

SMALL MAMMALS FROM THE MOST RADIOACTIVE SITES NEAR THE CHORNOBYL NUCLEAR POWER PLANT

ROBERT J. BAKER, MEREDITH J. HAMILTON, RONALD A. VAN DEN BUSSCHE, LARA E. WIGGINS,
DERRICK W. SUGG, MICHAEL H. SMITH, MICHAEL D. LOMAKIN, SERGEY P. GASCHAK,
ELENA G. BUNDOVA, GALENA A. RUDENSKAYA, AND RONALD K. CHESSER

*Department of Biological Sciences, Texas Tech University, Lubbock, TX 79409
(RJB, MJH, RAVDB, LEW)*

Savannah River Ecology Laboratory, Drawer E, Aiken, SC 29802 (DWS, MHS, RKC)

International Research and Development Agency of Ukraine, Kiev-1, Ukraine (MDL)

Research Industrial Association "Pripyat," Scientific Technical Center, Radiology and

Lands Recovery Department, Chornobyl, Ukraine (SPG, EGB, GAR)

*Present Address of MJH and RAVDB: Department of Zoology, Life Sciences West,
Oklahoma State University, Stillwater, OK 74078*

This study was designed to estimate the impact of pollution resulting from the meltdown of Reactor 4, Chornobyl, Ukraine, on the taxonomic diversity and abundance of small mammals in the surrounding area. Trap sites included the most radioactive areas within the 10-km exclusion zone, a site within the 30-km exclusion zone that received minimal radioactive pollution, and five sites outside of the 30-km exclusion zone. Within the exclusion zones, 355 specimens representing 11 species of small mammals were obtained, whereas 224 specimens representing 12 species were obtained from outside the exclusion zone. It is concluded that the diversity and abundance of the small-mammal fauna is not presently reduced at the most radioactive sites. Specimens from the most radioactive areas do not demonstrate aberrant gross morphological features other than enlargement of the spleen. Examination of karyotypes does not document gross chromosomal rearrangements.

Key words: Chornobyl, Chernobyl, radiation, karyotypes, pollution, biodiversity

On 26 April 1986, the worst disaster at a nuclear power plant to date occurred in Reactor 4 at the Chornobyl Nuclear Power Plant creating a highly polluted environment adjacent to the reactor and raising the background level of radiation for about one-third of the earth's surface (Segerstahl, 1991). The release of radiation from the meltdown affected populations of wild rodents as far away as Rome, Italy (Cristaldi et al., 1990) and Sweden (Cristaldi et al., 1991). The explosion and subsequent reactor fire at Chornobyl were estimated to have released 50 (Mourad and Snell, 1987; Powers et al., 1987) to 200 (Sich, 1994) $\times 10^6$ Curies of radiation. Areas within 10 km of the reactor were contaminated with complex radioactive particulates associated with fuel rods and graphite from the reactor core

(Medvedev, 1991). Intense heat from the meltdown graphite fire created an aerosol of volatile elements that spewed into the atmosphere for 10 days. Thus, radioisotopes were transported by prevailing winds over most of Europe and Asia. About 135,000 people were evacuated from a 30-km radius around Reactor 4 in Ukraine and Belarus (Fig. 1). Authorities established a 10-km exclusion zone that is still tightly controlled for access and human activities. These restricted areas are named the 30-km zone and the 10-km zone, respectively. Two reactors remain functioning today; however, other human activities within the 10-km zone are restricted by check stations and a fence around the zone. Although there are areas within the 10-km zone that have undergone activities to control radiation, such

