65 Pennsylvanians and causing $300 million in damage (Witten, 1985; Fuller, 1987). That evening, at 7:10 P.M. EDT, the only F5 tornado ever observed in the state, with winds that may have been 260-300 mph, moved from Trumbull County, OH, into Mercer County, causing 8 deaths and 60 injuries along its 14-mile path in Pennsylvania. The impact of the May 31, 1985 outbreak on Pennsylvania risk statistics is examined later in the paper.

SPATIAL DISTRIBUTION OF PENNSYLVANIA TORNADOES

Figure 3 shows tornado distribution by county for the period 1950-1996 (tornadoes that crossed county boundaries are included in each county they affected). In general, maxima are found in western Pennsylvania and on the Piedmont Plateau in the southeastern part of the state. Westmoreland County, with 25, tops the list, followed by Crawford County with 23 and Lancaster and Chester Counties with 22. Note that no tornadoes have been observed in the 1950-1996 period in Juniata and Pike counties (although each of these counties had one confirmed tornado prior to 1950). Fulton County's one tornado, an F0, occurred in 1996, and may have gone uncounted if not for an intensive severe weather monitoring program in progress during the summer of 1996 in Central Pennsylvania (see Appendix 1).

To more accurately gauge risk, the disparity in areal size among the counties must be considered. Figure 4 shows the number of tornadoes per hundred square miles for the period 1950-1996, which we will refer to as "tornado density." The general locations of relative maxima are unchanged from Figure 3, but the top three counties are now in southeastern Pennsylvania: Philadelphia (3.8), Lebanon (3.3), and Montgomery (3.1). Meteorologically, the distributions shown in Figures 3 and 4 are easily explained. The western and southeastern parts of the state have easier access to warm, moist low-level air needed to power severe thunderstorms. The variable, hilly terrain of central and northern Pennsylvania interrupts the flow of warm, moist air feeding into thunderstorms, acting to inhibit severe thunderstorm formation and to weaken or dissipate many storms before they reach tornadic proportions.

Although meteorological reasoning can adequately explain the overall tornado distributions in Figures 3 and 4, population density undoubtedly plays a non-negligible yet difficult-to-quantify role. There is a high correlation between tornado density (Figure 4) and population density (see Figure 5). We will address these demographic issues in more detail in a future article.

Figure 6 shows the distribution of Pennsylvania tornadoes by season: 1 January - 15 May, 16 May - 15 August, 16 August - 31 December. These three "seasons" were selected because tornado occurrence increases rapidly during May and decreases rapidly during August. Thus, the 16 May - 15 August interval was chosen to characterize the period with greatest tornado risk. It can be seen from Figure 6 that there are subtle but substantial shifts in tornado density between these seasons.

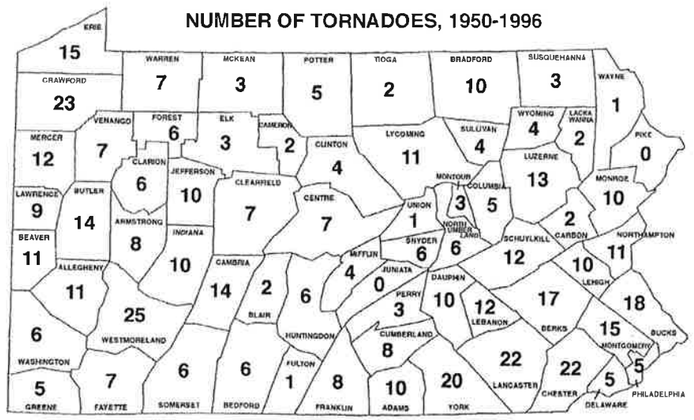

FIGURE 3. Number of tornadoes observed in each county of Pennsylvania during the period 1950-1996.

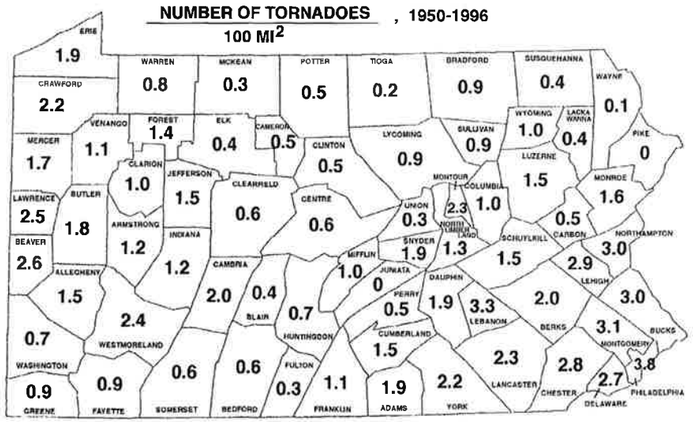

FIGURE 4. Number of tornadoes per 100 mi^2, by county, during the period 1950-1996. The statewide average is 1.1.

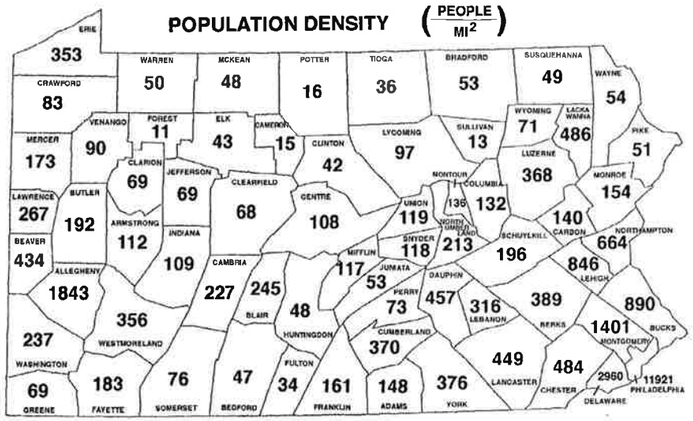

FIGURE 5. Population density, by county (1990 census).

During January through early May (Figure 6a), the greatest tornado density is centered near York County, east of the mountains in south-central Pennsylvania, and the highest density is about 25% of the peak during May-August. There is virtually no risk of tornadoes in the hilly regions of northwestern Pennsylvania.

During the prime tornado season, Figure 6b, maximum tornado density shifts to western and southeastern Pennsylvania. The highest density is in Philadelphia County. Thus, there has been about a 150 km eastward shift in the region of maximum density between Figures 6a and 6b.

During the August-December period, Figure 6c, tornado density begins to shift westward toward that of Figure 6a. The tornado density in Philadelphia County drops to zero, and the maximum density shifts to Lebanon County, about 37% of the peak density in Figure 6b. While some of the seasonal shifts may be attributed to small sample sizes, it is tempting to speculate that the tornado maximum immediately east of the mountains during the "cool" seasons may be related to the terrain of Pennsylvania. At these times of year, might stronger west winds aloft be forcing a lee trough at low levels whose convergence helps to trigger strong thunderstorms?

RISK, TORNADO INTENSITY, AND PERIOD OF RECORD

The pattern of occurrence in Figure 4, derived from the period 1950-1996, generally resembles the analysis given in Dailey (1970) for the period 1953-1969.

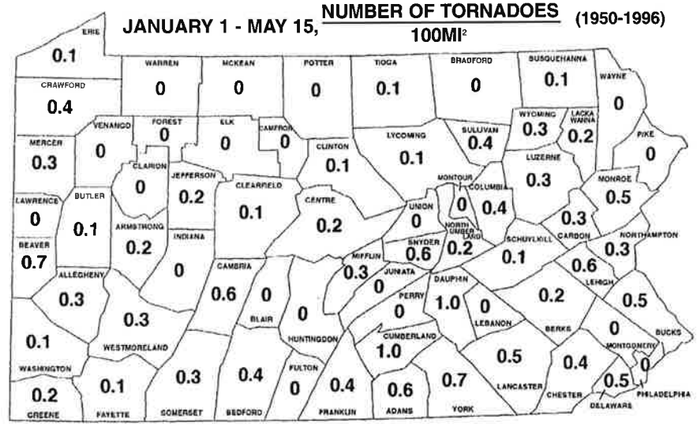

FIGURE 6a.

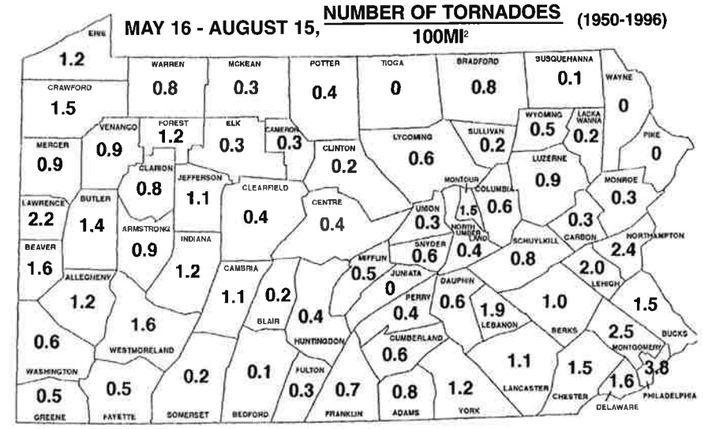

FIGURE 6b.

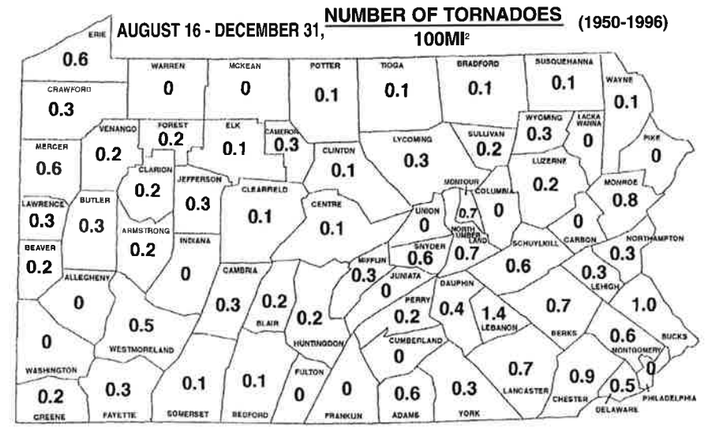

FIGURE 6c.

FIGURE 6. Number of tornadoes per unit area, by county, during the period 1950-1996, for various "seasons": (a) January 1 to May 15, (b) May 16 to August 15, and (c) August 16 to December 31. The statewide averages are 0.2, 0.7, and 0.2, respectively.

However, from the standpoint of risk assessment, merely increasing the period of record is not the entire answer because all tornadoes are not equally intense. Most are barely able to unroof a home, and home-demolishing twisters are exceedingly rare. A more complete risk assessment should take this intensity variability into account. At the time when Dailey (1970) constructed his climatology, there had been no organized attempt to categorize tornado intensity quantitatively. Fujita's introduction in the early 1970s of a scale of tornado damage and wind speed makes feasible an analysis of risk that incorporates variations in intensity.

In the remainder of our assessments of tornado risk, we consider only those tornadoes of F2 or greater intensity. We make this choice for several reasons. These stronger tornadoes are the most damaging, so they tend to be better documented than weaker F0 and F1 tornadoes. Furthermore, of the 77 tornado-related fatalities in Pennsylvania since 1950, only one was caused by a tornado rated less than F2, while approximately 93% of the 1077 tornado-related injuries in Pennsylvania since 1950 resulted from tornadoes rated F2 or higher.

Figure 7 maps the significant-tornado density by county, similar to Figure 4, except only tornadoes rated F2 or higher are considered (i.e., those having peak winds of more than 50 m/s). The general pattern continues to show maximum density in southeastern and western Pennsylvania, although the specific counties of maximum density are now Lebanon, Lancaster, York, Erie, and Crawford.

