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Original article

Current and potential landscape functions of areas with the remnants of World War II bombing in the Koźle Basin, southern Poland

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ABSTRACT

Wars bring civilisation and environmental disasters. In the forests and wetlands of the Koźle Basin (southern Poland), clusters of bomb craters remain, which are associated with the air campaign conducted by the USAAF to disable the Third Reich's fuel facilities. They are among the most spectacular in Europe today. There are nearly 6,000 large bomb craters with a diameter of 7-15 meters and smaller ones from the fall of unexploded ordnance. These areas, with their characteristic scarred relief, currently pose difficulties in terms of economic use. The depressions left after the bombs fell, naturally became small sedimentation basins and niches that were taken over by nature. Landscape and nature mapping of the surveyed areas, altered by the bombing, in conjunction with historical data, suggest that they require protection in the form of two landscape-nature protected complexes (a form of landscape protection in Poland). They can serve as environmental and historical education zones, wildlife sanctuaries, as well as areas for the introduction and reintroduction of species. This is important in a region where hundreds of years of agricultural dominance, as well as decades of intensive industrial development and urban settlement, have caused major changes in the natural environment and degradation of its structures. Similar historical sites, trails and cultural parks dedicated to the war campaigns have been introduced in different European countries.

KEY WORDS: bomb craters, ecological niche, protection of natural and historical values

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1. Introduction

Wars bring civilisation and environmental disasters. New elements of the evidence of war are appearing in the environment, such as bomb craters, which are often present in extensive groups (i.a. PASSMORE ET AL., 2014; PASSMORE & CAPPS-TUNWELL, 2020; DOLEJŠ ET AL., 2020; WAGA & FAJER, 2021; WAGA ET AL., 2022a). Some of these are filled with water. These "scars of war" turn into refuges over time for various plant and animal species (WARWICK, 1949; VAD ET AL., 2017; KRASZNAI-K ET AL., 2018; BOLGOVICS ET AL., 2019).

In the 1930s and 1940s, Germany compensated for the lack of oil by synthesizing hydrocarbons (LEVINE, 1992; EHLERS, 2009). There were three large plants for liquid fuels produced from coal: Odertal as well as Blechhammer South and North were located in the Koźle Basin (at that time the Kozle Basin was part of eastern Germany). From July to December 1944, the 15th United States Army Air Force conducted bombing raids there (KONIECZNY, 1998; HADUCH, 2019; WAGA & FAJER, 2021). In this phase of the war, it was inevitable. After the air campaign, nearly 6,000 large craters, with a diameter of 7-15 meters and a depth often exceeding 2 meters, as well as smaller forms after the fall of unexploded bombs, were preserved in forested and wetland areas around Kędzierzyn-Koźle (WAGA & FAJER, 2021; WAGA ET AL., 2022a, b, d). These craters create a distinctive "pox-ridden" relief. All the depressions

became small sedimentation basins and niches, which became used by wildlife.

The aim of this research was to identify natural conditions in the two areas altered by the bombing, primarily: geomorphological, soil, hydrological and habitat conditions, among others, for potential species introduction. This is particularly important as the study area lies at the intersection of areas of intensive agricultural and industrial use, and a large part of the reservoirs and rivers there serve as waterways and recipients of wastewater (Fig. 1). Within these waters, there is a decline in biodiversity. The presence of areas deformed by military operations, now left to nature, provides an opportunity to protect wild species in danger of extinction and to restore their populations, as well as for selected complexes of forms to serve educational functions and historical memorial purposes. This can be implemented in the form of natural landscape complexes. The research presented here is a continuation of several years of work (WAGA ET AL., 2022a).

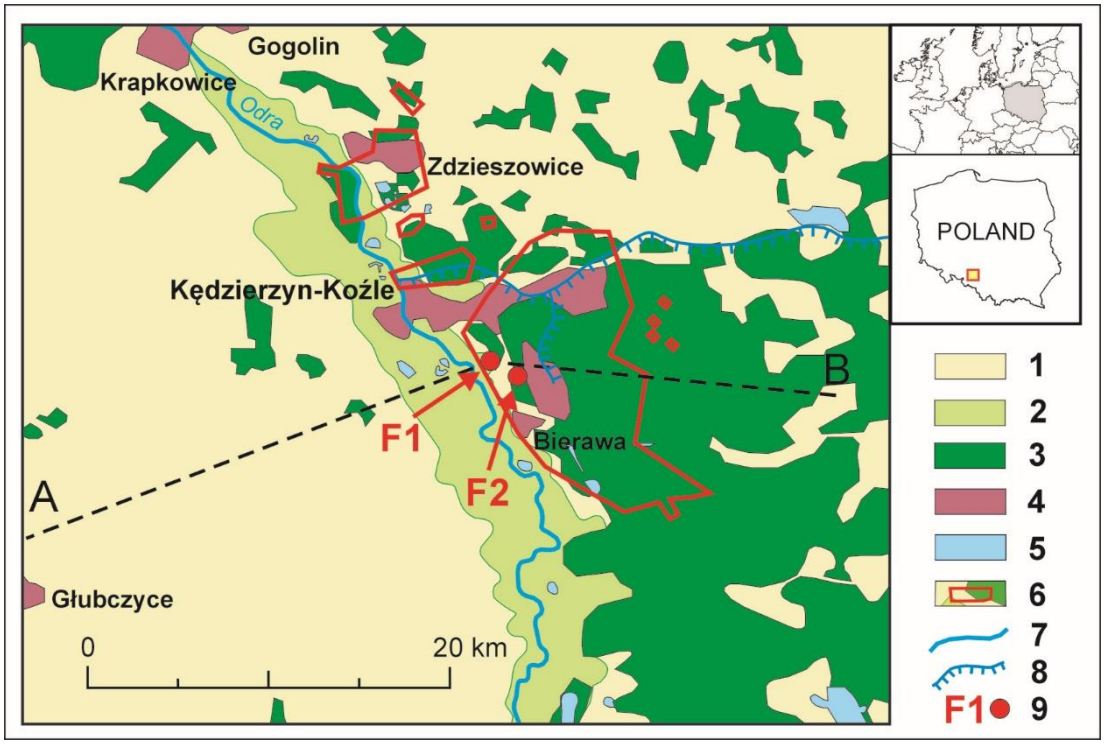


Fig. 1. Location of the study area
1 – fields, 2 – meadows, 3 – forests, 4 – urban-industrial areas, 5 – water reservoirs, 6 – areas bombed during World War II, 7 – rivers, 8 – channels, 9 – F1, F2 study areas (prepared by J.M. Waga)

2. Study area

Two study areas located in the central part of the Koźle Basin (southern Poland) (KONDRACKI, 1994), on the land of the villages of Brzeźce (F1) and Stare Koźle (F2) in the municipality of Bierawa, Opolskie Province, were selected for the study (Fig. 1). The third interesting area is located in Kędzierzyn-Koźle Azoty. Nearly the entire area is covered by varied Quaternary sediments: fluvioglacial and fluvial sands, gravels and loams, as well as aeolian sands. The valley bottoms are covered with silt and peat (KOTLICKI & KOTLICKA, 1980). The area features morphological steps associated with the deglaciation of the Odranian ice sheet, as well as a system of five river terraces (Fig. 2) (WAGA, 1994).