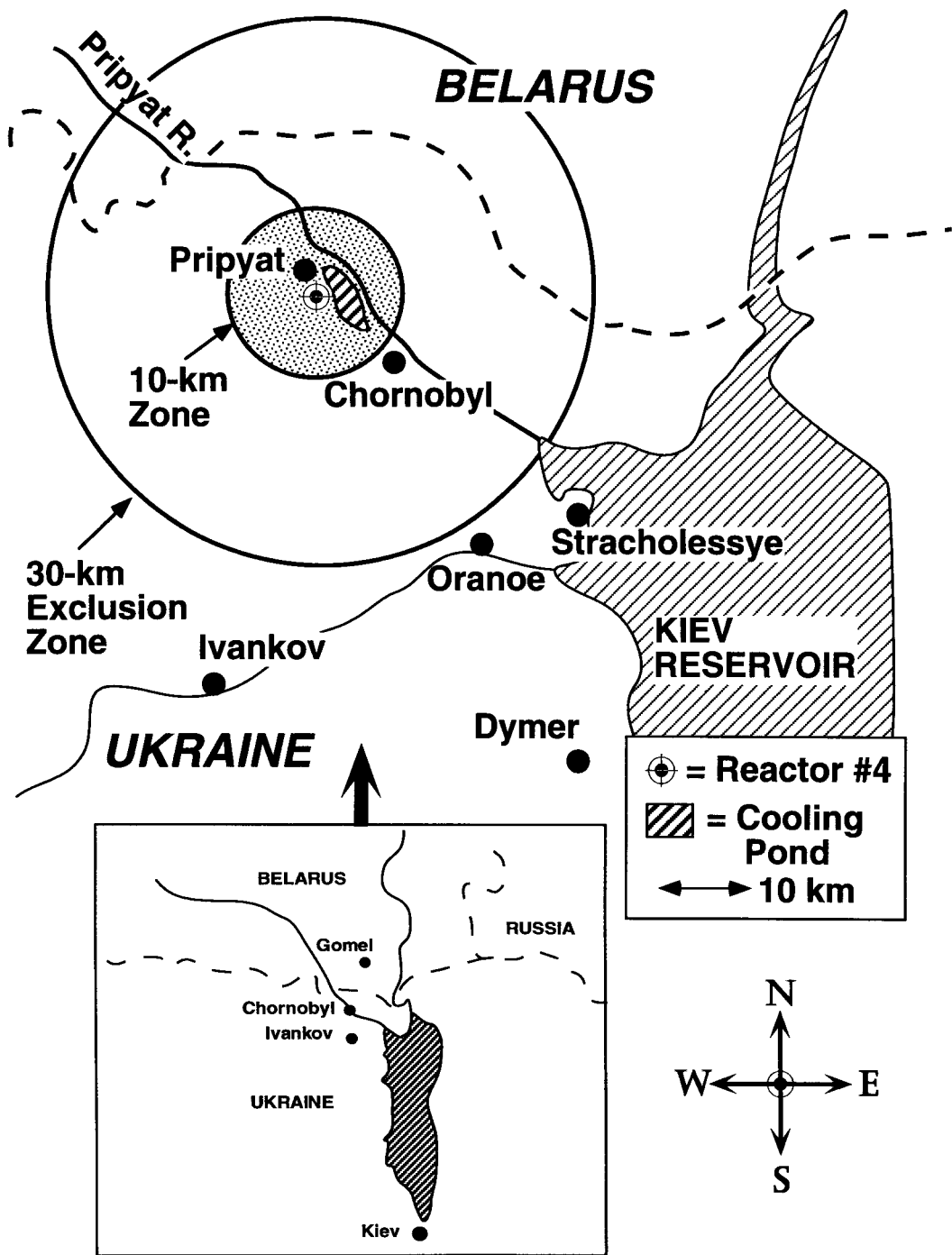


FIG. 1.—Map of the region under study at the Chornobyl Nuclear Power Plant (center of the circles) in northern Ukraine where mammal collecting sites were located. The 10-km and 30-km exclusion zones are the areas from which 135,000 persons were evacuated. Control localities were those outside of the exclusion zones.

as removal of top soil, burial of radioactive trees, construction of levees and enclosures, and planting trees and other vegetation, most areas within the 10-km zone have encountered minimal human disturbance since the accident.

Two major water features restrict movement of small mammals within the zone. The Pripyat River flows through the zone from northwest to southeast (Fig. 1). The only bridge that traverses the Pripyat River in the 10-km zone supports a railroad track, and it is unlikely that this bridge is used frequently by any native mammals as a dispersal route. There are times in winter when the river freezes over. A cooling reservoir that is separated by a levee from the Pripyat River also lies within the zone. This reservoir is ca. 12 km long and 2 km across at its widest point. It parallels the Pripyat River from the city of Pripyat to the southeastern edge of the 10-km zone. The Pripyat Marshes parallel the Pripyat River and cover vast areas of northern Ukraine and southern Belarus. The marshland is typified by numerous peat bogs, shallow ponds, and shrubby grasslands. These areas are now traversed by hundreds of man-made canals to control flooding and provide irrigation.

The dominant vegetation in the majority of the zone is evergreen (Scotch pine, which in many areas was planted in rows) and mixed-deciduous forest (Berg, 1950). Grassy fields within the 10-km zone are the result of clearance of the forest for agriculture or other purposes. Because of this reticulated pattern of fields and forest, the forest habitat is fairly continuous in most regions, whereas grassy fields are often islands connected only by the grassy roadsides along highways. This undoubtedly has an impact on movements among populations of small mammals that inhabit the grassy fields.

Pripyat was founded in 1970 and was a city of ca. 47,000 people in 1986. It was considered the most modern city in the former Soviet Union. It consisted of numerous high-rise apartments and office buildings

that stand empty today. The remainder of the human habitations in the exclusion zone consisted of small villages and towns, which usually included schools, churches, and single-family dwellings, many with thatched roofs. All areas of human habitation have been abandoned within the 10-km zone except a cafeteria for workers, limited space in Pripyat for laboratory work and other activities, and the two currently active nuclear reactors (Units 1 and 3).

We initiated a program to examine effects of a nuclear meltdown on organisms that live in this contaminated environment. Our initial report of these studies involves the mutation rate in the cytochrome-b gene in *Microtus* (R. J. Baker et al., in litt.). The present study is concerned with diversity, distribution, and karyotypes of small mammals that live in the most radioactive sites within the 10-km zone. It was our experimental design to locate the most radioactively contaminated sites (Gluboyke Lake, Red Forest, Chistogalovka; Fig. 2a) within the 10-km zone and to compare the mammalian fauna found there to fauna found in similar sites (Orchard in the 10-km zone, Rechitsa in the 30-km zone; Fig. 2a) experiencing lower levels of contamination from the reactor meltdown. Additionally, we trapped minimally contaminated localities southeast of the reactor outside of the 30-km exclusion zone (Fig. 2b).

STUDY AREA

Collecting localities are shown in Figs. 2a and 2b. Coordinates were recorded on an Ensign GPS device, Trimble Navigation. The X and Y coordinates give kilometers east of the 36th TransMercator line and kilometers north of the equator, respectively.

Collecting Localities

Ten-km exclusion zone.—Gluboyke Lake (51°26'49.1"N, 30°04'04.2"E) was the most radioactive environmental site that we encountered. Radioactivity as measured by an electronic dosimeter (Siemens Model EPD-2) ranged from 5 to >100 millirems/h. The amount of radioactivity was locally variable, with the greatest

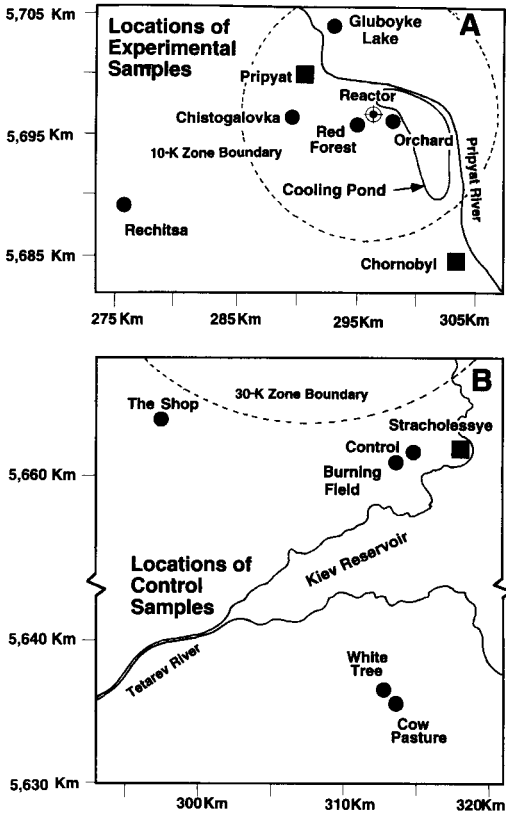


FIG. 2.—Maps of the collecting localities for small mammals in the 10-km and 30-km exclusion zones. (A) The Prip'yat and Chornobyl sites were not collecting localities and are provided only as reference points. Rechitsa is the only location depicted here that is outside of the 10-km zone. (B) Map of the collecting localities for small mammals in the control regions outside of the 30-km exclusion zone. The X and Y coordinates give kilometers east of the 36th Universal TransMercator line and kilometers north of the equator, respectively.