Two additional adjustments are incorporated into the tornado risk statistic. First, we note that although gradations in damage exist within a tornado's path, the assignment of an F-scale to a tornado is based on the *maximum* damage along the path. As an example, a detailed mapping of an F3 tornado that struck near Tampa, FL, on October 3, 1992, is shown in Figure 8. Note the small fraction of the tornado damage swath that actually sustained F3 and F2 damage. Thus, most of the damage along the path of a tornado is F0 and F1 damage. To accurately compute the true risk of F2 or stronger tornado wind speeds, it is necessary to know the fractions of the total damage path of F2, F3, F4, and F5 tornadoes actually affected by F2 or stronger wind speeds.

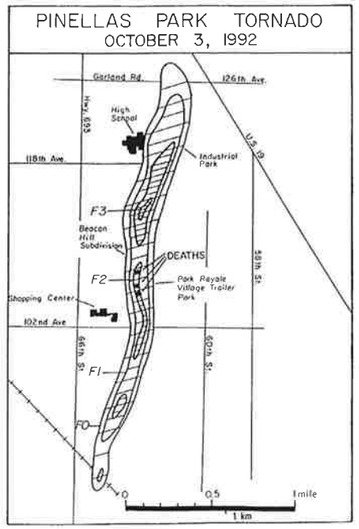

FIGURE 8. A mapping of Fujita-Scale variations along the path of a tornado near Tampa, FL on October 3, 1992. Although this tornado is rated F3, note the small fraction of the total area of the tornado path that actually experienced F3 damage. Mapped by Brian E. Smith of the Storm Prediction Center (NOAA, 1992).

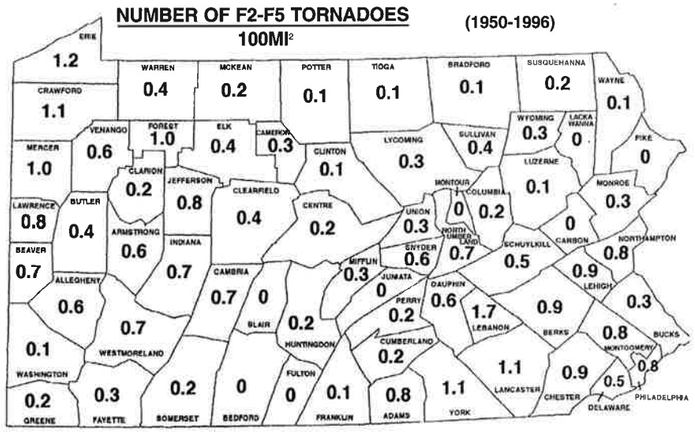

FIGURE 7. Number of tornadoes rated F2 or higher per 100 mi², by county, during the period 1950-1996. The statewide average is 0.3.

To estimate these fractions, many detailed mappings of tornadoes are necessary, but few such surveys exist for Pennsylvania tornadoes. Detailed mappings are available for the 147 "Superoutbreak" tornadoes that struck from Michigan to Alabama on April 3-4, 1974, compiled by Theodore Fujita and his colleagues. From these mappings, they estimated the fraction of the area of a tornado of F-scale N that showed damage characteristic of F-scale N, N-1, etc. (Abbey and Fujita, 1975). These DAPPL (Damage Area Per Path Length) values are given in Table 3. The four fractions in the highlighted row are the values used to incorporate F-scale gradations into our risk assessment; these values (0.117, 0.105, 0.087, and 0.050) are estimates of the fractions of the path of an F5, F4, F3, and F2 tornado, respectively, that would be expected to experience damage of at least F2 intensity.

To calculate a risk statistic for a particular county that takes into account F-scale gradations, the total areas of the paths of all F2, F3, F4, and F5 tornadoes that have affected that county within a specified time period must be known (call these areas A_2, A_3, A_4, and A_5, respectively). Then, if A is the total area of the county, the fraction of the total county area that has experienced tornadic winds/damage of at least F2 intensity during the specified time period is estimated as

$$\frac{A_2 * 0.050 + A_3 * 0.087 + A_4 * 0.105 + A_5 * 0.117}{A}$$

This fraction can be interpreted as the probability that any point in the county would experience F2 or higher tornadic winds/damage over a time period as long as covered by the data set used to compute the value.

In principle, this DAPPL approach to risk assessment is superior to other approaches. In practice, however, several aspects of implementing this refinement must be discussed. Recall that the fractions in Table 3 were determined from a tornado outbreak in the Midwest and not a collection of Pennsylvania tornadoes. Although it is reasonable to assume that these values would be representative, at least approximately, of strong Pennsylvania tornadoes, Schaefer et al. (1986) concluded that these fractions are not necessarily invariant from one tornado outbreak to another.

TABLE 3. Fraction of the area of the path of a tornado of F-scale N that sustained damage of at least F-scale N that sustained damage of at least F-scale N, N-1, N-2, etc (from mappings of 3 April 1974 Superoutbreak tornadoes).

		F-SCALE OF TORNADO					
		5	4	3	2	1	0
F-SCALE OF DAMAGE	0	1.	1.	1.	1.	1.	1.
	1	.322	.311	.287	.216	.129	0
	2	**.117**	**.105**	**.087**	**.050**	**0**	**0**
	3	.037	.028	.019	0	0	0
	4	.009	.006	0	0	0	0
	5	.002	0	0	0	0	0

Approximately 150 tornadoes rated F2 or higher have been reported in Pennsylvania from 1950 to 1996 (18 were F3, 8 were F4, and 1 was F5). Path length and/or path width is not known for about 15% of these twisters (primarily F2 tornadoes). In these cases, the median path length and/or median path width for Pennsylvania tornadoes of that F-scale was used. In actuality, both mean and median values were tested as proxies, with little impact on the results. Adopting the philosophy that missing values were probably indicative of less-extensive tornado paths, we used median values, which were slightly smaller than mean values.

Frequently, discrepancies existed among databases: these discrepancies involved not only path length and width, but also F-scale rating (F1 vs. F2 was especially troublesome) and whether the tornado had a continuous or a skipping path. Most F-scale discrepancies were decided using a "best-two-out-of-three" rule: when all three primary databases provided an F-scale, with two sources in agreement, that common F-scale was used. When only two sources of F-scale were provided, all available information about the tornado was carefully weighed to draw a reasonable conclusion. A similar procedure was used for path length, path width, and continuous/skipping discrepancies. If the tornado was determined to have skipped (and no additional information was given), the reported path length was multiplied by 0.25 to take into account the intermittent path.

The second adjustment that we incorporate into our tornado risk statistic recognizes that although the record of tornadoes in the first half of the 20th century is much less complete than during the latter half, many of the more damaging pre-1950 tornadoes are well documented. Although including the pre-1950 period in a risk assessment would, in general, deflate risk values, information about pre-1950 tornadoes should not be ignored if the risk assessment for a given county increases with its inclusion. As an example, consider a county with no observed F2 or higher tornadoes during the period 1950-1996 but an F3 in 1944. This county would, in reality, have non-zero risk, but the risk would be estimated as zero if only the period 1950-1996 was used. Thus, for each county, we compute two values of risk: one using the 1950-1996 period and one using the 1916-1996 period. The larger of the two values is used as our DAPPL hybrid risk statistic for that county.

The annual risk of experiencing tornadic wind speeds in excess of 50 m/s (F2 or stronger tornado damage), using the hybrid DAPPL approach, is shown in Figure 9 for each Pennsylvania county. Asterisks indicate counties for which the longer period of record (1916-1996) was used. The values represent the probability (units of 10^{-4}), based on the historical record, that a given point in the county would experience F2 or higher tornadic winds in a 100-year period.

As can be seen in Figure 9, the risk of being struck by F2 or greater tornadic winds, in excess of 50 m/s, ranges

from zero to more than 60 in units of 10^{-4} per hundred years in Pennsylvania. Thus, the maximum risk value, in Forest County, is about $6x10^{-5}$ per year. Seventeen counties have risk in excess of 10 units, i.e., in excess of $1x10^{-5}$ per year, and the statewide risk is slightly lower than that, $7.4x10^{-6}$. In an absolute sense, the risk in Pennsylvania is about 5-10% of the risk in the Midwest (about $1x10^{-4}$ to $6x10^{-4}$ per year; Schaefer et al, 1986).

Immediately evident in Figure 9 is the dominance of the May 31, 1985 outbreak on F2 tornado risk. The corridor of highest values stretches from Mercer, Crawford, and Erie Counties in northwestern Pennsylvania eastward to Clinton, Lycoming, and Union Counties, parallel to the core area of destruction of the 16 F2-F5 tornadoes that touched down that day. Sparsely populated Forest County, which was hit by two F4 and one F2 tornado on May 31, 1985, has the highest risk. Of the seventeen counties with a DAPPL value greater than $10x10^{-4}$, only two, Westmoreland and Lebanon, were not affected by a tornado on May 31, 1985. There is no evidence of a comparable outbreak in earlier tornado data dating to 1875 and before. Thus, true risk values in affected counties could be only ~40% or less (i.e., using period of 122 years rather than 47) of the values shown in Figure 9.

To illustrate the extent to which one day dominates this risk statistic, we recomputed the DAPPL values without including the May 31, 1985 tornadoes. These new risk values are shown in Figure 10. The statewide

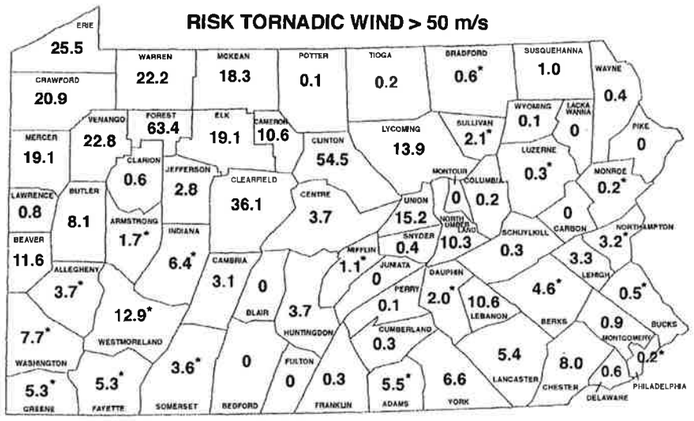

FIGURE 9. Annual risk of tornadic wind speeds of 50 m/s or greater, using the hybrid DAPPL method, for each county of Pennsylvania. The values represent the probability (units of 10^{-4} per 100 yr), based on the historical record, that a given point in the county would experience F2 or higher tornadic winds in a 100-year period. Asterisks indicate values that were computed using the longer 1916-1996 period. The statewide average is 7.4.

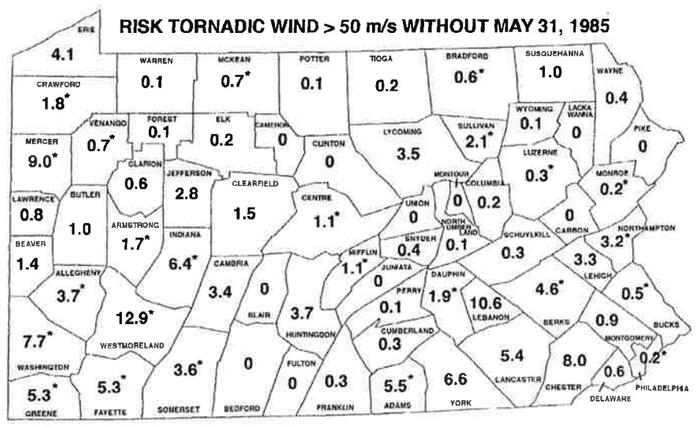

FIGURE 10. Annual risk of experiencing F2 (50 m/s) or stronger wind speeds, as in Figure 9, but computed without including the tornadoes of May 31, 1985. The statewide average is 1.5.

average drops from 7.4 to 1.5 units. With this approach, the southwestern portion of Pennsylvania (Greene, Washington, Westmoreland, Fayette and Indiana Counties) and the Piedmont Plateau (Adams, York, Lancaster, Lebanon, Chester, and Berks Counties) are regional hot spots. In large part, the maximum in the southwestern part of the state results from the June 23, 1944 outbreak (see Table 2), further demonstrating the sensitivity of Pennsylvania tornado statistics to just a few events. Thus, there is little reason to feel particularly safe in a county with a relatively low present-day DAPPL - it only takes one tornado outbreak to rearrange the map.

