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Urban forest condition and succession in the abandoned city of Pripyat, near Chernobyl, Ukraine

Igor Laćan[a,*], Joe R. McBride[b], Duane De Witt[c]

[a] University of California, Cooperative Extension, 80 Stone Pine Road, Half Moon Bay, CA 94019, USA
[b] Department of Landscape Architecture and Environmental Planning, University of California, Berkeley, 202 Wurster Hall, MC 2000, Berkeley, CA 94720, USA
[c] Urban Planner, Santa Rosa, CA 95407, USA

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ABSTRACT

Following the April 26, 1986, accident at the Chernobyl nuclear power plant (Ukraine), the nearby city of Pripyat was contaminated and then quickly abandoned with its urban trees largely intact, resulting in a unique "city forest" that has remained un-maintained for over one-quarter of a century. We assessed the composition and condition of city trees in Pripyat, and documented the process of ecological succession in an attempt to predict the future urban forest, by surveying trees on 40 plots distributed across 4 urban tree habitats (street-side, tree grove, lawn, and pavement). The plots contained 20 species of trees, and were dominated by the seedling age-class, with as many as 8980 *Acer platanoides* seedlings/ha. Among the urban habitats, street-side and tree grove plots had the highest density of regenerating trees. Regeneration varied by species, with some (e.g., *Populus nigra* 'Italica') regenerating in every plot where mature trees were present, while others (e.g., *Aesculus hipocastaneum*) not regenerating at all. Based on the regeneration patterns and tree species characteristics, we expect the future urban forest of Pripyat to contain a mosaic of oak/maple areas (street-side, grove, and lawn habitats) with poplar/aspen areas on the pavement habitat. Condition of mature trees was good in over 50% of surveyed trees, while the rest exhibited the defects common to other urban trees (e.g., co-dominant stems), but also displayed characteristics generally absent from trees in other cities (e.g., very high live crown ratios). In its current age-distribution, species composition, and condition of its urban trees, Pripyat demonstrates the ongoing change from the primacy of anthropogenic factors (e.g., trees selected for ornamental characteristics) to ecological ones (e.g., shade tolerance) in shaping the composition and condition of an abandoned urban forest.

Introduction

> "The cleanliness and abundance of greenery and flowers are the striking features of the new town under construction (Pripyat)" From a 1976 monograph "Pripyat—a New City in Ukraine"

The most serious accident to date in the history of nuclear power occurred in the early hours of April 26, 1986 when one of the reactors exploded at the Chernobyl (Ukrainian: Chornobyl) nuclear power plant about 100 km north of the Ukrainian capital Kiev (Ukrainian: Kyiv). A problematic reactor design, combined with operator errors and knowledge gaps, led to multiple explosions and a subsequent 10-day fire, which released large amounts of radiation into the environment. Considering just the most troublesome radioactive elements, an estimated 85 petabecquerels (PBq) of radiocesium (^{137}Cs) was released (NEA, 2002), more than twice than about 37 PBq of ^{137}Cs estimated released in the 2011 Fukushima Dai-ichi disaster (Stohl et al., 2012).

Much of the escaped radioactive pollution settled out around the power plant, severely contaminating the local villages as well as the nearby city of Pripyat, which was hastily evacuated on April 27, 1986. The radioactive fallout was sufficiently hazardous that a 30-km exclusion zone was established where all human activity was restricted and permanent habitation was prohibited; in total, over 100,000 persons were evacuated from the exclusion zone, most of them having received on average 15 milisievert (mSv) of radiation (about five times the yearly background dose; NEA, 2002).

Decontamination measures undertaken after the accident were only marginally successful, and because of the long-lived radioactive isotopes still present (e.g., ^{137}Cs has a half-life of 30 years)

* Corresponding author. Tel.: +1 510 684 4323.
E-mail address: ilacan@ucanr.edu (I. Laćan).

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the exclusion zone remains mostly depopulated. The city of Pripyat remains abandoned and its urban trees – although largely undamaged by the radiation – have not been maintained since 1986.

Despite the depopulation, the Chernobyl area has been extensively studied since the accident. The initial studies in the exclusion zone focused on the human consequences of radiocontamination, and noted the uneven distribution of radionuclides in the environment around Chernobyl. Some areas near the power plant received doses of fallout high enough to kill trees (lethal dose is about 20 Gy), with the doses as high as 100 Gy in a few areas (Smith and Beresford, 2005, p. 270, cf. the lethal dose for humans ≈5 Gy). One of these areas became known as "red forest" where dying Scotch pines (*Pinus silvestris* L.) turned red en masse within weeks of the accident; they were subsequently felled and buried on-site. Most of the exclusion zone, however, – including the city of Pripyat – was contaminated to a lesser degree, making it unsafe for human habitation but not lethal to resident biota or trees.

Subsequent studies have explored the ecological consequences of radioactive contamination combined with a sudden removal of human influence on the area. These effects and their interactions have been examined in a number of studies (see Møller and Mousseau, 2006 for a summary), evaluating effects from the genetic level (e.g., Kovalchuk et al., 2000), to physiological (e.g., Camplani, 1999), and population-level changes (Møller et al., 2006). Studies on trees focused on the genetic effect of radiation (Kalchenko et al., 1993a, 1993b; Rubanovich and Kalchenko, 1994; Kovalchuk et al., 2003), with some studies also including the impact on physiology and growth (Arkhipov et al., 1994) and recent works demonstrating ecosystem-level depression in productivity (Møller et al., 2012; Mousseau et al., 2014).