concentration of radionuclides distributed in a narrow band of deep grass along the north side of the lake. Other habitat included a scrubby, short forest of deciduous trees. The level of radioactivity at this locality was great enough to kill pines, which were locally common before the meltdown. There was a sufficient number of dead trees (standing and fallen) that occupied a significant portion of the understory. Trap sites at this locality consisted of deep grass along the north side of the lake, grassy sides of the levee

on the east side of the lake, and the forested regions that had some clear understory and some grassy, brushy understory.

Chistogalovka (51°22'48.4"N, 30°01'29.3"E) was an abandoned communal farm that was converted into an experimental agricultural area for several years after the accident. Electronic dosimetry readings ranged from 3 to 15 millirems/h. Fenced areas were used to maintain livestock to assess uptake of radionuclides. The area was abandoned once again in 1991. Habitat on the south side of the road consisted of deep grassy fields. Along the north side of the road there were grassy ditches of intermittently flooded areas adjacent to a mixed forest of deciduous and evergreen trees. Wooden and wire fences subdivided the farm land. Traps were set mainly in grasslands, although some forest edge also was sampled.

Red Forest (51°22'23.6"N, 30°05'49.0"E) was a mature stand of evergreen trees before the accident. This area received a level of radiation sufficient to immediately kill these evergreens. Electronic dosimetry readings during our collecting ranged from 3 to >100 millirems/h. As these trees died, the forest became red; hence the name. The current habitat in the Red Forest is grassy fields with small shrubs and weeds. The Scotch pine forest, which originally occurred here, has been removed and dead trees were bulldozed and buried in rows of berms that now are covered with native grasses.

The Orchard (51°22'29.3"N, 30°08'25.4"E) is the site of an apple orchard that was abandoned at the time the cooling reservoir was built (ca. 1970). Much of the area currently consists of a second-growth upperstory with intermittent open grassy areas. The northern border of the Orchard is on the banks of the cooling reservoir, and this was the least radioactive of the four sites in the 10-km zone adjacent to the reactor. Electronic dosimetry readings ranged from 2 to 4 millirems/h.

Thirty-km exclusion zone.—Rechitsa (51°18'34.1"N, 29°55'44.6"E), before the explosion, was a communal farm used for grazing cattle and growing potatoes. The area has now succeeded to grassland interspersed with shrubs. Some low-lying areas hold water for portions of the year and are surrounded by cattails (*Typha*). The level of radioactivity at this site is low, ranging from 1 to 2 millirems/h.

Outside the 30-km exclusion zone.—Electron-

ic dosimetry readings for all sites outside never registered >1 millirem/h and the majority of readings were below the sensitivity of the instrument. Background readings using a Geiger counter were 100–250 disintegrations/h.

Control Site ($51^{\circ}04'29.4''N$, $30^{\circ}21'24.2''E$) was a grassy field with intermittent weeds and shrubs. This locality was surrounded by pine forests and traversed on the south side by a highway. On the southwest side there was a large cultivated wheat field.

Burning Field ($51^{\circ}04'05.7''N$, $30^{\circ}20'19.6''E$) was separated from the Control Site by a pine forest and consisted of a large grassy field on the border of the Kiev reservoir. Deposits of sphagnum moss were burning beneath the surface during our collecting trip. Entrance into this field is marked by a Great Patriotic War (World War II), Soviet-tank memorial, and the area is used by locals as a park and as a pasture for grazing cattle.

The Shop ($51^{\circ}05'20.0''N$, $30^{\circ}06'27.6''E$) comprised a broad expanse of deep grass along the edge of an evergreen forest. Lower areas consisted of flooded swampy regions, and the site was traversed by two canals that served to drain the low-lying locations. This locality was used as a militia check station after the explosion (1986–1990) through which exiting traffic from the exclusion zone was channeled and relocation assistance was provided. When the check station was abandoned, all buildings were removed and only a few concrete pits (used to change oil, repair engines, etc.), barbed-wire fences, and concrete slabs remained. This is the only locality outside the 30-km zone that was not actively grazed by cattle.

White Tree and Cow Pasture ($51^{\circ}50'55.6''N$, $30^{\circ}20'21.6''E$; $51^{\circ}50'29.2''N$, $30^{\circ}21'06.9''E$) were proximate areas of overgrazed fields that had short, sparse grass and scattered shrubs. A 1-km-wide band of Scotch pines separated the two areas, and thick evergreen forests with occasional deciduous stands traverse the northern and southern borders of these fields.

METHODS

Specimens were collected during three time spans; 16–24 May 1994, 26 August–9 September 1994, 4–22 May 1995. Specimens were trapped using Sherman live traps, usually baited with rolled oats (other local grains and sardines were used with minimal success). As access to

the zone is highly regulated, traps were checked as early as a driver and vehicle could be obtained each day. Live specimens were returned to a laboratory either at Stracholesse, which is immediately south of and outside the 30-km zone, or Pripyat, which is 2 km N of Reactor 4 and inside the 10-km zone (Fig. 1).