In the forests of the Koźle Basin there are: podzolic soils, rusty soils, gley soils, lessive soils, brown soils, peaty soils, mucky soils, fluvisols and arenosols (MAPA SIEDLISK LEŚNYCH..., STEC-KARAŚ, 2020;). The agricultural areas in the Odra Valley are dominated by fluvisols, with fewer silt-peat, muck and mucky soils. On the higher terraces, weak acid brown and lessive soils are found (MAPA GLEBOWO-ROLNICZA...).

The entire study area belongs to the Odra River basin (ATLAS PODZIAŁU HYDROGRAFICZNEGO..., 2005). In the study zone, water is shallow, or at the ground surface. In many places it was drained through drainage ditches into rivers (MAPA HYDROGRAFICZNA...). At present, there are only artificial bodies of water: harbour and shipping channel basins, post-mining workings, settling ponds, breeding ponds and other small ponds in bomb craters.

On the River Odra, near Brzeźce, in the years: 1903, 1985, 1997 and 2010, devastating flood waves took place with culminations in rises in water

levels: 172.64, 172.30, 173.50 and 172.90 m.a.s.l. A maximum flow of 3120 m³/s was recorded in 1997 (OPERAT OCHRONY..., 2012), so the paleomeander at the F1 study area is protected by a dike as a polder. The second study area (F2) – in Stare Koźle – is flooded by local watercourses up to 176.5 m.a.s.l.

The Koźle Basin, which is open to the northwest and south, is easily affected by large-scale circulation processes in the atmosphere. According to the climatic regionalisation of WOŚ (1993), it is part of the XXV South Lower Silesia region, with a mild, moderately warm climate. The value of the average annual air temperature of 8.6°C is among the highest in the country, as is the length of the growing season of 210-220 days. This has a beneficial effect on plant development. The annual temperature amplitude there is 20.5°C, and average annual precipitation reaches 638 mm (STEC-KARAŚ, 2020). Within the Koźle Basin, the formation of the local climate is influenced by the phenomena of short-term thermal inversions and the urban heat island.

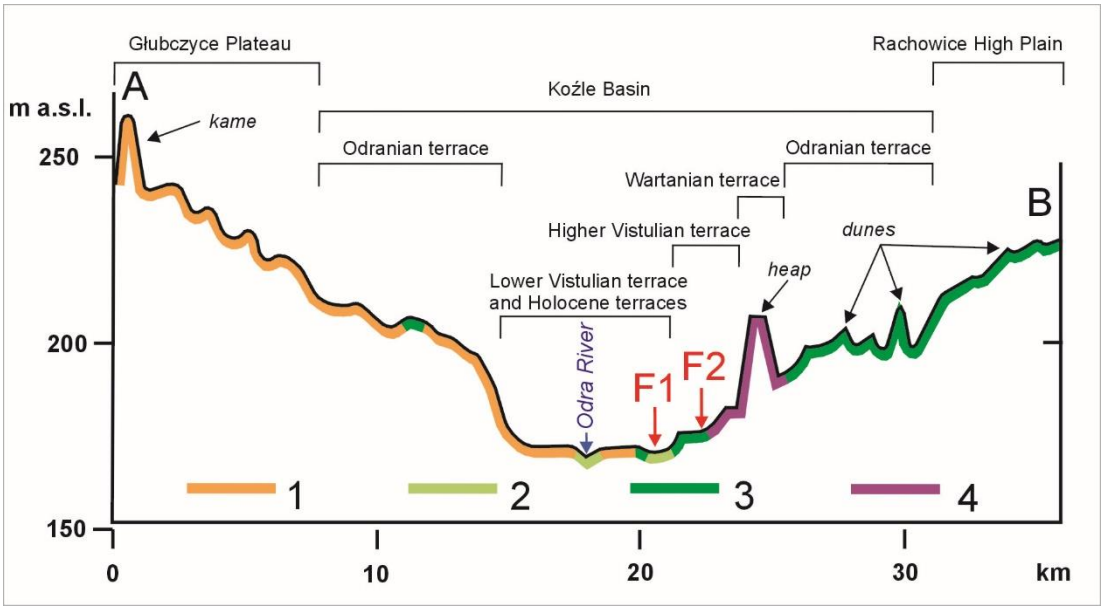


Fig. 2. Morphological profile of the Koźle Basin. 1 – 4 – as in Fig. 1 (prepared by J.M. Waga)

According to forest regionalisation, the studied areas belong to the "Lasy Raciborskie" (Racibórz Forest) mesoregion in the "Kraina Śląska" (Silesian Land) (ZIELONY & KLICZKOWSKA, 2010). The potential vegetation of these areas is: Tilio-Carpinetum (higher terrace of the River Odra), Ficario-Ulmetum typicum (low terrace), and Salici-Populetum (paleomeander bottoms) (MATUSZKIEWICZ, 2008). Among the habitat types of forests on different soils were: mixed fresh and moist forests (LMśw/w), moist forests (Lw), mixed fresh and moist pine forests (BMśw/w), alder forests (Ol), including ash forests (OlJ), and riparian forests (Ł) (Fig. 3A). In the Koźle Basin, however, anthropogenic changes in habitats are observed, especially in areas used for agriculture and former farmland, and even their far-reaching degradation. The forests of the study areas are classified as abiotic, biotic and anthropogenic hazard zones. Industrial emissions from plants in the Kędzierzyn-Koźle agglomeration are particularly troublesome. Invasive forestry work is also a threat to some landforms, soils, and some habitats (WAGA & FAJER, 2021; WAGA ET AL., 2022c).

Study areas F1 and F2 are occupied by forest habitats, and small areas of area F1 are also occupied by open and semi-open habitats. There are mainly tree stands introduced after World War II, except for a few sections in Brzeźce, where there are 85-130 year-old trees (Fig. 3B). The paleomeander area in Brzeźce, in terms of its environmental conditions, relates to the larger and naturally richer "Zdzieszowice Wetland" (MAKOWIECKI & KOZIARSKI, 2001). While the F1 area has maintained continuity of land use types over the past 100 years, much of the F2 study area, was used as fields and meadows as recently as the early 1940s (Fig. 4). The effects of bombing and atmospheric pollution were the reason for the introduction of a forest there with the alien species *Quercus rubra* and *Pinus nigra*.