DISCUSSION

We have presented an updated tornado climatology of Pennsylvania, combining data from several sources for the period 1916-1996. Although the tornado record is much less complete in the first half of the 20th century, we recognize that valuable information from the pre-1950 period should not be ignored, particularly if it increases the risk assessment in a particular region. Thus, we have presented a hybrid risk statistic, which typically uses the more recent 1950-1996 period in order to reflect more comprehensive reporting of tornado occurrence, but includes the 1916-1949 period for counties where use of a longer period of record results in an increased tornado risk. Nevertheless, the overall risk will tend to be somewhat underestimated by this approach because of systematic underreporting of tornado frequency, particularly in low-population-density regions. However, the impact of the 31 May 1985 tornado outbreak leads to a probable overestimate in some counties.

The hybrid risk values are rendered somewhat unstable by the overall rarity of strong tornadoes and the comparatively short period of record. The calculation of the DAPPL statistic clearly illustrates that rare event statistics can be heavily skewed by one large event; in the case of Pennsylvania tornadoes, the event is the May 31, 1985 outbreak. The small sample size of Pennsylvania tornadoes at the F3, F4, and F5 levels dictates that just a few days will dominate such statistics. Such dominance adds credence to the conclusion that because of the limitations of the available data on Pennsylvania tornadoes, all empirical tornado risk assessments should be viewed with caution, particularly when focusing on increasingly local areas. Abbey and Fujita (1979) discussed use of a spatial weighting function to assess local risk values as a way of reducing these statistical anomalies.

Given the rare nature of violent tornadoes in Pennsylvania and the relatively short period of imperfect record, a relative minimum in any tornado statistic in a particular county should not breed complacency among its residents with respect to safety precautions. One wide, long-path F4 tornado next summer could, conceivably, elevate a county to the highest risk in the Commonwealth. With this in mind, a multi-county (or full-state) averaging approach is probably the best way to view tornado risk assessment, particularly in states such as Pennsylvania that experience few violent tornadoes. Statewide average risk values are included in the captions of the figures in this paper.

In building the DAPPL risk assessment, we acknowledged several sources of uncertainty. These uncertainties are partly due to the inadequate documentation of areal extent and wind speed within tornadoes on a routine basis. The unfortunate fact is that a tremendous amount of tornado statistical information is based upon newspaper accounts or very limited surveys that did not culminate in precise mappings of path length, width, or wind speed along the path. There is clearly a need for improved reporting and well-documented surveys that would further reduce some of these uncertainties. In the ideal case, a mapping for each tornado indicating the shape of its path, the width at all points, and the wind speeds (damage intensities) at various locations along the path, would be produced. Surveying defines the areal boundaries of the tornado rather than just its starting and ending points. Such information is essential in order to more accurately compute the DAPPL risk statistic.

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APPENDIX 1
COOPERATIVE PROJECT TO STUDY PENNSYLVANIA SEVERE WEATHER

A special study was conducted in Central Pennsylvania beginning in May, 1996, to better document the occurrence of damage from severe thunderstorm winds and tornadoes and to determine where the damage occurred in relation to Doppler radar signatures of the storms. Participants from the Pennsylvania State University Department of Meteorology and the National Weather Service Office in State College, PA, drove more than 10,000 miles to examine damage following 12 days with severe weather. Additional surveys were conducted from aircraft. These surveys greatly augmented information that would otherwise have been gleaned primarily from telephone calls and newspaper accounts. The damage surveys allowed for accurate assessments of path length, path width, and F-scale for all 20 tornadoes in Central PA in 1996. Other NWS offices surveyed some of the remaining 8 tornadoes elsewhere in the Commonwealth.

As a consequence of the intensive surveys, Widenor (1997) indicates that at least one tornado path would have been classified as non-tornadic damage and three severe thunderstorm damage swaths were found that would otherwise have been undiscovered. On approximately a dozen other instances the nature of the storm was somewhat in question prior to the survey; damage was ruled tornadic on 8 occasions and non-tornadic on 4. In addition, two weak tornado paths were located in remote areas, but could not be dated with sufficient certainty to be listed as official tornado occurrences. None of the previously undiscovered tornadoes or questionable damage swaths were stronger than F1. These intensive surveys give credence to the hypothesis that the frequency of weak tornadoes may still be somewhat underestimated, though the error may no longer be large.

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RESEARCH NOTE

ASSESSING HISTORICAL WETLAND SEED BANKS USING Cs^{137}: A PILOT STUDY[1]

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ABSTRACT

Wetlands are often depositional environments and thus, are susceptible to stress resulting from disturbances occurring in the landscape. Assessing historic succession of plant communities is one way to examine the response of a wetland to these disturbances. A seed bank in a depositional environment can be an historic record of how a plant community has changed over time. Dating and characterizing the seed bank at different depths can provide a temporal analysis of community structure. This pilot study used Cesium 137 (Cs^{137}) as a radioactive marker to date wetland soils (and, therefore, the seed bank) of four wetlands in central Pennsylvania. Though Cs^{137} data for most sites considered were inconclusive, the project defined parameters which will make future Cs^{137} studies more definitive. Although we were unable to explicitly date soil depth layers, we determined that the seed bank data differed by site and depth (time). The results of this project show that seed bank analyses using Cs137 are feasible, and with some simple improvements defined by this study, accuracy can be improved to make this type of analysis a valuable tool for successional studies.
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INTRODUCTION

Wetland seed bank studies explore a variety of ecological questions. In 1859 Darwin used the presence of a pond seed bank to support his thesis for the dispersal of wetland species by birds. More recent literature has attempted to provide vegetation history by examining seed bank communities at different depths (van der Valk and Davis 1979, Nicholson and Keddy 1983, Leck and Simpson 1987). Others (van der Valk 1978, 1979, 1981, Keddy and Reznicek 1986, ter Heerdt and Drost 1994) have extensively researched the wetland seed bank's successional role in response to water level fluctuations. Our pilot study determines wetland seed bank composition and attempts to supplement that information with radioactive dating of the soil to give insight about vegetation history and succession.

Since 1993, the Penn State Cooperative Wetlands Center (CWC) has been assessing more than 50 reference wetlands in Pennsylvania. Reference wetlands are "...sites...that are chosen...to encompass the known variation of a group or class of wetlands..." (Brinson and Rheinhardt 1996). Reference wetlands provide benchmarks for monitored parameters such as soil, sedimentation rates, vegetation, hydrology and wildlife habitat. The standards can then be used to improve design standards for wetland mitigation projects (Brooks et al. 1996). One way to categorize reference wetlands and their associated functions is by their hydrogeomorphology (HGM) (Brinson 1993, Smith et al. 1995). Wetlands have been shown to have different functions and responses to stress based on their HGM subclass and disturbance regime (Bishel-Machung et al. 1996, Babb et al. 1997).

Wetlands are often depositional environments and, thus, are susceptible to stress resulting from disturbances occurring in the landscape (e.g. increased sedimentation from agriculture). Assessing historic succession of plant communities is one way to examine the response of a wetland to these disturbances.

It has been argued that a seed bank in a depositional environment is an historic record of how a community has changed over time (van der Valk and Davis 1979). Dating and characterizing the seed bank at different depths can provide an historic profile of wetland community structure. Although studies have examined the seed bank profile to provide information about vegetational history (van der Valk and Davis 1979, Nicholson and Keddy 1983, Gunther et al. 1984, Leck and Simpson 1987), no attempt has been made to date vegetational communities.

Cesium^{137} (Cs^{137}) is widely used as a radioactive date marker in soils as it is strongly adsorbed on clay and organic particles and is nonexchangeable (Davis 1963, Ritchie and McHenry 1990). It is produced during nuclear fission, so its presence in the environment is due strictly to nuclear testing (Walling et al. 1986). Radioactive testing started in the US in 1952 with measurable amounts of fallout Cs^{137} beginning in 1954 (Wise 1980), and was banned in 1964 after peak testing activity in 1963 (Pennington et al. 1973). In the early 1970's, several independent reports concluded that the vertical distribution of fallout Cs^{137} in sediments coincides with the time distribution of radioactive fallout Cs^{137} deposition from the atmosphere and thus can be used to infer a geochronology for sediment profiles (Krishnaswami et al. 1971, Ravera and Premazzi 1971, Robins and Edgington 1972, McHenry 1973, Pennington et al. 1973, Ritchie et al. 1973). This means that sediments deposited before and after atomic testing contain no radioactive fallout and negligible concentrations of Cs^{137}. Sediments deposited during the testing period, however, will show high concentrations of Cs^{137}. If a peak in Cs^{137} concentration could be identified, it would be possible to identify that the soil and the accompanying seed bank were deposited during the period of 1954-1963. This would allow us to date three separate seed bank communities.

The objectives of this study were:

1) to conduct a pilot study to assess the possibility of using Cs^{137} data to date soils and seed bank communities in wetlands within the central Appalachians; and

2) to assess the wetland seed bank at different depths in order to evaluate possible historic plant communities.

MATERIALS AND METHODS

Study Sites

We sampled the seed bank from four wetlands in central Pennsylvania (Figure 1). A summary of each study site is given in Table 1. The Bald Eagle Palustrine Emergent (PEM) site is categorized as a slope wetland (HGM subclass). Slope wetlands can be fed by groundwater or overland flow, and are located on a topographic gradient. It is also necessary to note that evidence suggests the Bald Eagle PEM site has been farmed and plowed in the last 30 years (Brooks et al. 1996).

Both the McCall Dam and Sand Spring sites are riparian depressions (HGM subclass). Riparian depressions are associated with streams, but their water source is groundwater, so their hydrology is disconnected from nearby streams. These sites have low rates of mineral sedimentation, but may have high organic deposition (Wardrop 1997).

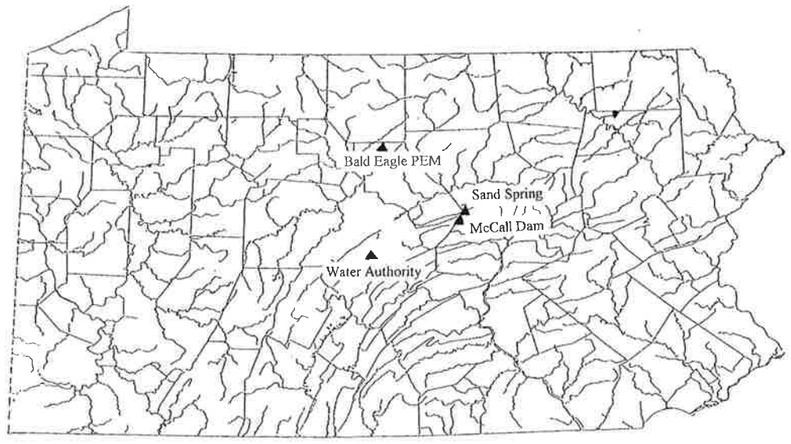

FIGURE 1. Location of the four reference wetland study sites in central Pennsylvania.

The Water Authority site is a headwater floodplain wetland. Wetlands from this HGM subclass have hydrology based on overland flow and overbank flooding associated with the stream along which they are located. The Water Authority wetland had a high rate of sedimentation that was primarily a result of agricultural activity upstream (Brooks et al. 1996).

Cesium 137

Cs^{137} soil samples were analyzed according to standard procedures at the Penn State Low Level Radiation Monitoring Lab. To try and locate maximum and minimum Cs^{137} concentrations, soil samples were assessed at 0-2.5, 2.5-5, and 5-10 cm depths for three sites. No data existed on expected depth to Cs^{137} maxima. Therefore, these depths were arbitrarily chosen so as to encompass probable depths to Cs^{137} deposition. Due to higher known sedimentation rates from agricultural activity, measurements were also taken at 10-15 cm for the Water Authority site.