To facilitate karyotyping, individuals were injected interperitoneally with 0.15 ml of 0.001% vinblastine sulfate, a mitotic inhibitor, ca. 15–30 min prior to sacrificing. Mice were anesthetized by an intramuscular injection of a 3:2 (by volume) solution of Ketamine-Ace Promazine in a concentration of $1\mu\text{g/g}$ of body weight and then sacrificed by cardiac compression. Specimens were weighed, levels of radioactivity were measured with a Victoreen Model 100 Geiger counter, and standard museum measurements were taken. For karyotypic analysis, both femurs were removed and bone marrow was flushed with hypotonic solution (0.075 M KCl). Bone marrow was incubated at 37°C for 15 min. A cell button was produced by centrifugation, and the hypotonic solution was removed with a pipette. Cells were then resuspended in a fixative consisting of three parts absolute methanol and one part glacial acetic acid. This centrifugation-fixation process was repeated three times. After the third fixation, one to two drops of the cell suspension were blazed dried onto a microscope slide. The remainder of the cell suspension was transferred to a 1.5-ml eppendorf tube, sealed with parafilm, and maintained at room temperature until returned to Texas Tech University for additional analyses. For each specimen, we dissected the lungs, femurs, and a muscle sample, which were dehydrated in a drying oven for examination of presence of radionuclides, froze liver, heart, kidney, spleen, and for males, testes in liquid nitrogen, and macerated samples of liver in lysis buffer (Longmire et al., 1992) for DNA extraction. For pregnant females, individual embryos were carefully dissected from the uterus, macerated, and suspended in lysis buffer. Voucher specimens consisted of either standard museum preparations of skins and skeletons, skeleton-only, or skull-only preparations, or were preserved in 10% formalin. All voucher specimens will be catalogued into the mammal collection of The Museum of Texas Tech University. Permission to archive these specimens in the Texas Tech collection has been obtained from the university, the director of the museum, Gary Edson,

and the Bureau of Radiation Safety, Texas Department of Health. However, details of protocols currently are being established through the Texas Tech Radiation Safety Office.

We followed Wilson and Reeder (1993) for taxonomic designations. As used herein, fundamental number (FN) is number of arms of the autosomal complement. Karyotypes are presented in figures only where they were available for specimens collected in the most radioactive regions. We have used the English translation of the Ukrainian, Chernobyl, rather than the Russian, Chernobyl, name of this region.

RESULTS

A total of 6,659 trap nights produced 579 specimens. Trap success was significantly greater within the exclusion zones (9.5%) than outside the exclusion zones (7.6%: $\chi^2 = 6.96$, *d.f.* = 1, *P* < 0.05).

Taxonomic Diversity

Within the 30-km zone (3,720 trap nights) we obtained 355 specimens repre-

senting 11 species: [*Neomys fodiens*—water shrew, *Sorex araneus*—common shrew, *Sicista betulina*—birch mouse, *Microtus arvalis*—common vole, *M. oeconomus*—tundra vole, *M. rossiaemeridionalis*—common cryptic vole, *Clethrionomys glareolus*—bank vole, *Apodemus agrarius*—Old World field mouse, *A. flavicollis*—yellow-necked mouse, *A. sylvaticus*—wood mouse, *Micromys minutus*—harvest mouse; Table 1]. Although no voucher specimens were saved, four other species of small mammals were observed. Fragmentary skins of *Erinaceus europaeus* (eastern European hedgehog) were found as road kills within the 10-km zone. We examined two specimens of *Rattus rattus* (roof rat) collected by workers at a fish compound from inside the buildings adjacent to the Orchard (Fig. 2a). A mummified *Mus musculus* (house mouse) was found in an abandoned building in Pripyat.

TABLE 1.—Number of individuals of each species listed by collecting locality. Only individuals for which voucher specimens were made are included in the table. All individuals of *Microtus* listed to species were identified by karyotypic characteristics. Individuals listed as *Microtus* and *Apodemus* were found dead in the traps, and positive identification cannot be made until permission is obtained from University Radiation Safety Officers to bring voucher specimens into the formal museum collection. We think these specimens will be assignable to specific taxa already listed.

Site	Taxa						
	<i>Erinaceus europaeus</i>	<i>Neomys fodiens</i>	<i>Sorex araneus</i>	<i>Sicista betulina</i>	<i>Microtus arvalis</i>	<i>M. oeconomus</i>	<i>M. rossiaemeridionalis</i>
Exclusion zone							
Highly contaminated 10 km							
Gleboyke Lake	0	1	11	0	9	14	9
Chistogalovka	0	0	0	2	11	3	2
Red Forest	0	0	0	0	15	5	17
Less highly contaminated							
Orchard	0	0	0	0	10	0	22
Rechitsa	0	0	0	0	13	0	0
Outside of exclusion zone							
Little to no contamination							
Control Site	3	0	1	0	13	0	33
Burning Field	0	0	2	0	3	1	0
The Shop	0	0	0	0	12	12	4
White Tree	0	0	0	0	5	0	0
Cow Pasture	0	0	0	0	1	1	0
Total	3	1	14	2	92	36	87

Burrow systems of moles (probably *Talpa europaea*) were observed in the evergreen forest on the southwest side of the cleared area called the Red Forest ca. 2 km W of Reactor 4.

South of the 30-km zone (2,939 trap nights) we obtained a total of 224 specimens representing 12 species [*Erinaceus europaeus*, *Sorex araneus*, *Microtus arvalis*, *M. oeconomus*, *M. rossiaemeridionalis*, *Clethrionomys glareolus*, *Ondatra zibethicus*—musk rat, *Apodemus agrarius*, *A. sylvaticus*, *Mus musculus*, *Micromys minutus*, and *Mustela nivalis*—European common weasel; Table 1]. Individuals of *E. europaeus* and *O. zibethicus* were caught by hand, whereas the remainder were trapped with Sherman live traps.

Species Accounts

Erinaceus europaeus.—Individuals of this species were observed outside the zone at dusk and at night. Our restriction from the 10-km zone during these hours may have contributed to our failure to observe live specimens within the exclusion zone.

The karyotype (not figured) of specimens collected outside the 30-km zone ($2n = 48$, $FN = 88$) is indistinguishable from that described by Geisler and Gropp (1967).

Neomys fodiens.—A male of this species was collected on the north side of Gluboyke Lake within the most radioactive band of heavy, semi-flooded grass. Attempts to collect additional specimens by saturating this band of grass with 80 traps baited with sardines failed to produce specimens of either *Neomys* or *Sorex*.