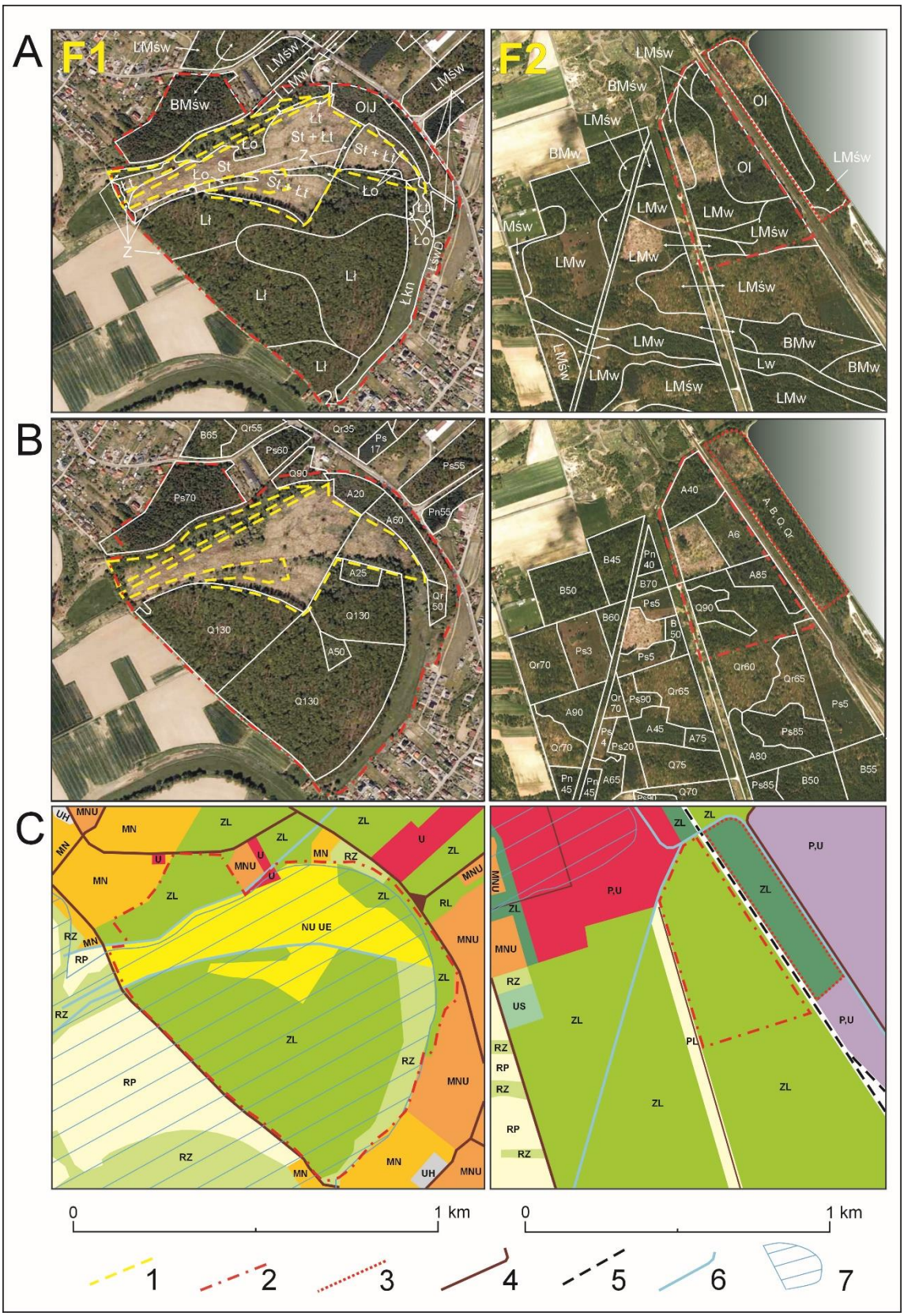


Fig. 3. Characteristics of the F1 and F2 study areas

1 – boundary of the "Gacek" ecological site, 2 – boundary of the proposed nature and landscape complexes, 3 – valuable area in Kędzierzyn-Koźle Azoty; 4 – roads, 5 – railroads, 6 – watercourses, 7 – flood areas; explanations of letter symbols in the text; (orthophotomaps: polska.e-mapa.net); 3A – Habitats (prepared by J.M. Waga, compiled from Stec-Karaś, 2020), 3B – Dominant species in stands and average age of trees: Q – oak, Qr – red oak Ps – Scots pine, Pn – black pine, A – alder, B – birch (prepared by J.M. Waga, compiled from Stec-Karaś, 2020), 3C – Spatial development (prepared by J.M. Waga, compiled from Uchwała..., 2017 and Prognoza oddziaływania..., 2019)

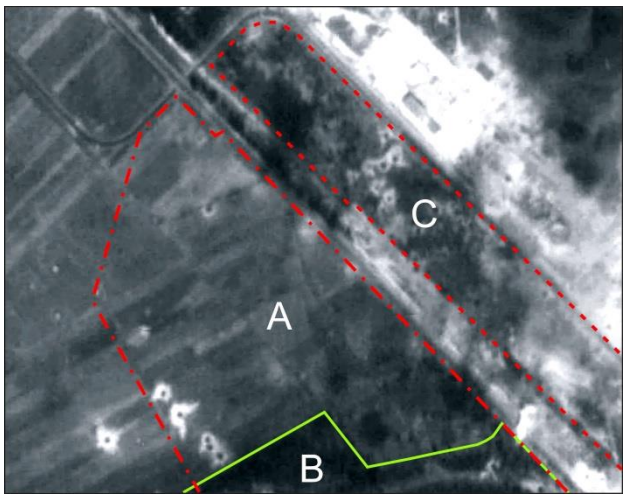


Fig. 4. A fragment of an aerial photograph from 27.08.1944; A – fields and meadows, B – forest, C – land belonging to IG Farbenindustrie Haydebreck (from the collection of the National Archives; https://catalog.archives.gov/id/204903592, accessed on 16 March 2023)

In terms of zoning arrangements, the surveyed areas included forest land (ZL) (Fig. 3C), and near Brzeźce also grassland (RZ), farmland (RP) and an unused section designated as a service area (U). The surveyed and proposed are for protection in Brzeźce is adjacent to areas with residential (MN), residential-service (MNU) and service (U) functions, as well as road lanes. It is bordered to the southwest by fields and grasslands (RP, RZ). In the northeast, area F2 is adjacent to the railroad route Kędzierzyn-Koźle – Racibórz as well as industrial and service areas (P, U). In the north there are wooded areas (ZL), and in the northwest there is an area for investment (P, U), with an off-road field. Adjacent on the south are forests, through which runs a high-voltage power line. The land beneath it is designated for forest plantations (PL).