Seed Bank

Seed bank samples were analyzed following Cole (1991). Samples were obtained from the four wetland sites by digging soil cores, approximately 196cm^2 in surface area, to a depth of 20 cm in 3-5 random locations during December 1994. These were held in cold storage (4°C) until February 1995. Samples were dried intact for 24 h and surface organic matter was removed. To approximate depths representing the pre-1954, 1954-1963, and post-1963 communities, slices of 0-5, 5-10, and 10-15 cm depths were separated in the lab. These sub-samples were sifted to remove roots, tubers, and organic matter.

Two methods were used to assess seed bank content at each level: seedling emergence and the seed-flotation method (Poiani and Johnson 1988). For the flotation method, each sample was sifted, and a 40 ml sub-sample of soil was mixed with 200 ml of a 60% sugar solution. Organic material (including seeds) floated to the top and soil dropped to the bottom. The organic material was decanted onto filter papers and then sorted under a 40X stereomicroscope. Seeds were extracted from the filter paper and identified using specimens from the Penn State University Herbarium and seed identification manuals (Martin 1954, Cunningham 1957, Mason 1957, Martin 1961, Montgomery 1977, Davis 1993). It was impossible to identify some species, but unknown species differed from other unknown species, so differing unknowns were labeled with letters in Table 2. Similarly, it was not possible to determine some *Carex* species, so these unknown species of *Carex* are lettered in Table 2.

For the seedling emergence method, samples were grown in a glasshouse heated at 20°C for six months. To promote the germination of all wetland species, samples were split into two different germination regimes: emergent and submergent. Sub-samples of a 200 ml volume were mixed with 200 ml of peat and 25 ml of lime. Emergent samples were over-head watered daily, and

TABLE 1. Description of wetland study sites in central Pennsylvania (Brooks et al., 1996)

	Bald Eagle PEM	McCall Dam	Sand Springs	Water Authority
HGM subclass	Slope	Riparian Depression	Riparian Depression	Headwater Floodplain
system	low to moderate energy	low energy headwater	low energy headwater	high energy
dominant herbaceous species	*Dipsacus sylvestris* *Solidago sp.* *Solidago uliginosa* *Senecio aureus* *Fragaria virginiana*	*Carex emoryi* *Carex retroflexa* *Rubus hispidus* *Triadenum virginicum*	*Brachelytrum erectum* *Coptis groenlandica* *Glyceria sp.* *Thelypteris noveboracensis* *Carex folliculata*	*Phalaris arundinacea* *Impatiens capensis* *Cirsium sp.* *Solidago rugosa*
dominant woody species	*Cornus amomum* *Elaeagnus umbellata* *Cornus racemosa* *Ulmus rubra* *Cornus sp.*	*Alnus incana* *Pinus strobus* *Acer rubrum* *Picea sp.* *Quercus rubra*	*Hamamelis virginiana* *Nyssa sylvatica* *Quercus rubra* *Acer rubrum* *Betula allegheniensis*	*Cornus sp.* *Acer negundo* *Lonicera morrowii* *Viburnum sp.* *Rosa multiflora*
soil	Brinkerton silt loam	Philo and Atkins very stony loam	Buchanan very stony loam	Melvin silt loam
organic matter	8%	16%	36%	6%
surrounding land use	agriculture and forest with pockets of development	eastern deciduous forest	eastern deciduous forest	agricultural lands, with some forest fragments
disturbance regime	moderate	pristine	pristine	severe
wetland area (ac)	2.0	0.2	0.2	0.3
median water level (cm)	-34.0	-4.5	-17.5	-120.0

submergent samples were kept under 1-2 cm of water. Pre-flowering individuals were identified using investigator's expertise, or when flowering, seedlings were identified using Newcomb (1977). It was not possible to identify some species that did not flower over the sixth month period.

To determine if number of seeds and number of species were dependent on the depth of the sample, chi-square test with P<.05 was performed for each layer of each site, both for number of seeds and number of species (Zar 1984). Community similarity was tested with the Jaccard Coefficient of Community, with a score of 1.0 being similar, and 0.1 being dissimilar (Ricklefs 1990).

TABLE 2. Soil seed bank composition, based on the seed-flotation method, at 0-5cm, 5-10cm, and 10-15cm for the four reference wetlands. Numbers of individuals are listed in columns to the right. Numbered "Unknown" species refer to species that are known to differ from other unknown species, but cannot be identified. Lettered *Carex*es are species that are known to differ from other species of *Carex,* but cannot be identified.

Bald Eagle PEM: 5cm		***Water Authority: 5cm***		***McCall Dam: 5cm***		***Sand Spring: 5cm***	
Carex scoparia	27	*Carex vulpinoidea*	5	*Glyceria striata*	27	*Carex crinita*	18
Unknown P	25	*Verbena sp.*	4	*Carex stipata*	18	*Betula sp.*	15
Carex vulpinoidea	23	*Carex stipata*	4	*Fraxinus nigra*	11	*Carex* B	12
Carex B	23	*Dipsacus sylvestris*	3	*Viola sp.*	6	*Brassica sp.*	6
Lycopus sp.	13	Unknown Grass	3	*Lycopus americanus*	5	*Carex* A	6
Verbena hastata	12	*Panicum sp.*	3	*Carex* A	4	*Betula sp.*	2
Panicum sp.	9	Unknown F	3	*Carex lurida*	3	*Carex stipata*	2
Carex G	8	Unknown H	2	*Carex* D	3	*Viola sp.*	2
Carex stipata	6	*Urtica dioica*	2	*Carex folliculata*	2	Unknown K	2
Lycopus americanus	5	13 others at (1) each	13	*Panicum latifolium*	2	3 others at (1) each	3
Dipsacus sylvestris	3			6 others at (1) each	6		
Urtica dioica	3						
Unknown O	3						
Viola sp.	3						
Daucus carota	2						
Oxalis stricta	2						
Unknown K	2						
Allium sp.	2						
Unknown M	2						
9 others at (1) each	9						
29 species	182	22 species	42	16 species	87	12 species	68
Bald Eagle PEM: 10cm		***Water Authority: 10cm***		***McCall Dam: 10cm***		***Sand Spring: 10cm***	
Carex vulpinoidea	14	Unknown A	14	*Carex stipata*	29	*Carex* B	10
Lycopus sp.	14	*Carex vulpinoidea*	6	*Glyceria striata*	20	*Carex crinita*	6
Carex B	17	Unknown F	5	*Carex* A	11	*Carex lurida*	4
Viola sp.	4	*Rubus sp.*	3	*Viola sp.*	6	*Carex stipata*	4
Betula sp.	3	*Verbena sp.*	3	*Lycopus americanus*	4	*Kalmia sp.*	3
Carex scoparia	3	*Carex stipata*	3	*Carex* E	3	*Rubus sp.*	3
Carex C	2	*Barbarea vulgaris*	2	Unknown A	2	*Brassica sp.*	2
Unknown O	2	10 others at (1) each	10	*Carex lurida*	2	*Juncus sp.*	2
12 others at (1) each	12			*Carex* D	2	*Lycopus sp.*	1
				Fraxinus nigra	2	*Lythrum salicaria*	1
				4 others at (1) each	4	*Polygonum sp.*	1
						7 others at (1) each	7
20 species	71	17 species	46	14 species	85	15 species	44
Bald Eagle PEM: 15cm		***Water Authority: 15cm***		***McCall Dam: 15cm***		***Sand Spring: 15cm***	
Lycopus sp.	6	*Carex vulpinoidea*	9	*Glyceria striata*	22	Unknown A	28
Carex scoparia	5	*Carex* C	8	*Carex stipata*	16	Unknown F	10
Malva moschata	2	*Barbarea vulgaris*	4	*Carex* A	6	*Verbena sp.*	6
Carex B	2	Unknown A	2	*Carex* E	6	*Carex stipata*	6
Viola sp.	2	Unknown F	2	*Lycopus americanus*	5	*Sambucus canadensis*	2
5 others at (1) each	5	9 others at (1) each	9	*Fraxinus nigra*	3	*Urtica dioica*	2
				Carex F	2	*Carex* C	2
				Viola sp.	2	*Betula sp.*	3
				2 others at (1) each	2		
10 species	22	15 species	34	10 species	64	9 species	59

As a basis for comparison, seed bank studies typically express density as seeds per m^2. As such, densities for each layer were estimated from the flotation data and listed in Table 3.

RESULTS AND DISCUSSION

Cesium 137

One of our objectives was to identify minima and maxima in Cs^{137} concentrations in order to label the Cs^{137} peak and the 1954-1963 community. As shown in Figure 2, a Cs^{137} peak was identifiable only at McCall Dam. This allowed us to date the communities occurring at this site. The lack of a defined peak in the Water Authority data was likely due to our underestimation of the sedimentation rate, thus we believe we did not sample deep enough. The lack of a defined peak in the Bald Eagle PEM data was probably because Cs^{137} levels in the soil layers were mixed by plowing, which is a major cause of redistribution of Cs^{137} in soils (Ritchie and McHenry 1990), or as noted earlier, perhaps we did not sample deep enough. It has been shown that Cs^{137} in plowed soils shows a uniform distribution through the plow layer (Cline and Rickard 1972, Ritchie and McHenry 1973), so it should still be possible to date the soil if we sampled in finer increments.

Although defined Cs^{137} peaks were not present at all sites studied, we assumed increasing age with depth across sites. Future studies should sample 2cm increments of soil to make Cs^{137} distribution patterns more obvious (J.C. Ritchie, USDA ARS Hydrology Laboratory, pers. comm.).

Seed Bank

Seedling emergence studies provided sparse data (Table 4) that differed significantly from the flotation data. The lack of correlation of the flotation study and seedling emergence is not uncommon (Roberts 1981). Seedling emergence studies attempt to quantify the readily germinable fraction of the seed bank, however this method underestimates the seed bank because specific germination requirements vary with species, and it is not likely that all will be met by a single prescribed germination treatment (Gross 1990). Flotation estimates both the viable and non-viable seed bank, but small seeds may be underestimated with this method (Roberts 1981). One improvement in the seedling emergence method might include increasing germination through the use of horticultural growth chambers and fluctuating greenhouse temperatures (R. Berghage, Penn State University, pers. comm.). Also, future seedling emergence studies should include transporting plants to pots until they flower and can be identified.

Because more species and total seeds were found in the flotation study, our conclusions relied primarily upon those results. The data (Table 2) show that wetland seed bank communities differ by site and by depth (date), and consistent with other studies (Leck 1989) there is a general decline in number of seeds and number of species with depth. Exceptions to this decline might be

TABLE 3. Densities for all sites based on flotation data are expressed for each layer as seeds/m^2.

	seeds/m^2			
Depth (cm)	**Bald Eagle PEM**	**McCall Dam**	**Sand Spring**	**Water Authority**
0-5	226,408	135,596	84,592	52,248
5-10	297,316	11,196	51,004	57,224
10-15	27,368	79,616	19,904	42,296

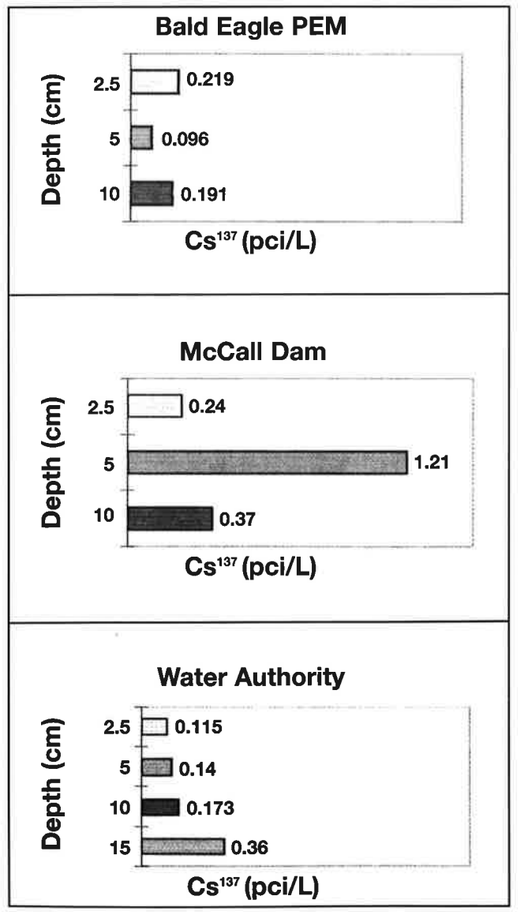

FIGURE 2. Concentrations of Cesium 137 in pci/L at 0-2.5, 2.5-5 cm, 5-10 cm, and 10-15 cm, for three reference wetlands.

due to sample contamination during handling and transport of seed bank samples. Species area curves (Figure 3) suggest that 5 samples is not enough to adequately sample species richness, and future studies should use more samples per site.