Sorex araneus.—Specimens generally were collected in moist, semi-aquatic conditions. Karyotypic variation was documented within our sample with $2n = 27-29$, $FN = 36$ (Fig. 3). Variation in centric fusion is common throughout the range of this species and the number of autosomes can vary from 18 to 36 (Fredga and Nawrin, 1977; Hausser et al., 1985; Král and Radjabli, 1974; Olert and Schmid, 1978). It is unlikely that the variation we observed was the result of radioactivity. In some specimens, however, there was a small second arm on one pair of autosomes, and if

TABLE 1.—Extended.

Taxa										
<i>Microtus</i>	<i>Clethrionomys glareolus</i>	<i>Ondatra zibethicus</i>	<i>Apodemus agrarius</i>	<i>A. flavicollis</i>	<i>A. sylvaticus</i>	<i>Apodemus</i>	<i>Mus musculus</i>	<i>Micromys minutus</i>	<i>Mustela nivalis</i>	Total
15	6	0	19	3	12	4	0	0	0	103
8	0	0	0	0	0	0	0	0	0	26
29	5	0	2	0	8	17	0	0	0	98
9	1	0	1	0	25	9	0	0	0	77
0	0	0	18	0	1	0	0	1	0	33
44	0	1	14	0	27	9	18	0	0	163
0	0	0	0	0	0	0	0	1	0	7
0	2	0	0	0	8	0	0	0	1	39
4	0	0	1	0	6	0	0	0	0	16
0	0	0	0	0	0	0	0	0	0	2
109	14	1	55	3	87	39	18	2	1	564

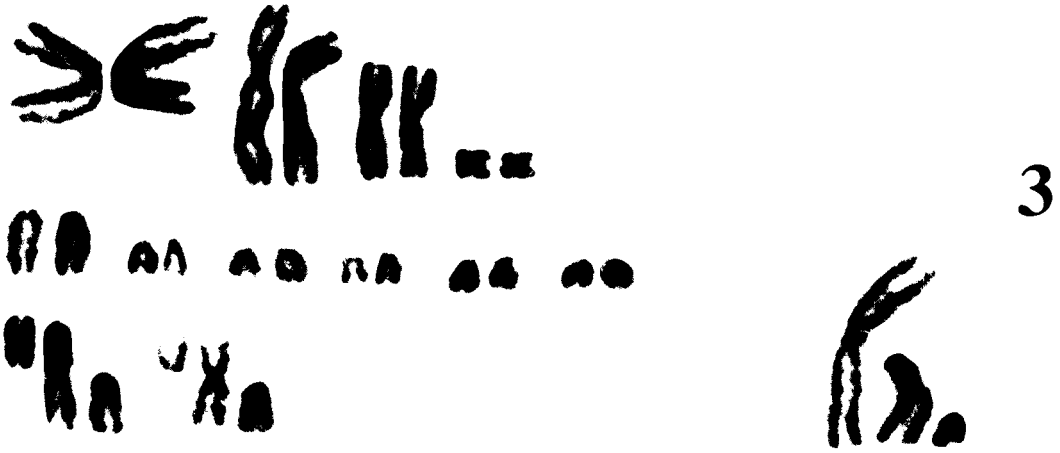


FIG. 3.—Representative karyotype of a male *Sorex araneus* (TK 48276). This individual was heterozygous for two centric fusions (first two chromosomal triplets on bottom row) and the species has been reported previously as being XYY (sex chromosomes are shown as third triplet on bottom row).

this is counted, the fundamental number will be elevated to 38, which is not characteristic of the previously described karyotypic forms. The sex-determining chromosomes are reported in the literature as XYY (Fredga and Nawrin, 1977; Hausser et al., 1985; Král and Radjabli, 1974; Olert and Schmid, 1978), and this is in agreement with what we report (Fig. 3).

Sicista betulina.—Two specimens were trapped at Chistogalovka in a grassy habitat adjacent to the deciduous forest on the north side of the road. The karyotype of this species had $2n = 32$ and $FN = 58$ (Fig. 4) with possible variation in centromeric position from that reported by Sokolov et al. (1987) as the A form. Because our chromosomal preparations did not have adequate chromatid definition, and our copies of Sokolov et al. (1987) are of poor reproduction, it is possible that any differences between the two may be an artifact. These authors describe a second karyotype for this species that consists of $2n = 44$ and $FN = 52$.

Microtus.—Three species of *Microtus* were obtained from the 10-km zone. *M. oeconomus* is a larger, darker-colored, longer-tailed, species that is relatively easily

distinguished in the field from *M. arvalis* and *M. rossiaemeridionalis*. Under field conditions, however, we were unable to distinguish *M. arvalis* from *M. rossiaemeridionalis*. In Table 1, all of the specimens listed as *M. arvalis* or *M. rossiaemeridionalis* were identified based on karyotype, whereas specimens that were not karyotyped are listed as *Microtus*.

Microtus arvalis is easily distinguished from *M. rossiaemeridionalis* based on karyotypes (Figs. 5 and 6). *M. arvalis* was taken at every locality trapped and appeared to be common in all drier, grassy habitats. Variation in fundamental number has been reported within *M. arvalis* ($FN = 58-90$), and most of the specimens within the Chernobyl sample appeared to have karyotypes similar to that described for *M. arvalis duplicatus* ($2n = 46$, $FN = 84$ —Král and Lyapunova, 1975), which has two pairs of small acrocentric autosomes. Within our sample, two other pairs of small chromosomes also varied in arm length from acrocentric to subtelocentric.