3. Methods

Three types of methods were used in the study. An analysis of source archival materials was carried out, including from the websites of the Bierawa Municipality Office (https://bierawa.pl), PIG PIB (https://www.pgi.gov.pl), Kędzierzyn Forest District (https://kedzierzyn.katowice.lasy.gov.pl), Geoportal Regional Infrastructure for Spatial Information of the Opolskie Voivodeship (https://cuw.mapy.opolskie.pl/mapy/), and detailed geological, geomorphological, hydrological and soil maps. Remote sensing methods have been used in the identification and analysis of the distribution of geo- and bio-components of the environment, as discussed in detail in the publications of WAGA ET AL. (2022a,b,c,d).

The field research aimed at verifying the results of the desk studies and describing specific objects, plants and animals. An initial natural inventory at a scale of 1:5000 was carried out in 2020-2022 using the on route observations method (KLIMASZEWSKI, 1978). Surveys of vegetation cover were carried out in spring and summer, of animals (mammals, birds, amphibians and reptiles, insects and bat habitats) adequately according to their seasonal behaviour throughout the year. The presence of mammals was documented on the basis of direct observation of specimens and traces of their activity – tracks, signs of foraging, droppings, burrows, lairs, etc. (ROMANOWSKI, 1998). Recognition of insects was limited to those easily seen and identified. Detailed hydrobiological studies was conducted independently in water-filled bomb craters (Fig. 5). Ultimately, a detailed wildlife inventory was conducted for all habitats at both sites.

The review of inanimate nature included field prospecting and documentation of major geological objects, hydrology, relief forms and others in accordance with the methodology used in the GeoSilesia project (http://www.geosilesia...), as well as making photographic documentation.



Fig. 5. Hydrobiological study of bomb crater at F1 study area (photo by J.M. Waga)

4. Characteristics of natural and cultural resources in the study areas and existing forms of protection

4.1. Area F1 in Brzeźce

The Brzeźce study area is postulated by the authors for protection in the form of a nature and landscape complex (Fig. 6), including natural and anthropogenic elements of relief, geological formations, soils, hydrological systems and plant and animal habitats. There is a fragment of a meadow terrace with a late-Vistulian dune 10 meters high (WAGA, 1994). This terrace is undercut

by a paleomeander with a radius of about 400 m, filled with sands, silts and peats. Inside the meander extends a meander bar with a radius of 250 meters, built of sands with gravel and some silts. Within it, it is possible to distinguish river bars transitioning to terraces from the turn of the Vistulian and Holocene. The highest point of the study area is located at the top of the dune (184.85 m.a.s.l.), and the lowest at the paleomeander drain (170.5 m.a.s.l.). The surface of the higher terraces reaches 176 m.a.s.l., and the lower terraces 172.5 m.a.s.l. The study area contains numerous bombing craters from World War II (WAGA ET AL., 2022a).

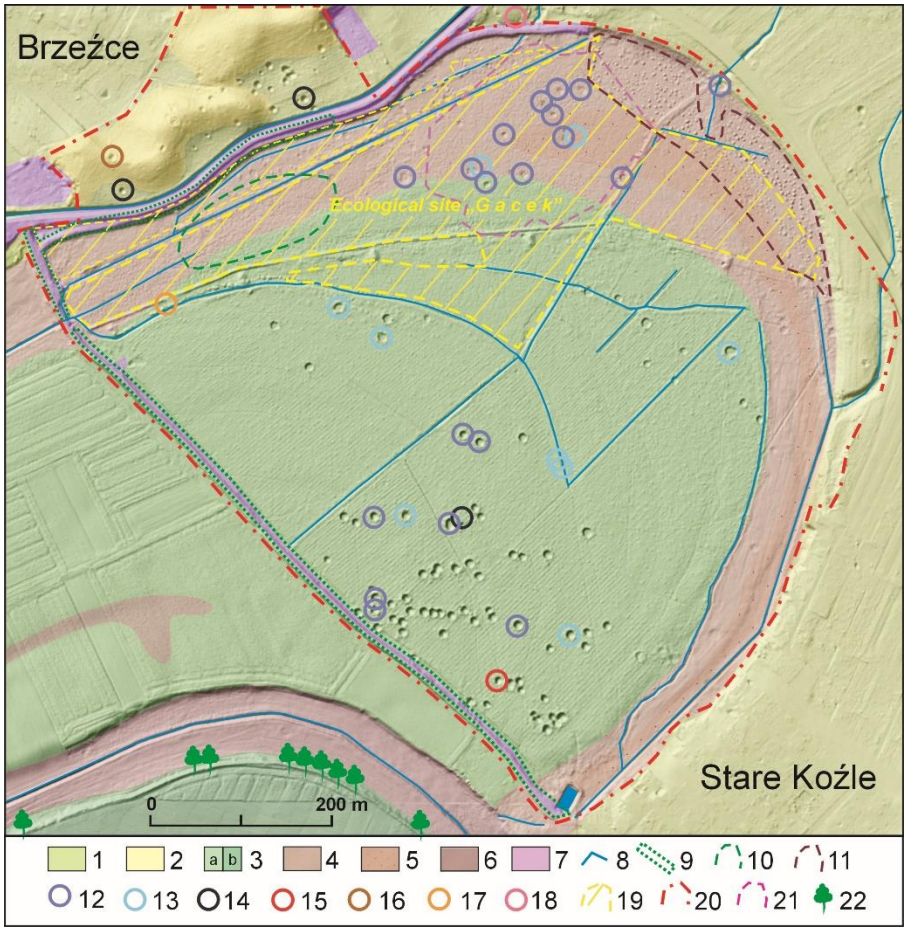


Fig. 6. F1 study area. Location of objects on the background of the geoenvironmental sketch (prepared by J.M. Waga; DEM available from: polska.e-mapa.net)

Terraces: 1 – Vistulian, with dune (2), 3a – from the turn of the Vistulian and Holocene, 3b – Holocene, 4 – lower, wetland part of the paleomeander, 5 – higher, silty and peaty part of the paleomeander, 6 – silt-sand fill of depressions, 7 – anthropogenic embankments and excavations, 8 – drainage ditches and channels, 9 – old-growth forest complexes and alleys, 10 – traces of the presence of beavers , 11 – alder forests, 12 – studied water reservoirs in craters, 13 – bathing grounds and wallows, 14 – badger burrows, 15 – places of intensive foraging (wild boar, deer, badger, fox, marten, weasel), 16 – large anthill of the red ant, 17 – deer mating site, 18 – *Hedera helix* site, 19 – "Gacek" ecological site, 20 – proposed boundaries of the nature and landscape complex, 21 – range of orthophotomap taken with a drone (Fig. 7), 22 – registered natural monuments

The meander bar in Brzeźce is dominated by brown fluvisols developed under riparian forests on ordinary clay and clay sands (Fig. 3A). On alluvium with a composition of heavy clays and loams there are gley fluvisols, and in the lowest zone of the former Odra riverbed there are muck soils composed of peats. On the meadow terraces, podzolic soils proper, rusty soils proper or podzolic soils formed from loose sands, as well as acid brown soils and podzolic gley soils proper on weak clay sands.