Table 2 lists species according to dominance. At the Bald Eagle PEM site, *Carex scoparia, Carex vulpinoidea, Carex B,* and *Lycopus sp.* dominated 0-5 cm, 5-10 cm, and 10-15 cm samples. At Water Authority, no species clearly dominated at any level. At McCall Dam, *Glyceria striata* and *Carex stipata* dominated throughout all three levels. Sand Spring has a dominant community of *Carex crinita, Betula sp*, and *Carex B* in the 0-5 cm layer, but the species composition changes in the 5-10 cm layer, and in the 10-15 cm layer an unknown species that is not present in the 0-5 and 5-10 cm layers clearly dominates.

More species were found in the uppermost layer for Bald Eagle PEM, Sand Spring and Water Authority (Figure 4), but this difference was statistically significant only for the Bald Eagle PEM site ($X^2_{\text{Bald Eagle PEM}} = 15.256$) (Zar 1984). All other layers at all other sites had chi-square values that showed that species number is independent of depth ($X^2_{\text{Water Authority}} = 1.1046$, $X^2_{\text{McCall}} = 1.8568$, $X^2_{\text{Sand Spring}} = 3.1057$).

The abundance of seeds in each layer is shown in Figure 5. McCall Dam and Sand Spring sites show that there are generally more seeds in the upper layers, and chi-square values indicated that seed number varied significantly with depth for these two sites ($X^2_{\text{critical}} = 5.991$, $X^2_{\text{McCall Dam}} = 11.64$, $X^2_{\text{Sand Spring}} = 32.46$). Like many other seed bank studies (Leck and Simpson 1987), we found significantly more seeds towards the surface layer. The variation in this trend occurs at Bald Eagle PEM, where seed number was dependent on depth ($X^2_{\text{Bald Eagle PEM}} = 171.41$), but more seeds were found in the 5-10 cm layer, and this variation may be attributed to plowing. At Water Authority, seed number was found to be independent of depth ($X^2_{\text{Water Authority}} = 1.84$).

We used the Jaccard Coefficient of Community (Ricklefs 1990) to determine community similarity among sites and depths (Table 5). No samples represented similar communities (i.e., no samples had a Jaccard Coefficient of 0.5 or higher), even those within the same wetland at different depths. These data are unusual relative to two of the reference wetlands. Sand Spring and McCall Dam are both in the same hydrogeomorphic subclass (riparian depression) and in the same watershed (Brooks et al. 1996), so we expected that historically they may have been affected similarly, generating similar seed bank communities. Based on our results, these two wetlands are, and were once, very different.

Historical insights given by these differing seed bank communities are of value in reference wetlands vegetation because they reiterate markers of possible change in watersheds. These results can be used to provide benchmarks for monitoring disturbance-related shifts in vegetation (Brooks et al. 1996).

TABLE 4. Seeds germinated in the greenhouse at 0-5cm, 5-10 cm, and 10-15 cm for four reference wetlands. "Unknown" species refer to species that are known to differ from other identified species, but cannot be identified.

Bald Eagle PEM: 5cm		**Water Authority: 5cm**		**McCall Dam: 5cm**		**Sand Spring: 5cm**	
Brassica sp.	1	*Carex stipata*	2	*Carex stipata*	4	*Carex stipata*	2
Carex stipata	6	*Barbarea vulgaris*	1	*Digitaria sp.*	3		
Barbarea vulgaris	6	Unknown grass	21	Unknown grass	2		
Ranunculis acris	4	*Urtica diocia*	7	*Scirpus sp.*	1		
Urtica diocia	1	*Scirpus sp.*	1	*Viola sp.*	6		
Unknown grass	3	*Solidago hispida*	4				
Unknown herb	1	*Solidago patula*	1				
7 species	22	7 species	37	5 species	11	1 species	2
Bald Eagle PEM: 10 cm		**Water Authority: 10cm**		**McCall Dam: 10cm**		**Sand Spring: 10cm**	
Carex stipata	2	Unknown grass	4	*Carex stipata*	5	*Carex stipata*	3
Barbarea vulgaris	1	*Urtica diocia*	1				
Unknown herb	2	*Panicum capillare*	1				
		Solidago hispida	1				
3 species	5	6 species	7	1 species	5	1 species	3
Bald Eagle PEM: 15cm		**Water Authority: 15cm**		**McCall Dam: 15cm**		**Sand Spring: 15cm**	
Carex stipata	1	*Barbarea vulgaris*	5	*Carex stipata*	5	*Carex stipata*	2
Ranunculis acris	1	*Urtica diocia*	1	*Digitaria sp.*	1		
Malva moschata	3			Unknown grass	1		
3 species	5	2 species	6	3 species	7	1 species	2

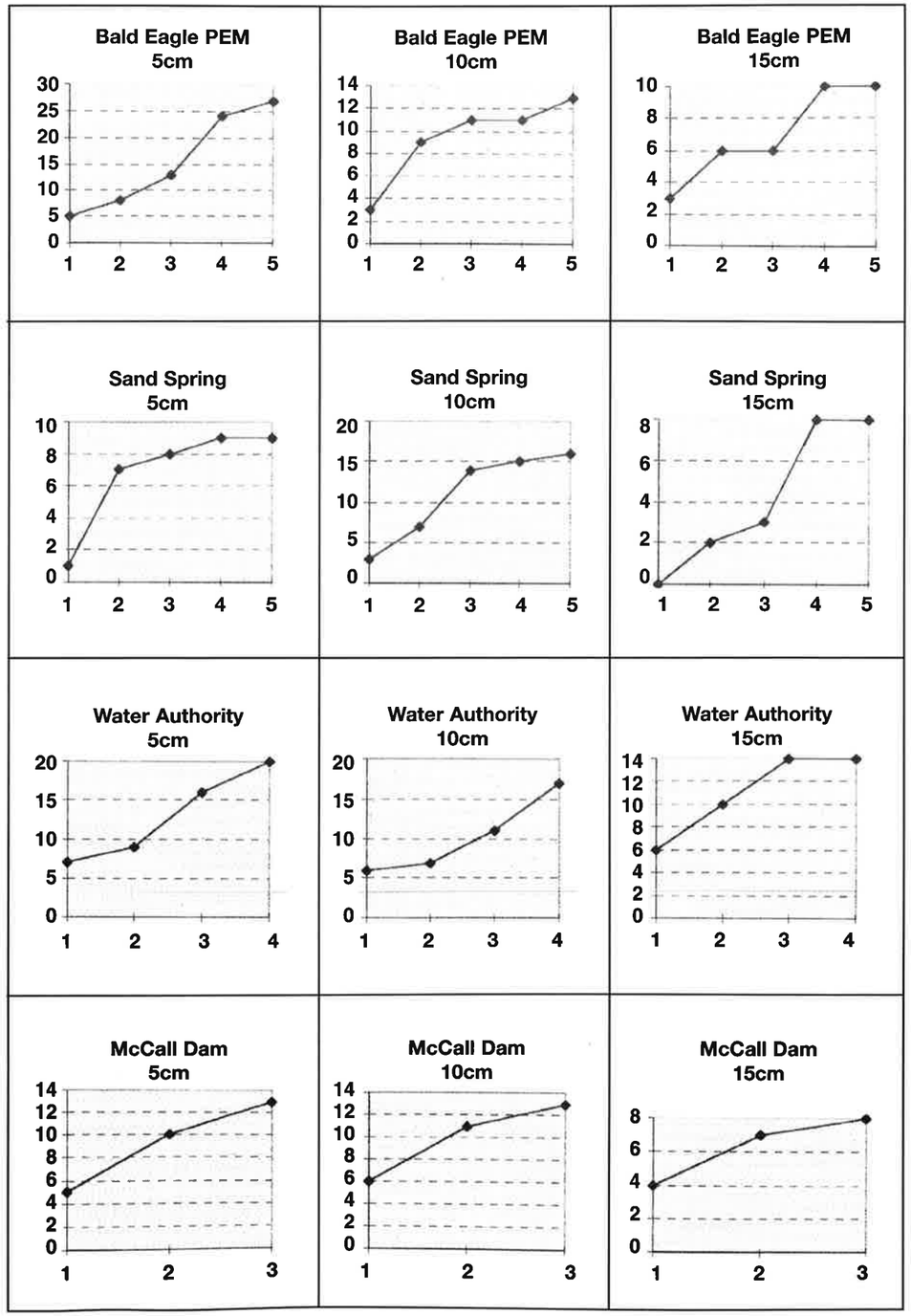

FIGURE 3. Species area curves for 0-5cm, and 10-15cm at each reference wetland based on flotation data.

CONCLUSION

Although Cs^{137} data were inconclusive, our results suggest that with improvements in sampling methods, these inconsistencies can be remedied. If we develop a site-specific sampling technique that is based on the sedimentation rate of a given site (or a given HGM subclass), we can more accurately estimate the depth of the Cs^{137} peak, and then sample corresponding soil depths. We now have sedimentation rates for many reference wetlands in Pennsylvania (Brooks et al. 1996), and applying these rates to determine sampling depths

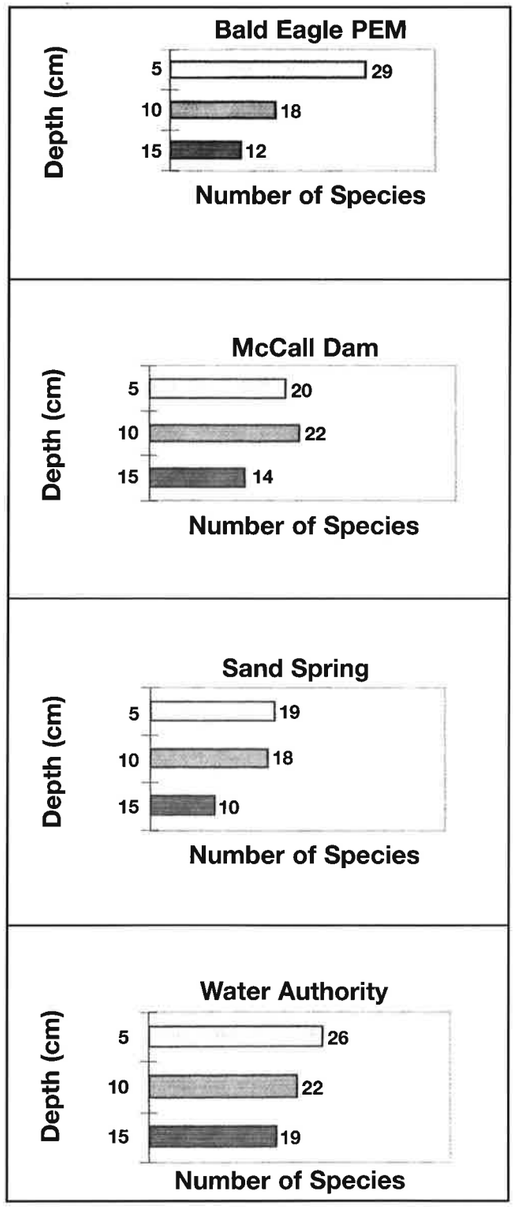

FIGURE 4. Total number of species for all samples found at 0-5 cm, 5-10 cm, and 10-15 cm for four reference wetlands based on flotation data.