The taxonomic history of *M. rossiaemeridionalis* has been confusing because there are no methods to distinguish this species under field conditions from *M. arvalis*

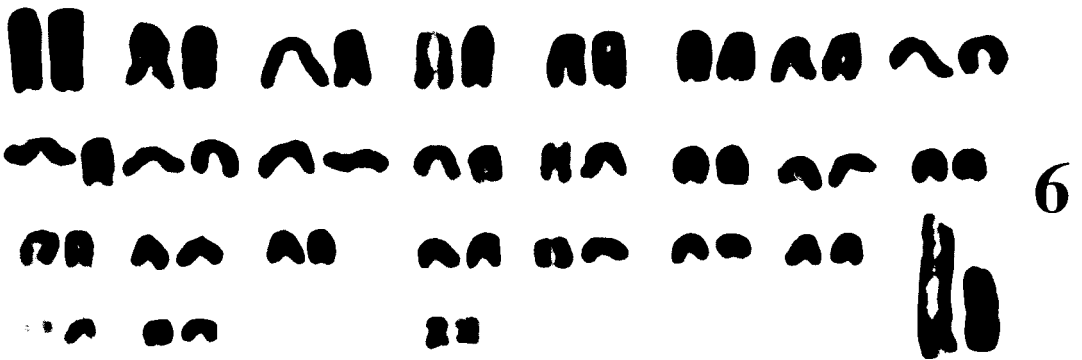
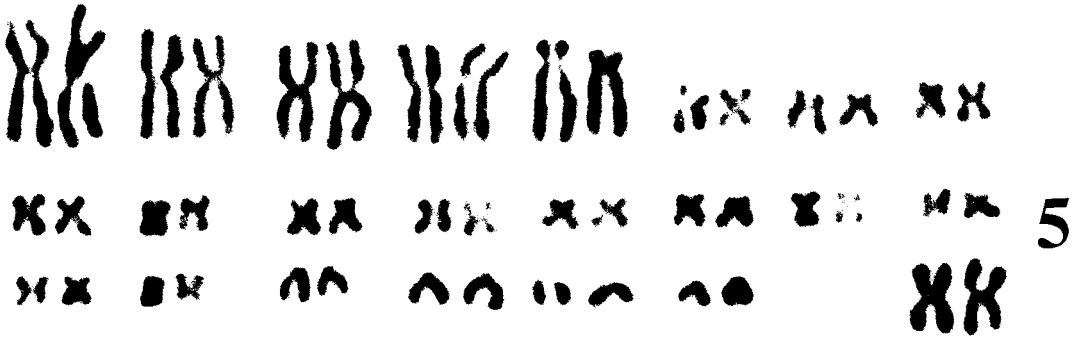
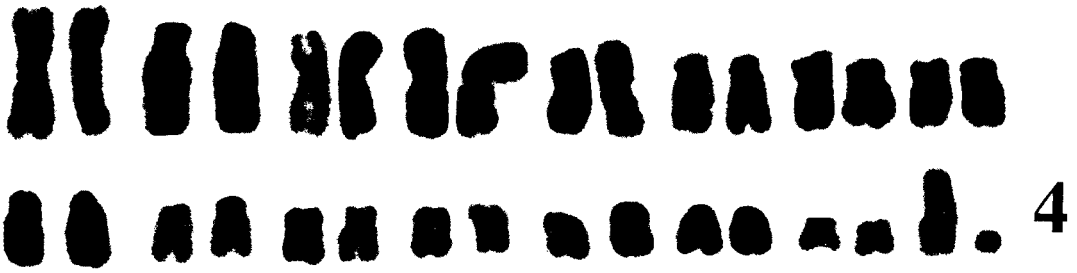


FIG. 4.—Representative karyotype of a male *Sicista betulina* (TK 48378). Sex chromosomes are the right-hand pair on the bottom row.

FIG. 5.—Representative karyotype of a female *Microtus arvalis* (TK 44864). Sex chromosomes are the right-hand pair of the bottom row.

FIG. 6.—Representative karyotype of a male *Microtus rossiaemeridionalis* (TK 44842). Sex chromosomes are the right-hand pair of the bottom row.

(Fredga et al., 1990). The two are easily distinguished karyotypically, but most type specimens that are assignable to the *arvalis-rossiaemeridionalis* complex do not have karyotypic data available for them. Other names that have been applied to this spe-

cies include *caspicus*, *epiroticus*, *ghalgai*, *muhlisi*, *relictus*, *rhodoponsis*, and *subarvalis*. In this region of Ukraine, *M. arvalis* and *M. rossiaemeridionalis* are truly sympatric (Zagorodnyuk, 1991) and often were captured in adjacent traps across a wide

variety of grassy habitats. We were unable to determine any habitat preference that distinguished the two. The karyotype for *M. rossiaemeridionalis* ($2n = 54$, FN = 54; Fig. 6) was entirely acrocentric, except for one pair of small biarmed elements, and did not differ from that reported by Zivkovic and Petrov (1974), Zima et al. (1981), and Fredga et al. (1990). The only individual observed with an atypical karyotype was collected outside the 30-km zone and possessed a $2n = 53$ with a single, large, biarmed element, one pair of small biarmed elements, and 50 acrocentric elements.

Specimens of *M. oeconomus* were collected from six of the 10 localities trapped (Table 1). *M. oeconomus* occurred in the more swampy regions within the zone, whereas *M. arvalis* and *M. rossiaemeridionalis* were in the higher, more xeric habitats. This species has $2n = 30$, FN = 54 (Fig. 7). Zima and Král (1984) reported $2n = 30$ and FN = 56 with variability occurring in position of the centromere in the smallest element. In the literature, this element has been reported as occurring as a submetacentric (Fredga and Bergstrom, 1970), subtelocentric (Král, 1972), or an acrocentric (Nadler et al., 1976). In our specimens, the smallest elements occurred as acrocentrics.

Clethrionomys glareolus.—Because the trees that were killed in the Red Forest were highly radioactive, this forest was leveled and covered with soil. *Clethrionomys* was obtained where these dead trees were exposed to the surface within the Red Forest. Additionally, specimens were taken in the forest regions and roadside ditches at Gluboyke Lake. The karyotype of our specimens ($2n = 56$, FN = 56, Fig. 8) was similar to that reported in the literature (Gamperl, 1982; Zima and Král, 1984). In our specimens, there were short second arms on at least two pairs of autosomes. If these short arms are assigned a fundamental number, they will differ from published reports. The X chromosome is acrocentric

and the Y chromosome is a small biarmed element.