Within the study area, two systems of flowing surface water can be distinguished (Fig. 6). The first is the tributary from Brzeźce, which runs in the northwestern part of the area – a transit channel encased in concrete slabs, draining water from the "Kędzierzyn" Nitrogen Plant. Despite its isolation from the other system, it plays an important role in the migration of aquatic species, such as beaver, into the study area. The second system consists of anthropogenically transformed beds of watercourses, episodically draining the forested areas of the Vistulian sandy terraces. In many sections, these beds are dry, and water appears on the surface only within the studied paleomeander in Brzeźce.

In the northeast, under the escarpment of the higher terraces, there are bog-springs abundantly supplied by groundwater. The area is occupied by nicely formed alder forests. The rest of the paleomeander is drained by drainage ditches, also carrying rainwater from the higher part of the catchment area (Fig. 6). Most of the ditches and bomb craters there are constantly filled with water.

Almost the entire study area in Brzeźce is managed by the State Forests. They carry out conservation activities – they have designated special management units and various types of facilities and conservation areas (Fig. 7). In Brzeźce, some forests meet more than one criterion for inclusion in special management units. In a floodplain polder, a "near-natural forest" is protected in a riparian habitat, where there is likely to be continuity of ecotypes of stand species. It is characterised by the exceptional richness of the flora in both species and structural terms. There are old-growth forests of various ages, and of particular value, left to maintain natural succession. The group includes: 170, 130 and 90-year-old oak, ash, elm, alder, and other species. They are also subject to protection as "valuable tree stands". It also contains "animal sanctuary protection zones" of 8.10 hectares, 14.11 hectares and 4.33 hectares, as well as a "rare and endangered European forests" zone. Also assigned to the special management units were "forests of natural and scenic value in wetland and riparian habitats" (Fig. 3A & 7). In Brzeźce there are two wetlands of 0.79 and 1.10 hectares.

In the non-forest areas of the paleomeander in Brzeźce, only its southeastern section is currently used as hay meadows (Łkn) (Fig. 3A & C). Former wet meadows, established on hydrogenic soils, have been mostly overtaken by reed rushes (St) in the central, northern, and western parts. In the midst, a *Molinia* meadow (Łt) persists in places. On the contact line with the forest and around clumps of trees, willow thickets (Lo) can be found. To the east, a small section of the slope of the meadow terrace is occupied by degraded fresh meadows (ŁświD) with a belt of old-growth forest. Along the roads, on the dykes of the polder, the water channel and on the embankment shielding the underground water pipeline, tree plantings (Z) in the form of avenues and rows have been introduced.

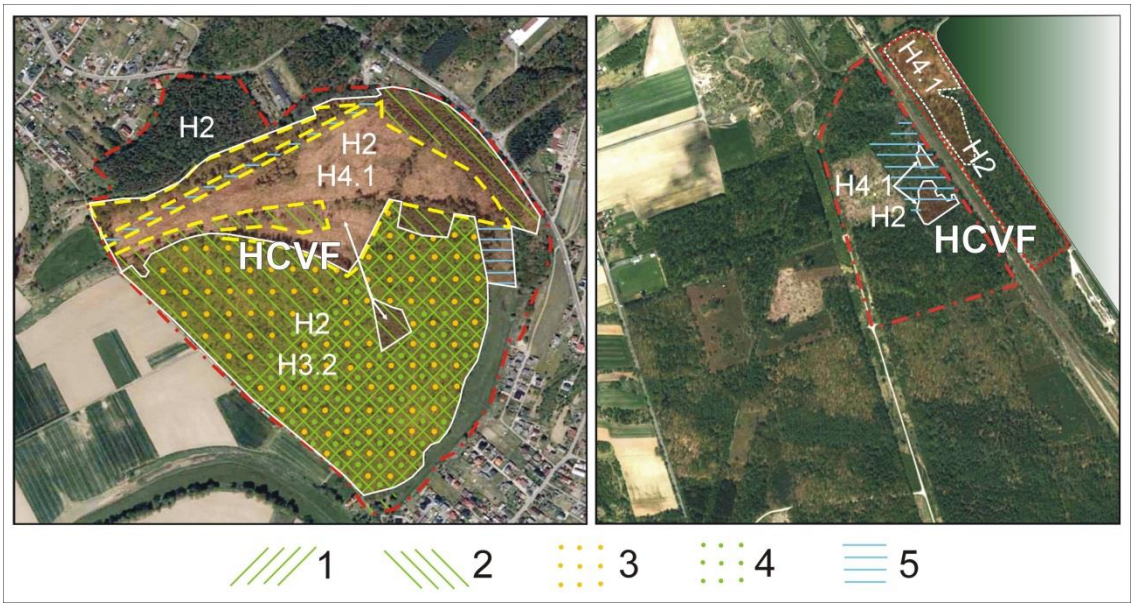


Fig. 7. Nature conservation forms of the Kędzierzyn Forest District (prepared by J.M. Waga based on Stec-Karaś, 2020; orthophotomaps: polska.e-mapa.net):
HCVF – forests with special natural values, including water protection (H4.1) and ecosystems that are rare and endangered in Europe (H3.2); forests: 1 – close to natural character, 2 – valuable in terms of nature and landscape in wetland and riparian habitats, 3 – rare and endangered on a European scale with zones of protection for animal sanctuaries, 4 – valuable stands of trees, 5 – wetlands; boundaries as in fig. 3; Forms of nature conservation proposed by the authors: HCVF – forest complexes that play a significant role in the landscape, on a national, macro-regional or global scale: areas with bomb craters (H2), water protection forests (H4.1)

A significant part of the open, and semi-open, areas of the F1 study area is occupied by the "Gacek" ecological site (CENTRALNY REJESTR...) (Fig. 3, 6 & 7). It was established under Decree No. 0151/P/9/2003 of the Opole Province Governor (ROZPORZĄDZENIE..., 2003) on an area of 14.00 hectares. It includes habitats and sites of rare, or protected, species, including nesting sites for waterfowl. In its close vicinity are multi-object natural monuments (Fig. 6) – groups of pedunculate oak trees – *Quercus robur* with a circumference of 4–6 m.

To the north of the "Gacek" ecological site, on the bank of the Vistulian meadow terrace, there is a dune complex with distinctly different dry habitat conditions (Fig. 3 & 6). This is a pine forest habitat on loose sand, occupied mainly by *Pinus silvestris* with certain deciduous species: *Quercus robur, Quercus rubra* and *Betula* species. These contrasting habitats are separated by the aforementioned channel draining water from the Azoty district of Kędzierzyn-Koźle, located along the edge of the terrace.