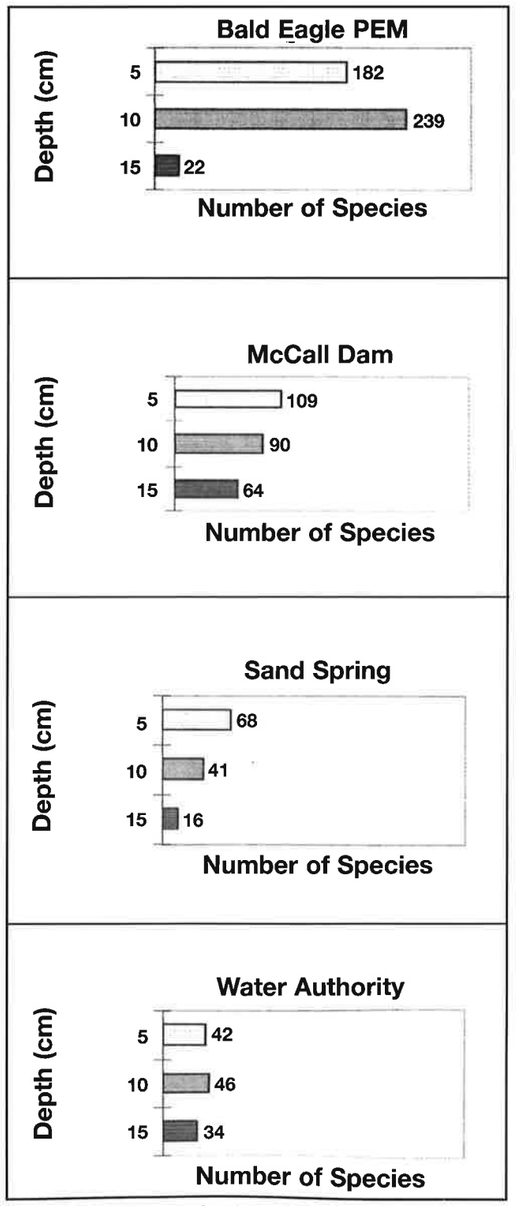

FIGURE 5. Total number of seeds for all samples found at 0-5 cm, 5-10 cm, and 10-15 cm for four reference wetlands based on flotation data.

TABLE 5. Jaccard Coefficient of Community for the four reference wetlands at 0-5cm, 5-10cm, and 10-15cm, based on flotation data. A score of 0.25 - 1.0 represents similar communities, 0.24 and below represents dissimilar communities (Ricklefs, 1990). Bold values point out low values for Sand Spring and McCall Dam, sites which are classified in the same hydrogeomorphic subclass.

0-5 cm	BESP PEM	Water Authority	McCall Dam	Sand Spring
BESP PEM		0.242	0.071	0.108
Water Authority			0.027	0.03
McCall Dam				**0.167**
Sand Spring				

5-10 cm	BESP PEM	Water Authority	McCall Dam	Sand Spring
BESP PEM		0.188	0.166	0.2
Water Authority			0.069	0.032
McCall Dam				**0.16**
Sand Spring				

10-15 cm	BESP PEM	Water Authority	McCall Dam	Sand Spring
BESP PEM		0.042	0.111	0.055
Water Authority			0.042	0.26
McCall Dam				**0.055**
Sand Spring				

should lead to more successful Cs^{137} analyses. We can also sample for Cs^{137} at 2cm increments, and recognize complications associated with plowed sites.

Since both methods provide different information, future studies should include both seedling emergence and flotation. Also a combination of methods, e.g. seedling emergence followed by hand sorting of ungerminated seeds, is recommended for a faster, more comprehensive estimate (ter Heerdt et al. 1996).

Our results show that it is possible to determine vegetational communities at different soil depths, and this makes seed bank analyses a very valuable tool for assessing vegetational succession. Seed banks are intact records of natural history. Any site that is impacted by sedimentation is subject to changes in plant communities. The seed bank of a site, along with other corollary data, is a record of how that community has evolved in response to changing land uses through time. Using the dated seed bank communities provided by the Cs^{137} analysis, historical records such as aerial photographs can be consulted in order to assess seed bank response to changing land use.

This pilot study supports the feasibility of seed bank analyses using Cs^{137}. If sampling techniques and other methods are improved upon by applying what this study has found, seed bank analyses using Cs^{137} (along with other data) can become an instrument for describing the impacts of historic land use.

ACKNOWLEDGMENTS

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COMMENTARY

AN OVERVIEW OF MEDICAL EDUCATION IN NIGERIA[1]

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ABSTRACT

Medical education in Nigeria has gone through varying phases: from training in traditional medicine to the modern system, based on the model existing in Western Europe and America.

Reverend Henry Venn of the Church Missionary Society of Great Britain (CMS), in 1861, conceived the idea of a school to train Africans in medical and surgical sciences. Dr. O. Harrison in 1862, established the first medical school in Abeokuta.

The Yaba Medical School was established in Nigeria in 1930. It provided a medical officers course that lasted five years: two years of premedical and three years of clinical training.

In the early 1940s, the medical faculty of the University College, Ibadan was established. The faculty developed standards and curricula that were similar to British Universities. Between 1960-1972, medical schools were established at Lagos, Zaria, Enugu, Benin and Ile-Ife. The period from 1972 to the present has seen the creation of additional medical schools at Ago-Iwoye, Ekpoma, Port Harcourt, Calabar, Nnewi, Ilorin, Jos, Kano, Sokoto, Maiduguri and Ogbomosho. Each medical school has developed standards and curricula similar to the first medical faculty at Ibadan. All medical schools operate pre-medical, pre-clinical and clinical curricula.

The Federal and State Governments of Nigeria control and fund all seventeen medical schools in the country. The governmental supervisory institutions for these medical schools are the Ministries of Education and Health, National Universities Commission and the Nigerian Medical and Dental Council.

Student selection and enrollment are conducted through the Joint Admission and Matriculation Board (JAMB). The number of graduates has steadily increased over the years (95 physicians in 1968 to 11,294 physicians in 1993).

Postgraduate medical education has continued to make steady progress under the supervision and control of the National Postgraduate Medical College of

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Nigeria with headquarters in Lagos. This body awards fellowships for advanced study in the different specialties.

The problems in the medical education system and the future of medical education in Nigeria are discussed.

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INTRODUCTION

Medical education in Nigeria, and indeed in most of Africa, started in a milieu of traditionalism in which medical knowledge was a scarce resource and therefore not open to public scrutiny.

The arrival of Christian missionaries and colonial rule to the African continent, brought changes in Medicine (1).

In this commentary we propose to look at the historical background of medical education in Nigeria, present status, oversight and evaluation and projections into the twenty-first century.

HISTORICAL DEVELOPMENT OF MEDICAL EDUCATION IN NIGERIA

Nigeria today has a system of medical education based on the model existing in Western Europe and in America. Before the emergence of this system, Nigeria had its own system of medical education.

Training in traditional medicine was based on apprenticeships in which trainees came directly under the tutelage of a specialist.

With the establishment of modern allopathic medicine in Nigeria by missionaries from Britain, the need to train modern medical personnel emerged. In 1861, Reverend Henry Venn of the Church Missionary Society (CMS), Abeokuta, conceived an idea to provide a school to train Africans in medical and surgical science. Dr. O. Harrison, the resident Missionary Doctor, was mandated to establish a school. The school started in Abeokuta in 1862 with four students, including Nathaniel King - the first Nigerian to practice modern medicine in Nigeria. The school had a vigorous program which included lectures in anatomy, physiology, natural philosophy, chemistry, botany and *materia medica*. Adeloye (2) indicates that the program was comprehensive and was considered hectic by the students. The death of Dr. Harrison in 1864 terminated this first medical school in Nigeria.

In 1930, colonial authorities in Nigeria established a high level medical training school, the Yaba Medical School. This placed Nigeria behind some African countries in the establishment of medical schools. Medical schools were already in existence in Cape Town, South Africa (1912); Dakar, Senegal (1918); Khartoum, Sudan (1924); and in Kampala, Uganda (1924).

Fafunwa (3) states that the Yaba Medical School was established to provide a course of study which was of limited scope, yet adequate to equip those who had completed it with sufficient knowledge to enable them to carry out useful work as medical assistants in the government medical services. There was no attempt to give training in medicine which approached the professional standards then recognized in Great Britain.

The school started with 13 students in medicine and 57 in pharmacy (4). The medical officer course lasted five years: two years of preclinical, and three years of clinical training (5). Other courses offered included the medicinal dispenser course which took three years and the course for pharmacist which took five years (2).

The early medical graduates from this institution were offered the opportunity to complete the medical program in Great Britain.

In the early 1940s, there was a shift in educational policy of the colonial authorities in Africa. This led to the establishment of three University Colleges at Ibadan (Nigeria), Accra (Ghana) and Sierra Leone. The Medical Faculty comprised seven departments (Anatomy, Physiology, Medicine, Surgery, Obstetrics and Gynaecology, Preventive and Social Medicine and Pathology) and was one of the foundation faculties at the University of Ibadan (3). The degree program was structured into premedical, preclinical and clinical courses spanning eight years.

Ashby (6) has indicated that the medical faculty, being an integral part of a University College that pursued British standards, developed standards and curricula that were the same as in British universities. There was insistence on medical qualification that could guarantee the practice of medicine in London as well as in Nigeria. What followed, was medical training that was not consistent with the health needs of Nigeria.

CURRENT PATTERNS OF MEDICAL EDUCATION

Medical School

Post-colonial Nigeria saw the growth of medical colleges and faculties as a way to address the problems of inadequate numbers of doctors in the country. The Third National Development Plan (1975-1980) (7), provides for the preparation of fully trained physicians. Currently, Nigeria has seventeen medical schools, the highest number in Africa. Table 1 denotes the comparative development of medical schools in Africa. With the exception of a few countries (Egypt, Ethiopia, Kenya, Uganda and South Africa) that have added one or two and Nigeria that has three additional medical schools

since 1985, most countries have maintained the 1985 array of medical schools.

There are basically two stages in the post-independence growth of medical schools. The first was the period immediately after independence (1960-1972). This period saw the creation of medical school in Universities started by both the Federal and Regional Governments. The medical schools established during this period included those at Lagos, Zaria, Enugu, Benin and Ile-Ife. The second period (1972 to date) represents the establishment of medical schools at Ago-Iwoye, Ekpoma, Port Harcourt, Calabar, Nnewi, Ilorin, Jos, Kano, Sokoto, Maiduguri and the Ogbomosho. The growth of medical schools, in Nigeria particularly, in the period since 1972, was a product of the interaction of political and economic factors prevalent in the country during this period. Nigeria became an oil-rich nation and politicians capitalized on this wealth by building institutions such as medical schools in their local areas.