Apodemus agrarius.—This species was common in our collections, appeared in a variety of habitats, and generally was sympatric with *A. sylvaticus* at most locations. The karyotype of *A. agrarius* ($2n = 48$, FN = 54, Fig. 9) differed from those described for *A. sylvaticus* and *A. flavicollis* in that four small pairs of autosomes were biarmed. This agrees with the karyotype reported by Zima and Král (1984). We observed no variation in our sample.

Apodemus flavicollis.—This is the largest species of the three *Apodemus* that we collected in the zone. Our three specimens were obtained from the forested regions adjacent to Gluboyke Lake. Karyotypic data ($2n = 48$, FN = 46, not figured) were obtained from a single individual, did not differ from that described in the literature (Hirning et al., 1989; Vujosevic et al., 1991; Zima and Král, 1984), and were indistinguishable from that shown for *A. sylvaticus* (Fig. 10).

Apodemus sylvaticus.—This species was collected from open areas usually associated with herbaceous plants. It rarely was obtained in the thicker grassy areas where *M. arvalis* and *M. rossiaemeridionalis* were common. As described in Zima and Král (1984) and Hirning et al. (1989), whose samples came from widely separated geographic localities, the karyotype of this species ($2n = 48$, FN = 46, Fig. 10) was composed entirely of acrocentric chromosomes. We observed no variation from this previously described pattern. Both the X and Y chromosomes were acrocentric.

In Table 1, specimens listed as *Apodemus* were individuals that died in the traps during the night and their specific status was not recorded at the time they were prepared as voucher specimens. These individuals, however, are referable to one of the three species of *Apodemus* listed above.

Micromys minutus.—Single individuals of this tiny mammal were obtained at Rechitsa and the Burning Field. It appears to

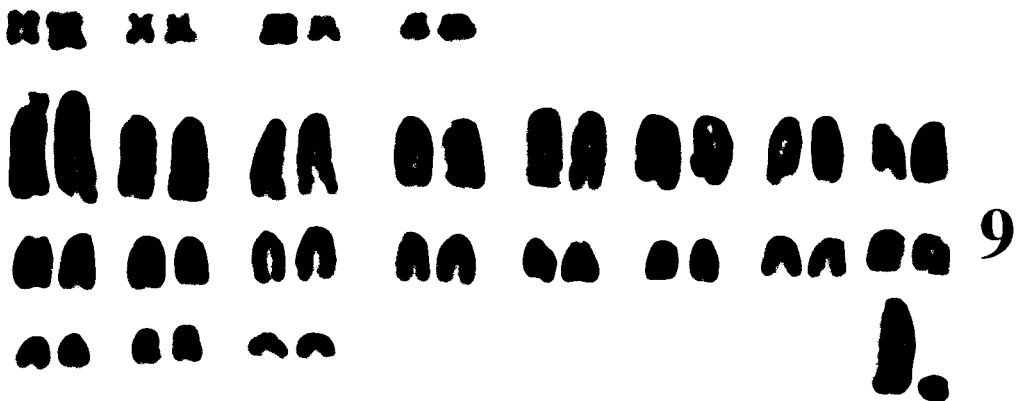
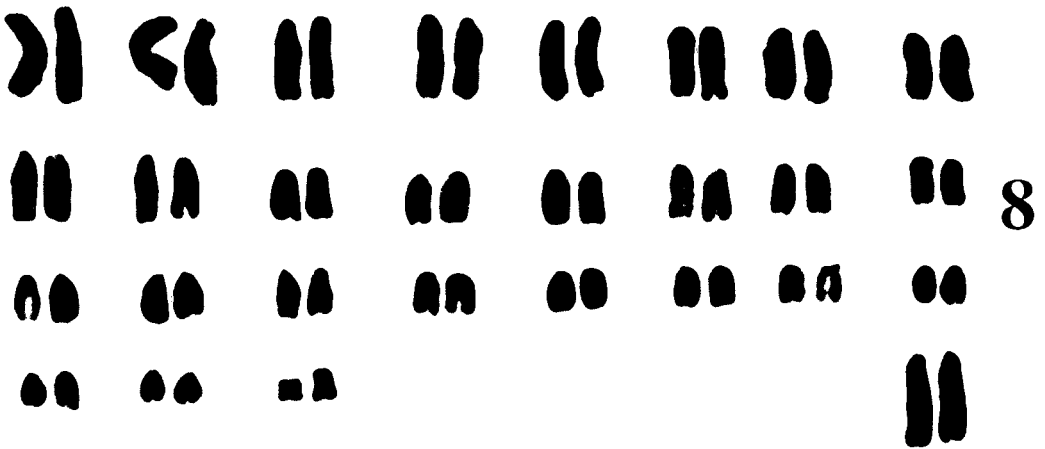


FIG. 7.—Representative karyotype of a male *Microtus oeconomus* (TK 44844). Sex chromosomes are the right-hand pair of the bottom row.

FIG. 8.—Representative karyotype of a female *Clethrionomys glareolus* (TK 48299). Sex chromosomes are the right-hand pair of the bottom row.

FIG. 9.—Representative karyotype of a male *Apodemus agrarius* (TK 44837). Sex chromosomes are the right-hand pair of the bottom row.



FIG. 10.—Representative karyotype of a female *Apodemus sylvaticus* (TK 44572). Sex chromosomes are the right-hand pair of the bottom row.

FIG. 11.—Representative karyotype of a female *Micromys minutus* (TK 44872). Sex chromosomes are the right-hand pair of the bottom row.

live in the taller, aquatic, cattail-like plants, which have been described as characteristic of the habitat of *Micromys*. As previously described in the literature (Judes, 1981; Král, 1972; Zima, 1983), the karyotype of this species ($2n = 68$, FN = 120, Fig. 11) was composed of a disproportionally large pair of submetacentric autosomes plus a graded series of 32 pairs of smaller autosomes. Of this graded series, six pairs had submetacentric centromeric positions, three pairs appeared to be acrocentric, and the remainder had a short second arm. Arm

length on the autosomes has been reported to vary (Judes, 1981).