According to the State Forests catalogue (KOMPLEKSOWY PROJEKT...), there are "valuable lands (including historical and cultural sites) and lands of special natural value" as well as "clumps, groups and single specimens of old trees" still deserving protection in Area F1. On the embankments of the polder and water channel, for example, there are oak avenues that constitute an important natural and cultural heritage site (Fig. 6).

The cultural values of the area include the hydrotechnical systems protecting the Brzeźce polder from flooding by the waters of the River Odra and serving to drain it, the Brzeźce tributary protected by a dyke and the water pipeline crossing the polder. Craters from bomb explosions from the air campaign in the second half of 1944 should be considered important (Fig. 6 & 8).

A summary of information on the natural objects of the study area is presented in Fig. 6 and Table 1. It also lists species for potential introduction.

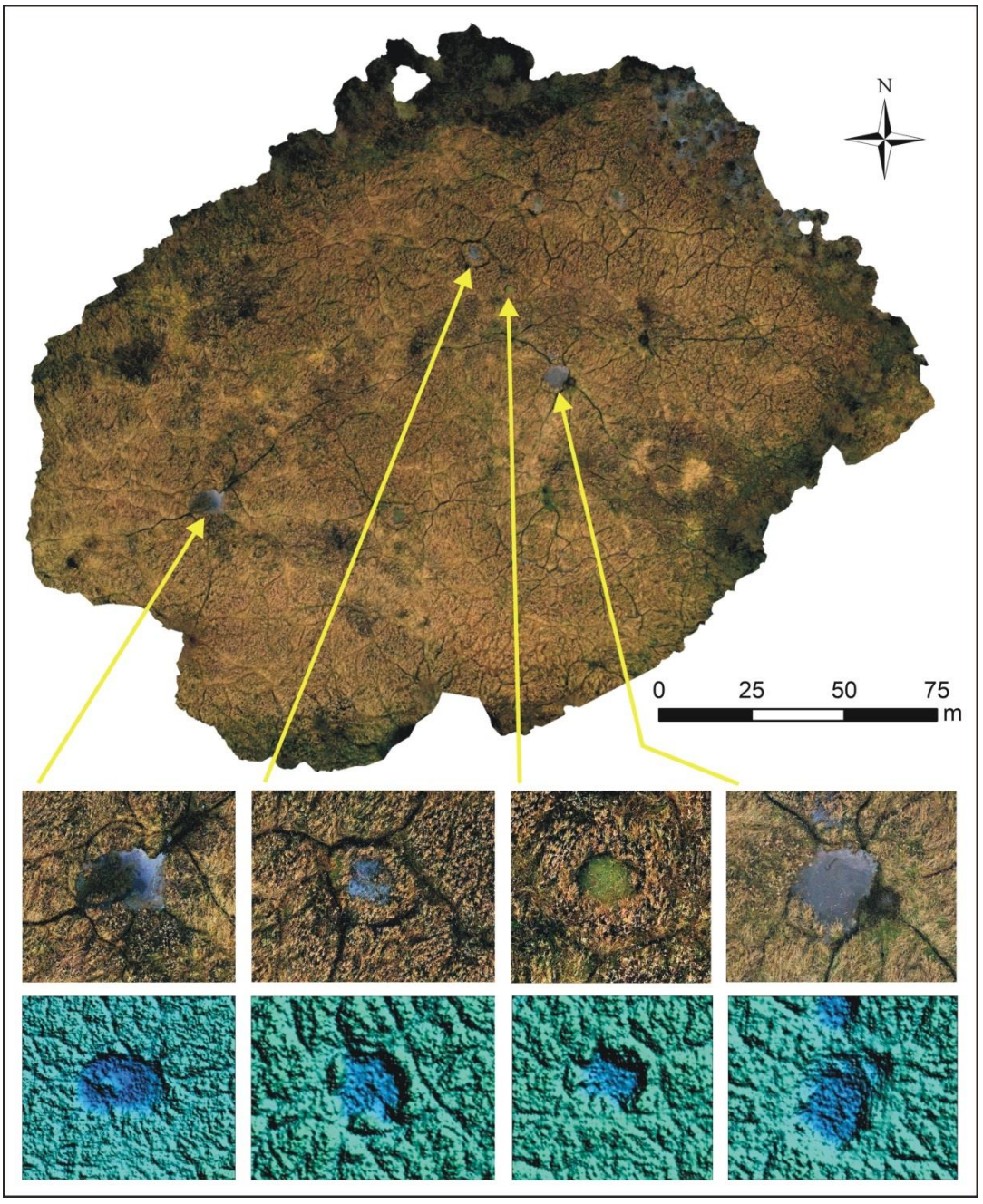


Fig. 8. Orthophotomap of the "Gacek" ecological site with bomb explosion craters and their coloured models from DTM (prepared by B. Szypuła)

Table 1. Nature elements of the studied areas and proposed species for possible introduction (prepared by the authors)

Flora	
Species found	Species proposed for introduction
Lesser celandine *Ficaria verna*, Wood anemone *Anemone nemorosa*, Common snowdrop *Galanthus nivalis,* Common broom *Cytisus scoparius,* Violet reichenbachiana *Viola reichenbachiana,* Yellow star-of-Bethlehem *Gagea lutea,* Hollow root *Corydalis cava*, Common comfrey *Symphytum officinale*, Lesser duckweed Lemna minor, Common ivy *Hedera helix,* Water violet *Hottonia palustris,*	Two-leaf squill *Scilla bifolia,* Wild garlic *Allim ursinum,*
Fauna	
Species found	Species potentially occurring and proposed for introduction
Eurasian beaver *Castor fiber* European badger *Meles meles,* Red fox *Vulpes vulpes*, Wild boars *Sus scrofa,* Roe deer *Capreolus capreolus,* Red deer *Cervus elaphus,* Common frog *Rana temporaria,* European grass snake *Natrix natrix*, Mallard *Anas platyrhynchos,* Eurasian blue tit *Cyanistes caeruleus,* Red squirrel *Sciurus vulgaris,* Middle spotted woodpecker Dendrocopos medius, Great spotted woodpecker *Dendrocopos major*, Roman snail *Helix pomatia,* Red wood ant *Formica rufa,* Jet ant *Lasius fuliginosus,* Freshwater copepods *Cyclops,* Beautiful demoiselle *Calopteryx virgo,*	European fire-bellied toad *Bombina bombina*, European tree frog *Hyla arborea,* Eurasian pygmy owl / Owl *Glaucidium passerinum / Strix,* Common newt *Lissotriton vulgaris,* Bats *Chiroptera,* Scarab beetle *Osmoderma eremita*

4.2. Area F2 in Stare Koźle

The F2 study area is also proposed for protection as a nature and landscape complex (Fig. 9). It is located within a terrace of the Vistulian age, made up of sands with loam interbeds. In the south, the surface of the terrace is overlain by aeolian sediments forming a low dune. To the north of it runs a trough-shaped denudation valley, filled by organic sediments up to 1 m in thickness. The part in the northern part of the study area is the lowest (176.2 m.a.s.l.), and the top of the dune is the highest (178 m.a.s.l.). The area has a relief that was severely transformed during World War II by the explosions of high-calibre air bombs. The surrounding area is drained by drainage ditches and crossed by transit channels from the "Kędzierzyn" Nitrogen Plant. In the valley, ditches and bomb craters are filled with water for the entire year, which is important for multiple species.