TABLE 1. COMPARATIVE DEVELOPMENT OF MEDICAL SCHOOLS IN AFRICA (1955-1988)

Country	1955	1960	1970	1975	1985	1997*
Algeria	-	1	3	3	9	9
Angola	-	-	1	1	1	1
Benin	-	-	-	1	1	1
Burtkina Faso	-	-	-	-	1	1
Cameroon	-	-	1	-	1	1
Central Africa Republic	-	-	-	-	1	1
Congo	-	-	-	1	1	1
C'ote d'Ivoire	-	-	1	1	1	1
Egypt	3	4	7	8	11	13
Ethiopia	-	-	1	1	2	2
Gabon	-	-	-	1	1	1
Ghana	-	-	1	1	2	2
Guinea	-	-	1	1	1	1
Kenya	-	-	1	1	1	2
Liberia	-	-	1	1	1	1
Libya	-	-	1	2	2	2
Madagascar	1	1	1	1	2	2
Mali	-	-	-	1	1	1
Morocco	-	-	1	1	2	2
Mozambique	-	-	1	1	1	1
Niger	-	-	-	1	1	1
Nigeria	1	1	5	6	14	17
Rwanda	-	-	1	1	1	1
Senegal	1	1	1	1	1	1
Somalia	-	-	-	1	1	1
South Africa	5	5	6	6	7	8
Sudan	1	1	1	1	3	3
Togo	-	-	-	1	1	1
Tunisia	-	-	1	3	4	4
Uganda	1	1	1	1	1	2
United Republic of Tanzania	-	-	1	1	1	1
Zaire	2	2	3	3	3	3
Zambia	-	-	1	1	1	1
Zimbabwe	-	-	1	1	1	1

Source: Extracted from WHO (8)
*Medical schools in African countries in 1997

THE OVERSIGHT OF MEDICAL EDUCATION

The Federal and State Governments control and fund all seventeen medical schools which are currently operational in Nigeria. The Government's supervisory institutions are the Ministries of Education and Health, National Universities Commission and the Nigerian Medical and Dental Council.

The Federal Ministry of Education formulates the National Policy on Education and this includes the medical schools. The Federal Ministry of Health influences medical schools through its role in the establishment of teaching hospitals which are so vital to the training of medical students. The direct control of medical schools falls on the National Universities Commission, a semi-autonomous agency that operates within the sphere of influence of the Federal Ministry of Education.

All medical schools in Nigeria operate within the University system and because of this, they are created and controlled by the National Universities Commission (NUC).

NUC gives guidelines and regulations for the operation of all medical schools. Before a medical school or faculty is established, NUC ensures that basic requirements, as to facilities and staff, are in place. NUC also ensures that all medical schools operate a curriculum that guarantees graduates adequate exposure and acquisition of skills and knowledge appropriately relevant for current medical practice. Once a medical school starts a program, after meeting the requirements of NUC, the next goal is to meet the requirements of the Nigerian Medical and Dental Council (9).

The Nigerial Medical and Dental Council (NMDC) was established by an Act of the Parliament in 1963 and it functions on the model of the British Medical Council, which was established in 1858. NMDC functions to regulate medical and dental practice in Nigeria. One of the statutory functions of NMDC is to accredit the institutions aspiring to train candidates for the medical and dental profession. In addition, courses of instruction are prescribed. Council also has the responsibility for supervising the nature of the instruction and examinations leading to the degrees to be granted.

The NMDC, through its Committee on Medical Education, establishes guidelines on standards to be attained by medical schools as well as organizing site visits to assess the operations of the medical school.

STUDENT SELECTION AND ENROLLMENT

The Federal Government of Nigeria set up the Joint Admission and Matriculation Board (JAMB) by decree in 1978, to oversee the admission of students into Nigerian Universities. JAMB conducts the University Matriculation Examination (UME) annually as a prerequisite to the placement of students into the universities.

Medical students are therefore admitted by JAMB into the various medical schools/colleges and faculties. The distinction between school/college and faculty lies in greater autonomy for the schools and colleges in carrying out their activities. Medical colleges are to be free from interference from the mainstream University.

The selection of students is based largely on their achievements in science-based courses (Biology, Zoology, Physics, Chemistry and Mathematics), as authenticated by their performances in the Senior Secondary Certificate Examinations (equivalent to British G.C.E. O'level and American High School) and the UME. Considerations are often given to candidates from the locality where the medical school is located and to candidates from the educationally backward areas of the country.

The Medical Schools at Ibadan, Lagos and Ife adopted the conducting of interviews of candidates in order to ensure that candidates for medical training have qualities other than purely academic ones. They have since dropped this practice with the establishment of JAMB.

Gusau (9) indicates that rapid expansion and creation of new medical schools has increased student intake. In the 1968-1969 academic year, there were only 1022 students for medicine and allied health sciences in Nigeria. By 1987-1988, this number had grown to 9839 matriculants. An interesting development is the progressive increase of female student enrollment. Whereas female students approximated 100 in the early 1980s, they exceed 200 in the late 1990s (9).

THE UNDERGRADUATE MEDICAL CURRICULUM

All the medical schools in Nigeria operate with premedical, preclinical and clinical phases of study.

Premedical

Students admitted by JAMB through the UME are taught for one academic year in the faculties of science in the various Universities. They take compulsory courses in Physics, Chemistry, Biology or Zoology, Mathematics and General Studies (use of English and the History and culture of Nigeria). The medical school most often does not have any input at this level.

Preclinical

After the premedical year, students come over to the medical school in their second year to begin their preclinical studies. Also, students who have obtained the equivalent of the British G.C.E. Advanced Level qualifications and admitted directly by JAMB without going through the UME, join at this stage. The students are given appropriate exposure in Anatomy, Biochemistry and Physiology for 18 months. Some of the medical schools e.g. Ilorin, Ile-Ife, Zaria and Jos attempt at this stage to also introduce the students to community medicine. It is worthy to note that none of the medical schools in Nigeria have adopted the integrative pattern of teaching or the problem-based learning system (10).

Clinical

After passing the preclinical examination, the students move on to the clinical phase where they are taught Pathology, Pharmacology, Pediatrics, Obstetrics and Gynaecology, Medicine, Ophthalmology, Anaesthesia, Surgery and Community Health for three years.

PRODUCTION OF MEDICAL GRADUATES

Medical doctors graduating from Nigerian universities have increased dramatically over the years. As the older medical schools continued to expand and new ones are established, the graduation of physicians has increased appreciably. In 1968, Nigerian medical schools graduated a total of 95 doctors. By 1974 and 1975 this figure had increased to 221 and 269 respectively and by 1978, the production of doctors had reached 675 (11 and 12). The 1980s saw further increases as the newest medical schools started graduating physicians (Table 2). By 1993, a total of 11,294 doctors had graduated from the Nigerian medical schools.

By 31 December 1993, 23,808 orthodox doctors trained within and outside the country had been licensed to practice medicine in Nigeria. Based on the National Population figure of 1993 (Population of 93,060,000), the doctor-population ratio in Nigeria in 1993 was 1 per 10,000. The WHO recommended target ratio for developing countries is 1 doctor: 8,000 persons. However, a state-by-state breakdown (Table 3) provides a useful basis for comparative analysis. Ratios for the various

TABLE 2. GRADUATES OF NIGERIA'S MEDICAL SCHOOLS 1978-1988

Institution	1978/ 1979	1979/ 1980	1980/ 1981	1981/ 1982	1986/ 1987	1987/ 1988
Benin	44	-	58	99	79	82
Calabar	-	-	-	9	-	141
Enugu	72	73	77	99	122	119
Ibadan	184	228	298	270	542	415
Ile-Ife	137	103	152	88	119	122
Ilorin	-	-	-	-	45	64
Jos	-	-	-	70	80	70
Lagos	160	141	166	204	124	137
Maiduguri	-	-	-	-	61	68
Port Harcourt	-	-	-	-	81	140
Sokoto	-	-	-	-	16	14
Zaria	78	94	65	61	63	67
Total	675	639	816	900	1332	1439

Source: National Universities Commission (13)
Note: By 1993, all the medical schools in Nigeria graduated 11,294 doctors

states in Nigeria differ enormously. Whereas some states, e.g. Lagos, Edo, Enugu, and Oyo have ratios well below 1:8,000, Yobe, Katsina, Taraba, Jigawa and others are grossly underserved (14). This trend has worsened in present day Nigeria with doctors opting to live and work in the large metropolitan areas.

EVALUATION OF MEDICAL SCHOOLS

The academic program of all Nigerian medical schools is under the direct supervision of the Senate of the respective university. In addition, all four professional examinations which medical students take are conducted with the active participation of external examiners. Previously, external examiners for the various subjects were invited from Great Britain and other Commonwealth countries. Recently, due to economic concerns in the country, medical schools have utilized external examiners from universities within Nigeria.

The National Universities Commission (NUC) controls the curricula of all medical schools by insisting that the schools follow the NUC minimum standard. The NUC conducts site visits to the medical schools periodically to ascertain that the schools still have the facilities and staff appropriate to graduate medical doctors.

Perhaps, the most important evaluation of the medical schools comes from the Nigerian Medical and Dental Council (NMDC).

Part of the regulatory role of the NMDC is to exercise remote oversight over the course of study prescribed for medical and dental students in Nigeria (11). The NMDC's Committee on Medical Education prepares guidelines of minimum standards required by the Council for all medical schools. Idowu (11) summarizes the focus of the NMDC guidelines as follows:

1. The subject matter which the curriculum must cover.
2. The minimum length of time which the student must spend in the undergraduate training program.
3. The facilities and resources: physical, manpower, equipment and supporting services which must be available to be certain of the adequate delivery of the subject matter in the time required and to the level desired.

To accredit a medical school, the Council ensures that the minimum standards are met. Teams of professional medical educators are sent to each medical school periodically in order to verify their staffing, student intake process and availability of equipment and facilities.

The medical schools in Nigeria also seek recognition from international professional bodies. The details of all of the requirements stipulated by NMDC for the medical schools are modeled on the same standards required of medical schools in more advanced countries. Six medical schools (Ibadan, Lagos, Ile-Ife, Enugu, Zaria and Benin) enjoy recognition from the General Medical Council of Great Britain. This, historically has allowed graduates of their medical schools to sit for the British qualifying examinations. Since 1996, graduates of all Nigerian medical schools are permitted to take this examination.

TABLE 3. DOCTOR/POPULATION RATIOS ON A STATE TO STATE BASIS IN NIGERIA

STATE	NUMBER OF DOCTORS	RELATIVE POPULATION PER DOCTORS
Abia	289	7,949
Adamawa	92	23,087
Akwa Ibom	196	12,039
Anambra	312	8,872
Bauchi	130	33,034
Benue	233	11,933
Borno	237	10,956
Cross River	230	3,111
Delta	345	7,450
Edo	700	3,085
Enugu	895	3,532
Federal Capital Territory	127	2,982
Imo	474	5,168
Jigawa	12	235,827
Kebbi	44	46,869
Kogi	124	16,343
Kano	266	21,177
Katsina	34	114,069
Kwara	407	3,849
Lagos	3,522	1,614
Niger	123	20,182
Ondo	344	11,292
Ogun	294	7,958
Oshun	405	5,440
Oyo	1,094	3,189
Plateau	506	4,513
Rivers	390	10,215
Sokoto	178	24,676
Taraba	27	54,837
Yobe	14	100,820

Based on the 1991 census figures National Population Commission, Lagos. (Mpi [14])

POSTGRADUATE MEDICAL EDUCATION

Postgraduate medical education started in Nigeria in 1971 under the management of the 'Joint Boards', composed of the members of the NMDC's Committee on Medical Education and the chairmen and secretaries of the examining boards for the various specialities. With the promulgation of Decree No. 67 of 1979, by the Federal Military Government, establishing the National Medical College, later renamed the National Postgraduate Medical College of Nigeria (NPMCN), the responsibility for postgraduate medical education was transferred to NPMCN. The functions of NPMCN included:

1. Accreditation of training institutions;
2. Organizing training courses and programs;

3. Conduct professional postgraduate examinations;
4. Award of postgraduate fellowships and diplomas.

The fellowship program is made up of three elements: the Basic Science Course (Primary), the Part I Course and the Part II Course. Each of these courses terminates with an examination. The program runs for a minimum of four years after the Basic Science Course. The Part I Course is junior residency training which spans two years. This is followed by a senior residency which also lasts two years, terminating with the Part II Final Fellowship Examination. Senior residency training includes a period of exposure in an overseas university. The one year abroad seeks to correct any weakness in the program which the underdevelopment of Nigeria might confer, thus affording some familiarity with the most modern research/therapeutic tools and instrumentation (15).