However, no study to date has considered the vegetation changes – "succession" – in the city of Pripyat, or the changes in the age structure, species composition, and size and condition ("health"), of the planted tree flora. Plant succession has been a topic of interest and controversy since the founding days of ecology (Cowles, 1899; Clements, 1916; Egler, 1954; Drury and Nisbet, 1973; Connell and Slatyer, 1977; McIntosh, 1985; Pickett et al., 1987). The initial concept of a progressive change in the development of vegetation over time suggested by Cowles (1899) and summarized by Clements (1916) was challenged by Tansley (1935), Egler (1954), Drury and Nisbet (1973), and Connell and Slatyer (1977), and the debate was partially resolved by a comprehensive framework proposed by Pickett et al. (1987). Two broad patterns of plant succession have been recognized. Primary succession occurs on substrates that have not previously supported plants, whereas secondary succession occurs on previously vegetated substrates. A particular type of secondary succession, known as old-field succession, occurs after the abandonment of agriculture (Oosting, 1942), where the important factors include the seed banks present in the formerly cultivated soil and the dispersal of seeds of species adjacent to the abandoned field. Studies of plant succession on demolition sites and abandoned land in urban areas have identified a parallel with old-field succession in the absence of landscape management (McBride, 2013; Rostanski, 2008; Dana et al., 2002; Sukopp and Werner, 1987; Vessel and Wong, 1987; Hardesty, 1984). Pripyat, a city established in 1970 and abandoned in 1986, offered a unique perspective on the succession processes of planted vegetation – including ornamental trees – in abandoned urban habitats, as the city infrastructure and plantings have remained largely undisturbed by humans since 1986.

The objectives of this study were to: (1) document the size and composition of urban trees that had been planted in Pripyat prior to the Chernobyl accident and the patterns of establishment of new trees since the accident; (2) predict the characteristics of the future urban forest in Pripyat; and (3) examine effects that prolonged absence of maintenance has on urban trees by evaluating tree condition, with a goal of furthering our understanding of urban forest change that could be applied to the maintenance of the current urban forests and the design of the future municipal plantings.

Study site, materials and methods

Located about 4 km from the nuclear plant, Pripyat was a city of about 50,000 people at the time of the accident, and served as the residential center for the administration staff and workers at the Chernobyl power plant and a local factory. The city layout strongly resembles that of the other "Atomograds" (lit. "Atom cities"), such as Obninsk and Dimitrovgrad in Russia, the "company towns" built in parallel with nuclear plants to house workers. A monograph on Pripyat published in 1976 describes the city – still under construction – as consisting of multiple five-story buildings and other residential high-rise structures (eventually they would include nine-story housing blocks) in a matrix of broad streets, lawns, and wooded open space areas, including one large park and 35 playgrounds. The city was divided into four sub-districts ("mikrorayon"), each consisting of an outer "ring" of residential high-rise blocks (that could house up to about 9000 residents), with green space, schools, and medical facilities situated in the "interior" of the microdistrict. One result of this layout was that children living in each microdistrict would not have to cross any streets to reach their local elementary school. Buildings devoted to culture (e.g., concert hall, theater), government and hospitality (e.g., hotel) were clustered around the main square, where the town's main thoroughfare terminated (Fig. 1). Leading toward the town's largest employer – the nuclear plant – Lenin Boulevard (Prospekt Lenina) was arranged with the in- and out-bound traffic lanes separated by a wide median planted with a double row of Lombardy poplars (*Populus nigra* var. 'Italica') and its sidewalks were lined with horsechestnut (*Aesculus hippocastaneum* L.); an analogous design can still be seen on Kiev's main thoroughfare, the Taras Schevcenko Boulevard. Pripyat was still growing at the time of the Chernobyl accident, and had been projected ultimately house as many as 80,000 residents.

Pripyat has a temperate continental climate (Köppen class Dfb), with hot summers (mean daily temp. maxima of 24.5 °C in July), cold winters (mean daily temp minima of −8.2 °C in January), and year-round precipitation (yearly mean 600 mm). Situated on alluvial terraces next to the Pripyat River, the town is underlain by sandy soils with good drainage. Local geography is flat, with low rolling hills, and the entire region is known as Polissya (approximately translated as "woodlands") and is noted for its large expanse of wetlands. Vegetation of the area includes wetland plants, mixed grasslands and woodlands, and lowland forests, and because the area had been inhabited for centuries, the local tree flora included both native *P. silvestris* and naturalized (e.g., *P. nigra* 'Italica') species common to Europe. Perhaps reflecting the somewhat limited appreciation of the natural environment, the 1976 monograph on Pripyat notes that "there was nothing but sand and sparse pine woods" in the area prior to the construction of the city (p. 7).

Pripyat was extensively landscaped with ornamental trees, shrubs, and flowers, in part because quality of life in the new town was seen as the main factor in attracting skilled nuclear workers (Read, 1993), and the combination of local climate and soils allows a relatively wide ornamental plant palette. Street trees discernible on the photographs from 1976 include *P. nigra* 'Italica', rowan (*Sorbus aucuparia* L.), European birch (*Betula pendula* Roth), Norway maple (*Acer platanoides* L.), and *A. hippocastaneum*, whereas the trees planted in groves around buildings included additional species, such as weeping willow (*Salix babylonica* L.) and *P. silvestris*. Especially prominent on photographs were the numerous