In the forest in Stare Koźle, there are muck gley soils and humic gley soils formed on loamy sands, and on the dune, there are podzolic soils proper. In the northern, northwestern, and southern parts of the area there are podzolic muck gley soils on loose sands and muck gley soils proper on weak clay sands, as well as muck soils on clay sands.

The entire study area in Stare Koźle is managed by the State Forests. Two “water protection forest areas" have been designated there, partially overlapping the "wetland area” (Fig. 7). These areas find their natural continuation on the other side of the Kędzierzyn-Koźle – Racibórz railroad track on a plot of land managed by the "Kędzierzyn" Nitrogen Plant.

Within the F2 study area, particularly worthy of note is the alder forest landscape, with quaking sedge, with ponds filling numerous bomb craters (Fig. 10A). This view, like the one near Brzeźce, vividly illustrates the events of the war. At least some old trees deserve preservation in the area in Stare Koźle. Most importantly, a beech tree growing on the edge of one of the craters located on a low dune (Fig. 10B). It is likely to be one of the first trees to colonise the site after the bombings, and may even have survived the event as a young specimen. Therefore, it is also a kind of a symbol. The information collected in the field about the qualities of the study area is shown in Fig. 9 and Table 1.

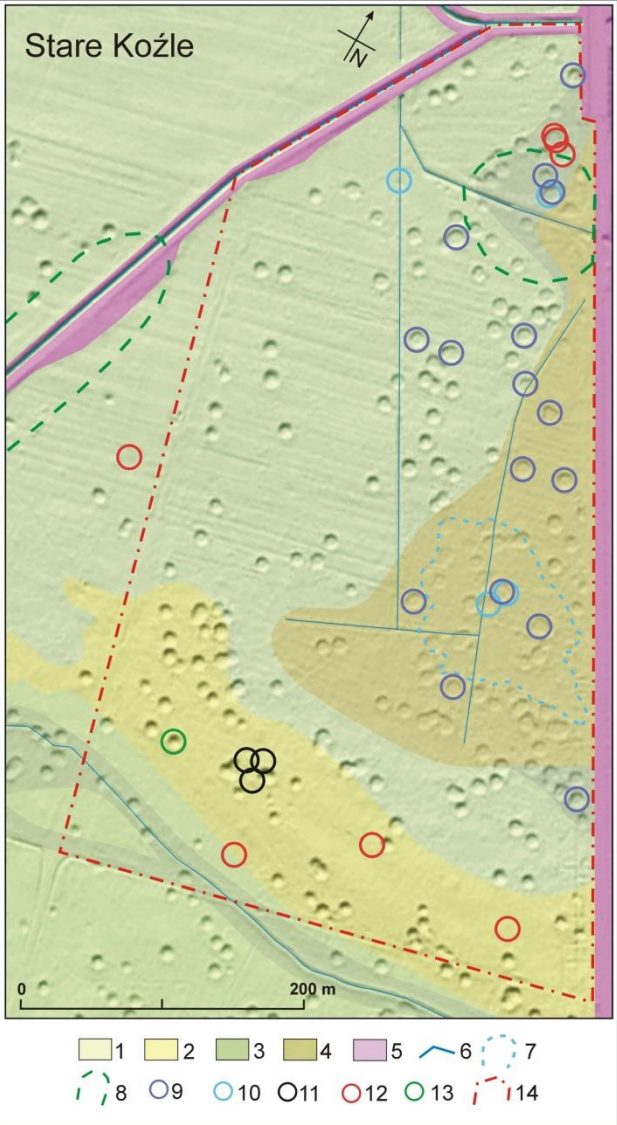


Fig. 9. F2 study area. Location of objects on the background of the geoenvironmental sketch (prepared by J.M. Waga; DEM available from: polska.e-mapa.net)
1 – Vistulian terraces, 2 – dunes, 3 – wetlands, 4 – wetland areas, 5 – anthropogenic embankments, 6 – drainage ditches and channels, 7 – alder forests, 8 – traces of beavers, 9 – surveyed water reservoirs in craters, 10 – bathing grounds and wallows, 11 – badger burrows, 12 – places of intensive foraging (wild boar, deer, badger), 13 – monumental beech tree on the edge of the bomb crater, 14 – proposed boundaries of the nature and landscape complex

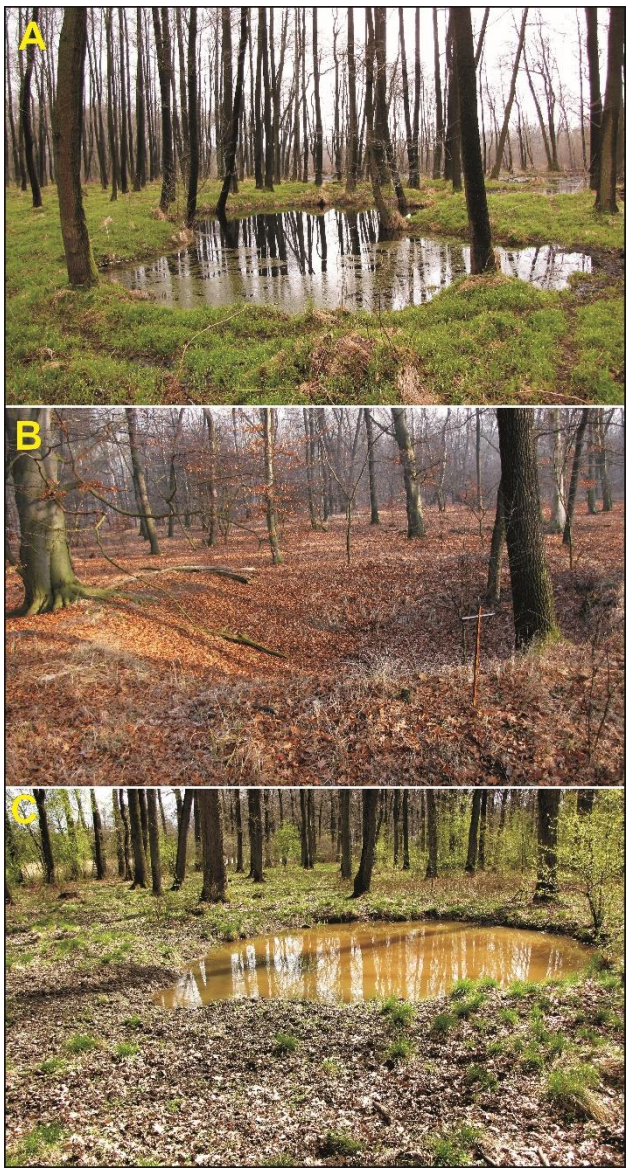


Fig. 10. A – Flooded bomb craters at F2 study area; B – Large beech tree above the crater on the F2 study area; C – Ungulate bathing ground in a crater at F1 study area
(photos by J.M. Waga)