At the end of the fellowship program, the graduates usually seek employment in the medical schools as Lecturers/Consultants (the equivalent of Assistant Professor).

Akinkugbe (16) indicates that up until 1987, the choice of specialty favored clinical medicine (Internal Medicine, Obstetrics and Gynaecology, Surgery, Pediatrics and Pathology). Public Health, which Ashby (6) believes to be of utmost importance in Nigeria, drew little attention. From 1972 to 1988, less than 5% of all medical specialists trained in Nigeria selected the area of Public Health (Table 4). This trend remains the same in present day Nigeria.

OTHER TRENDS OF EDUCATIONAL INNOVATION

With the introduction and enhancement of allopathic medicine in Nigeria, emphasis has gradually shifted away from traditional medicine (1). The Federal and State Governments have, however, taken various steps aimed at conserving and propagating the positive elements of traditional medicine. For instance, the Government has encouraged the integration of some aspect of traditional medicine into the curricula of the medical schools. The medical school at Sokoto, for example, has a department of traditional medicine, while the one in Jos has recruited herbalists into the department of pharmacology. It is not clear what impact these traditional elements have on the quality of the medical graduates of these institutions. It seems, however, that the governmental intention to integrate traditional medicine into the medical school curriculum is not achieving its objective. The reasons for this difficulty include:

1. The inability of the modern, western-oriented physician to see any positive elements in traditional medicine.
2. The secrecy within which traditional medicine operates;
3. Lack of scientific base and literature relating to the practice of traditional medicine;
4. The historical evolution of traditional medicine.

SCIENTIFIC RESEARCH

The ultimate goal of all healthcare workers is the improvement in health status of people and other living creatures sharing the same environment (18). To achieve this objective, concerted efforts must be made to improve the following:

1. Methods of clinical diagnosis;
2. Methods of laboratory investigation;
3. Use of therapeutic agents or procedures;
4. Use of prophylactic agents.

There is always the need to evaluate current practices and to investigate new potentially beneficial techniques, agents or interventions in the healthcare sector in Nigeria. The Nigerian medical schools and the teaching hospitals are at the forefront in seeing to the improvement of these areas. The academic staff of all of the medical schools (Lecturers and Consultants) teach and conduct research. The criteria for promotion leans heavily on the research capability of the faculty, viz-a-viz ability to publish research findings in reputable scientific journals. Accordingly, lecturers and consultants take their research seriously.

Lecturers in the medical schools are involved in the following types of research:

1. Clinical research combined with professional care;
2. Biomedical, non-therapeutic medical research involving human subjects;
3. Basic science research;
4. Epidemiological and social science research.

Due to limited funding for research, Nigerian medical scientists have recently focused their attention mainly on

TABLE 4. DISTRIBUTION OF THE TOTAL SUCCESSFUL FELLOWS OF THE NATIONAL POSTGRADUATE MEDICAL COLLEGE OF NIGERIA BY THEIR AREAS OF SPECIALIZATION 1972-1988.

Area/Faculty	Total No of	% of Total Candidates
Anaesthesia	6	1.5
Dental Surgery	5	1.3
General Medical Practice	15	3.8
Obstetrics & Gynaecology	69	17.6
Ophthalmology	26	6.6
Pediatrics	48	12.3
Pathology	32	8.2
Physics (Medicine)	88	22.5
Psychiatry	16	4.1
Public Health	16	4.1
Radiology	13	3.3
Surgery	55	14.1
Orthorhinolaryngology (ORL)	2	0.5
Total	391	100

Source: Bankole (17)
Note: From 1988 to date, although the number of doctors entering a residency program have increased, the general preference is still Internal Medicine Obstetrics and Gynaecology and Pediatrics.

epidemiological and social science research. These research efforts are achieving some success in understanding how diseases are transmitted and how behavior, cultural belief, leadership structure and family structure affect transmission and management of disease.

Most Nigerian medical scientists attend their various professional scientific meetings annually, where they present results of their research projects. Oyejide (18 and 19) indicates that more and more African scientists, including healthcare workers and healthcare administrators, are beginning to appreciate the importance of biomedical research. Since the inception of postgraduate medical education, an increasing number of physicians have been encouraged to conduct research projects during the course of their specialty training.

INTERNATIONAL COOPERATION AND EXCHANGE

Most Nigerian medical schools cooperate with international agencies and medical schools in Europe and America. For instance, the College of Medicine in Lagos, from its inception in 1962, has had staff from Toronto, Canada (especially in Anaesthesia and Clinical Pathology) and later developed linkages with the medical school of Rochester, N.Y. This was a most successful two-way exchange which involved young Nigerian teachers spending a year or two in research abroad and experienced Rochester staff visiting Lagos for short periods (15).

World Health Organization (WHO), United Nations International Children's Emergency Fund (UNICEF), United Nations Educational, Scientific, and Cultural Organization (UNESCO), United States Agency for International Development (USAID), Rockefeller, Ford and Carnegie Foundations have all been actively involved with the establishment, development and progress of certain medical schools. WHO runs a 13-month course in Immunology for teachers in the College of Medicine, Ibadan. It has also established centers at the departments of Obstetrics and Gynaecology at Ibadan and Benin. UNICEF has various centers at Benin, Jos, Maiduguri and Ibadan. UNESCO and USAID's assistance are mainly in providing literature, journals and equipment to the medical schools, while Rockefeller, Ford and Carnegie Foundations help fund specific projects in the medical schools.

Nigerian medical educators frequently utilize fellowship awards of the Association of Commonwealth Universities, Educational Commission for Foreign Medical Graduates (ECFMG), International Union of Physiological Sciences (IUPS) etc. in order to travel to advanced laboratories and institutions in Europe and North America in order to acquire added skills. These fellowship awards have helped to improve the quality of medical educators in Nigeria. Scientists from Europe and North America also visit the medical schools frequently for research and sabbatical visits. Recently, the economy of the country has curtailed such visits. Despite these conditions, the international agencies mentioned above and other non-governmental organizations (NGOs) still sponsor some visits from abroad to Nigeria.

CONCERNS FOR THE MEDICAL EDUCATION SYSTEM

The current macroeconomic changes in Nigeria have had an adverse effect upon health care and education in particular because of drastic cuts in funding, which have come to be associated with structural adjustment programs (SAP). It is evident that development policies have not seriously considered the development concerns of health manpower training institutions, especially the medical education sector. There has been a gnawing recognition of the negative impacts on medical education in Nigeria. An analysis of this trend, culled from a multitude of surveys, has pointed to the chronic paucity of manpower and teaching resources.

The ambience of the work environments in most medical schools in Nigeria today is becoming progressively less interesting. Mostly, they are ill-equipped, and facilities for training are inappropriate and unsatisfactory. They have failed to keep pace with developments in technology, and faculty feel deprived and restricted, leading to dissatisfaction and frustration. Even those who have received adequate training are unable to put their skills and talents to proper use because basic equipment is not available due to a mismatch between training and available technology (10).

While the importance of adequate staffing cannot be overemphasized, the critical need is to reorganize teaching aims and methods. The priorities of medical education need reorientation. The aims of such teaching should be to provide medical students with an understanding of normal structure, function, biochemical reactions and growth and development of the body, so that the student can apply this understanding in the problem-solving situation encountered by general physicians. It should also continue to inculcate in the students the scientific method and approach to their work, to prepare them to better understand all the disciplines covered in the overall medical curriculum. Therefore, some part of the learning experiences should be community-based, while most of the training has to be community-oriented.

The alternative solutions that have been considered to ameliorate this situation have ranged from the restructuring of medical schools to the restructuring of curricula and their implementation. The current thinking is in terms of reorientation of preclinical departments in medical schools towards more clinical direction. This would be a type of organization which, while safeguarding the preclinical disciplines, provides a greater interface for scientists with diverse interests, and offering greater

opportunities to relate clinical problems to the basic medical sciences. The problem-based medical curriculum attempts to bring this about in a structured way throughout medical school (10). Such an arrangement will better enable basic scientists to participate in important clinical research problems and provide maximum services to clinical departments. For the students it will mean more relevance, enhancement of their problem solving abilities and, above all, heightened motivation. For the basic science faculty to be able to play this role, they will need to learn new skills, broaden their knowledge base and develop a new set of attitudes.

THE FUTURE OF MEDICAL EDUCATION IN NIGERIA

The future of medical education, especially in the early twenty-first century, is likely to witness a gradual disappearance of mysticism with a strengthening of the knowledge in local medicinal herbs, some of which are likely to be purified for standard use.

With insistence by the Medical and Dental Council for maintenance of high standards and the threat of closing down some of the new medical schools, better funding will likely result. Not only are standards likely to be maintained, but more modern equipment is likely to be incorporated into medical services and medical education.

With the present trend in the production of more medical graduates, there is likely to be a further improvement in the doctor:patient ratio, enabling rural areas which are becoming increasingly electrified, to be better served with qualified doctors. Postgraduate medical education is likely to witness more designated teaching hospitals providing residency training including subspecialization using more modern equipment.

Presently, an unstable political and hence economic system is causing a drain of much needed brain power in medicine. A reversal of this trend is expected when the situation improves.

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ADDENDUM

"Water Quality Analysis of Twin Lakes, PA 1965-1993, A Unique Data Base" by Joyce E. Laudise, Robert A. Laudise, Thomas E. Graedel and Robert L. Barns, *Journal of the Pennsylvania Academy of Science*, Vol. 68: Number 2, 1994, pages 67-76.

In the above paper we made use of water analysis data provided by a commercial vendor. We have recently learned from that vendor that analysis errors and problems with sample results may have occurred in the vendors lab during the period 1987 through 1997. We have been unable to learn which if any of our data are in error. On this basis we are forced to discount all data in our paper for the years from 1987 forward.

We are continuing to monitor Twin Lakes using another analytical laboratory beginning in July of 1997 and will report our results at a later time. In closing, we emphasize that our data reported in the above paper for the period 1965-1987 are not in question.

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Darbaker Prize

The Darbaker Prize is a Pennsylvania Academy of Science (PAS) award given for outstanding scholarly contributions which use microscopic techniques and present microscopic illustrations in the reporting of biological research. The award is competitive amongst qualified papers submitted in association with the Academy's annual meeting.

The Pennsylvania Academy of Science established the Darbaker Prize in 1952. Funds for the award are made available through a bequest of the late L.K. Darbaker, 1939 PAS President. Referring to the award, Dr. Darbaker's will states: "Any sum applicable to the Pennsylvania Academy of Science shall be for grant or grants in Microscopical Biology."

To qualify for the Darbaker Prize, a scientist or scientists must: (1) have used microscopy (light, SEM, TEM, or other technologies) in the research they report, (2) submit in proper format a manuscript reporting the results of the completed study for consideration to be published in the *Journal*, (3) specifically state a request to the Editor of the *Journal* to have their manuscript considered for the Darbaker Prize for the current calendar year, and (4) be a member of the Pennsylvania Academy of Science. Darbaker Prize competition manuscripts are expected to be presented and submitted at the PAS annual meeting, but if not, manuscripts will be accepted for consideration within four weeks (28 calendar days) following the last day of the annual meeting. Only manuscripts that have successfully completed the review process and have been accepted for publication in the *Journal* will be eligible for the award.

The Editor of the *Journal* will examine all manuscripts submitted for award consideration to determine the fulfillment of requirements. The editor will then forward the eligible manuscripts with his/her and reviewers recommendations to the PAS President for final decision. The Darbaker Prize recipient or recipients will be informed of their selection by the President of the Academy. Formal public announcement of the Darbaker Prize will be made in the *Journal* at an appropriate time. The individual or individuals awarded the Darbaker Prize will receive a publication grant for page charges required to print their article in the *Journal,* and may or may not receive a monetary award.

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