Mustela nivalis.—The karyotype (not figured) of our single specimen from outside the radioactive area had $2n = 42$ and FN = 80. It was identical to the karyotype described by Omodeo and Renzoni (1966).

DISCUSSION

Our goal to better understand the significance of the world's worst nuclear-power-plant disaster on the biota that inhabit these polluted regions can be addressed

from several perspectives, such as effects on ecological diversity, fitness, mutation rate, and physiological health. Although nuclear deserts or monsters are perceptions that often are associated with radioactive pollution, our studies do not substantiate such ideas. Our observations do not suggest that there is a decrease in numbers or taxonomic diversity of small mammals in the most radioactive habitats sampled relative to that present in less-polluted regions (Table 1). Our studies show that a dynamic ecosystem is present in even the most radioactive habitats and that a diverse array of species of small mammals is a viable component in this ecosystem. In addition to the species of small mammals noted above, we observed during our travels and field work within the 10-km zone individuals of *Vulpes vulpes* (red fox), *Canis lupus* (gray wolf), *Alces alces* (moose), *Lutra lutra* (river otter), *Capreolus capreolus* (roe deer), *Sus scrofa* (Russian wild boar), and *Lepus europaeus* (brown hare). Feral dogs also are common in the city of Pripyat and were observed roaming in the more remote regions of the 10-km zone. Although our field parties spent a comparable amount of time in the regions beyond the 30-km zone, we did not observe any of these large wild mammals with the exception of a single brown hare at the White Tree locality and a moose that was killed by hunters a few hundred meters from the 30-km barricade near Stracholesyie. Physical signs such as tracks, dens, and feces of large mammals were observed outside of the exclusion zones, but it is our perception that the mammalian fauna, especially the large mammals, are more abundant in the highly radioactive 10-km zone than they are in areas outside the zone that do not exclude most human activities.

We handled hundreds of specimens and observed no bizarre gross morphological features consistent with ideas of nuclear monsters. The only atypical aspect that we observed was that a few individuals had

enlarged spleens, which were three to six times larger than is typical of small rodents.

Cooper and Hsu (1971) documented that radiation-induced chromosomal breakage in *Microtus* can produce atypical, aberrant karyotypic characteristics. Have the species that are distributed in the most radioactive areas evolved new chromosomal characteristics? When compared to previously published karyotypes and to the karyotypes of individuals from our samples from control regions, there was minimal chromosomal variation observed that could have been induced by radiation. Clearly, there was nothing comparable to the radiation-induced chromosomal rearrangements reported for *Microtus* by Cooper and Hsu (1971). Our initial observations of chromosomal variation within individuals from the most radioactive sites (>1,000 cells observed with only one centric fusion) did not reveal an abundance of atypical chromosomes. The only individual with an atypical karyotype came from a site outside the 30-km zone (*M. rossiae-meridionalis* collected from The Shop).

One factor that may account for the differences between our observations on small mammals at Chernobyl and the results of Cooper and Hsu (1971) is the amount and rate of radiation dosage. Cooper and Hsu (1971) X-irradiated male *Microtus agrestis* with 350 rads whole body dose at ca. 85 rad/min. We have not observed a location at Chernobyl where the native mice would encounter a dosage rate of this magnitude, although it is likely that at the time of the meltdown some individuals received an excess of 350 rads whole-body count. Our specimens also differed from those studied by Cooper and Hsu (1971) in that there was a substantial internal dose of radiation. *Microtus* from the Red Forest were found to have concentrations of ¹³⁷Cesium of ≤ 458 becquerels/g of dry muscle tissue. This would indicate that each gram of their tissues is subjected to 458 nuclear disintegration/s as a result of

internal dose. The external dose in the Red Forest can be many-fold that of the internal dose. Our analysis using standard karyotypes certainly does not have the resolution of more sophisticated methods such as G-banding (Ohtaki et al., 1982) or fluorescent in situ hybridization (Schull, 1995), so care must be taken when comparing our data to the results reported by these authors for Atomic bomb survivors of Hiroshima and Nagasaki.

Although results of gross chromosomal analysis have suggested minimal impact of the pollution resulting from the Chernobyl meltdown, the rate of mutation in the cytochrome-b gene in *M. arvalis* and *M. rossiaemeridionalis* has been estimated at greater than one mutation per 5,000 nucleotide sites per generation ($>2 \times 10^{-4}$; R. J. Baker et al., in litt.). It is difficult to understand how such an elevated rate of mutation does not negatively impact the health and relative fitness of individuals. It also is unclear if these small mammals can tolerate such an elevated rate of mutation over an evolutionary time frame. Studies of relative fitness and health aspects of individuals that have undergone substantial genetic mutation should better clarify the short-term interactions between the biological abundance of individuals at these radioactive sites and the reported high rate of mutation.

In conclusion, the small-mammal fauna is abundant in both number of individuals and number of species even in the most radioactive sites within the 10-km zone. The diversity of mammals within and outside of the 10-km and 30-km exclusion zones appears comparable. Numbers of large, wild mammals appear higher within the restricted areas and trapping success of small mammals within the exclusion zones was greater than outside the exclusion zones. Based on our observations, the magnitude of morphological and chromosomal aberrancy is not sufficient to readily identify the site as radioactively polluted without electronic sensing devices.

Care must be taken, however, when interpreting our results as they relate to ecological risk and health concerns of humans. The negative effects of the worst nuclear-power-plant disaster in the world on the diversity and population density of native mammals is no greater than the cumulative negative effects of farming, overgrazing, deforestation, and other activities characteristic of human populations. High population densities of native mammals within the contaminated regions are likely the result of the exodus of 135,000 people and not the benign effects of radiation. Small native mammals have a tremendous reproductive potential, and although there may be a shortened life expectancy and an increase in cancer and other health-related problems, a high population density could be maintained. Within this context, an elevated rate of cancer or an increase in spontaneous abortions could be present but masked in the "more young are born than can survive" axiom of population dynamics. In regards to human health, however, elevated rates of cancer and an increase in spontaneous abortions are not acceptable risks although they might not significantly impact growth of the human population.

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