5. Previous functions of the studied areas

The forests of both study areas enjoy the protective status granted by the State Forests (STEC-KARAŚ, 2020) in order to: preserve and enrich forest biodiversity, restore degraded and distorted plant communities, maintain and improve forest soils and habitats, and maintain water retention. Dying trees, such as ash trees, are replaced there with species with similar habitat and ecological requirements. In the industrial damage zone of the "Kędzierzyn" Nitrogen Plant, plantings of *Pinus nigra* and *Quercus rubra* were allowed. Currently, *Quercus rubra* has been declared an invasive species and dangerous to native flora due to the environmental changes it causes (TOKARSKA-GUZIK ET AL., 2012; DĄB CZERWONY...). At the same time, attention is drawn in the F2 area to the excessive growth of *Robinia pseudoacacia* – also included in category IV of invasive plants.

In Poland, water retention in catchment areas is important under conditions of ongoing climate warming. Aquatic and wetland ecosystems are key in this (KADYS, 2016; KOMPLEKSOWY PROJEKT...).

They retain and purify water, store large amounts of carbon and nitrogen (especially wetlands and peatlands) and create niches for many threatened and endangered plant and animal species. As centres of biodiversity, they influence the ecological balance of the surrounding forests, even if they have a primary anthropogenic origin – they were created in dammed areas, pits, basins from subsidence, or depressions from military activities. Small "ponds," including bomb craters, serve as wildlife bathing areas and watering holes, among other functions (Fig. 10C).

The study areas are dominated by moist habitats. In addition to extensive structures, there are also microhabitats, ecological clumps and biogroups classified as forests and other water protection lands (STEC-KARAŚ, 2020). Particularly important there are forests in wetland and riparian habitats, strips located along watercourses and around bodies of water, ecological sites, marshes, and wetlands designated for natural succession. Some of these areas are completely excluded not only from forest management, but also from other human interference. In the F1 and F2 study areas, this is taken advantage of, among others, by beavers, which penetrate such places and in different years try to create lodges.

The species composition of the flora and fauna of the study area relates to the former observations of MICHALAK (1968), although it shows less richness than in the "Zdzieszowice Wetland" (MAKOWIECKI & KOZIARSKI, 2001).

6. Proposals for new functions that fit into existing land use structures

The intention of the authors is to strengthen the natural structures of the study areas and integrate their protection with the preservation of the historical and cultural fabric of the area through the establishment of nature and landscape complexes. In addition to its natural and productive purposes, the functions of forests include serving as a place for recreation and education. In regional education, it is important to develop both environmental and historical awareness (HIBSZER, 2004, 2021). School field lessons can be a way to combine different strands of transmitted knowledge using examples of specific – multisensory experiences for audience – places, cases and events that are part of historical processes (ANGIEL ET AL., 2020, 2021). The study areas are well suited for such activities. However, it is necessary to develop tourism and education management plans there, which should include the primary conservation goals. It is necessary to direct and stimulate tourism and education in such a way that anthropogenic damage does not occur. In addition to newly developed trails, existing trails can be used for this purpose (SZLAKAMI POWIATU..., 2018), investing in information points enriched with new content and more detailed factual data, among other things.

Thematic references can be made to regional education in the study areas, such as:

- the diversity of natural conditions contrasting with each other – wet and dry habitats located within the large Odra paleomeanders and on the meadow terraces,
- River Odra as a waterway and the problem of flooding,
- history of Koźle as a defensive fortress,
- history of the "Silesian battle for fuel" of 1944,
- memory of the victims of the nearby concentration camps.

Although the forests located in the immediate vicinity of Kędzierzyn-Koźle are separated by settlements, industrial areas, and a network of linear infrastructure, locally in terms of nature they are very important areas where the diversity of fauna and flora is high (STEC-KARAŚ, 2020). Also, the clusters of bomb explosion craters associated with the air campaign carried out to disable the Third Reich's fuel plants are among the most spectacular in Europe today. In addition to their historical functions, they are important in diversifying water relations and habitat mosaic-like structures. This affects the colonisation success of some species. If environmental conditions are favourable (including adequate water and soil conditions), introduction activities of selected plant and animal species can be considered there (Table 1).

In addition to the evocative image of military action, recorded in the landscapes of the "perforated" forest, the craters are an important element of remembrance after the victims of both sides of the conflict – ordinary people, civilians and those dressed in uniforms, thrown into the vortex of an unnecessary provoked war. They can serve educational purposes as material historical testimonies. A short distance from the surveyed areas are World War II-era facilities – a system of shelters, air defence points and remnants of concentration camps.

Similar historical sites, trails and cultural parks dedicated to the war campaigns operate in France, Belgium, the Netherlands and other countries, including Eastern Europe (RYAN, 2007; PASSMORE ET AL., 2014; DUNLAVEY, 2015, 2017).

The possibilities of using the areas presented in the article for tourism and education stem from both their resources and the demographic potential of the neighbouring agglomerations of Kędzierzyn-Koźle, Katowice, Opole, Racibórz, and Rybnik.

7. Conclusions

The study area is characterised by a complex history of environmental transformation by human activity. In addition to the centuries-long transformation of the River Odra valley floor and its western bank into agricultural and settlement areas and the fight against floods, there was a stable system of large-scale forestry operated on the eastern bank until the 1940s. In just five years, this changed dramatically due to the rapid industrialisation of the area, followed by military action. These changes should be described as extreme. The war-related destruction over time paradoxically opened the way for natural self-reconstitution and the return of many species. New habitats have been created with numerous small reservoirs in craters, located in forests and meadows. Some of them have survived and can be used to maintain and enhance the biodiversity of the area.

The tumultuous events of the 5 years of wartime are recorded even more dramatically in the areas adjacent to the presented study areas – in graves, ruins of buildings from this period – evidence of enslavement, exploitation and extermination of people, as well as shelters and traces of fighting. This prompts an effort to develop a plan to protect these historical testimonies and to spread knowledge about them. The establishment of nature and landscape complexes can fit well into such activities.

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