“Hartera” paper plant and natural environment (Rijeka; Croatia)

Geography and geology of the broader area

The city of Rijeka is the largest Croatian port, the third-largest city in the Republic of Croatia, and the administrative center of the Primorje-Gorski Kotar County. It is located in western Croatia, on the northern coast of the Kvarner Bay. The Kvarner area is a partially enclosed channel in the Adriatic Sea, situated between the Istrian peninsula and the Vinodol-Velebit coast. It primarily consists of tectonically deformed and karstified Mesozoic to Cenozoic carbonate rocks (Pikelj & Juračić, 2013). The city of Rijeka is situated on rocks approximately 95 million years old, belonging to the geological period of the Cretaceous. During the Cretaceous, the Adriatic Carbonate Platform (ACP) - a vast plateau that encompassed the present-day area of the Rijeka region - was surrounded by a deep sea, parts of the vast Tethys Ocean. It was located about twenty degrees south, at approximately 25° North latitude, and was moving northward and northeastward towards present-day Europe. The area of Istria, Croatian Littoral, Gorski Kotar, Ogulin region, and parts of Lika that were situated in the northwestern part of the Adriatic Carbonate Platform (ACP), during the Cretaceous, resembled today's Bahamas. During that time, dinosaurs roamed the area that is now Istria (Klepač et al.,2012.).

In the wider area of Rijeka, in addition to Cretaceous rocks, there are also Eocene-age rocks and Quaternary sediments. Triassic and Paleozoic layers, which are quite widespread in neighbouring areas, are covered by younger deposits. Cretaceous layers appear as limestones, dolomites, and limestone or dolomite breccias, while Eocene clastic deposits consist of marls composed of limestones, slates, sandstones, conglomerates, and limestone breccias. The thickness of the marl deposits is 400-600 meters (HGI, 2009).

From a hydrogeological and engineering geological perspective, this entire area is divided into the carbonate, highly permeable karst unit, and impermeable marl deposits. The most significant watercourse of the Croatian Littoral is the Rječina River. It has a length of only 18.7 km, with an elevation difference of 325 meters between its source and the mouth. A strong spring located at the foot of the Gorski Kotar mountains drains underground water from a vast karst hinterland and has been used for water supply for a full century. In the middle course of the river, there is a dam and reservoir, and the waters of the Rječina are also utilized for electricity production (Prodan et al., 2012). The Rječina Valley is part of the Rijeka epicentral seismic area, where earthquakes with magnitudes up to M = 6 on the Richter scale have been recorded over the past two millennia (Herak et al., 1996.).

Figure 1: A view towards Rijeka

Natural vegetation of the broader area

Despite its coastal location along the Adriatic, the Northern Adriatic region biogeographically belongs to sub-Mediterranean floral region. This classification arises from several factors, including its relatively high annual precipitation, approximately 1500 mm, lower winter temperatures, the influence of the strong winter wind known as the bora, as well as its positioning at the northern boundary of the Mediterranean. Consequently, the classic evergreen vegetation typical of Mediterranean areas, featuring species like holm oak (Quercus ilex), green olive tree (Phyllirea latifolia), strawberry tree (Arbutus unedo), common myrtle (Myrtus communis), and mastic tree (Pistacia lentiscus), to name a few, is primarily found in sheltered and spatially rather restricted refugial sites.

The predominant climazonal vegetation here – the vegetation developed under general influence of the climate without anthropogenic influences - however, consists of forest stands populated by downy oak (Quercus pubescens), flowering ash (Fraxinus ornus), European hop hornbeam (Ostrya carpinifolia), and oriental hornbeam (Carpinus orientalis), forming the broad-leaves forests of the association Aristolochio-Quercetum pubescentis carpinetosum orientalis. The initial stage of degradation in these forests leads to stands primarily featuring oriental hornbeam and Jerusalem thorn Paliurus australis. Continued degradation results in the formation of floristically diverse, rocky Karstic grasslands, with the sedge Carex humilis being a dominant species within the Carici humilis-Centaureetum rupestris association. Note that almost all non-forested vegetation, including species rich rocky and dry grasslands, are man-made.

However, in areas that have undergone complete degradation, as most of the urban areas, vegetation is characterized by the prevalence of garlic cress (Peltaria alliacea), European stonecrop (Sedum ochroleucum), and certain therophytes - any (annual) plant which survives unfavourable seasons in the form of seeds only.

In the (sub)Mediterranean climates, the most unfavourable conditions plant experience during the summer draught.

The impact of the paper factory on the natural environment

The river Rječina is a short karst river, 19 km long, with a catchment area of 246 km2. Although Rječina is the most abundant river in the water area of the Primorje-Istria basins, it is characterized by significant seasonal fluctuations in accordance with the Mediterranean distribution of rainfall throughout the year. During these fluctuations, the maximum water flow is recorded in winter months, while the minimum occurs in summer. Therefore, during the summer months, anthropogenic chemical and physical impacts have the potential for a stronger effect on this river.

The negative impact of the operating Hartera factory on the natural environment, particularly on the Rječina River and its ecosystem, was multiple and significant, increasing with the intensity of operations and complexity of production processes.

In the initial period of operation, when the factory was still a paper mill, it used old rags as raw material, with low production capacity and a small number of employees. During this period, the impact of its operations on the flow of the Rječina River was relatively small, while the water was contaminated with (pathogen) microorganisms and organic compounds from dirty old rags.

In 1827, with the entry of the British merchant Walter Crafton Smith and the French industrialist Charles Maynier into the paper mill on the Rječina River, its "golden period" or rather, a dark era for the Rječina River, began. After taking over the factory, the new owners invested in its modernization, regulating the flow of the Rječina River and constructing canals to redirect water from the river for the utilization of hydrostatic energy, production processes, or the needs of the steam engine that was launched in 1833.

Following a major flood in 1852, a new canal was built, and the factory continued to develop technologically, adding two new steam engines, which put additional pressure on the Rječina River. At the turn of the century, the greatest efforts were directed towards ensuring sufficient energy for production processes and the use of a new raw material for paper production, cellulose. Paper production from cellulose became a more profitable process but had a stronger negative impact on the environment, particularly in terms of pollution and contamination with various chemical compounds.

According to S. Zrnčević (2019), the wastewater generated in all segments of the production chain of paper production is a mixture of about 240 to 250 different elements and compounds such as nickel, copper, chromium, lead, sodium, nitrogen, phosphorus, sulfur and their compounds, biologically non-degradable organic compounds, fatty acids, as well as chlorinated resins, phenols, and hydrocarbons. Many of these compounds are known to be acute or chronic toxins for both humans and animals. In addition, these waters are characterized by high electrical conductivity, relatively high or low pH values depending on the process used, turbidity, and intense odor. In the past, paper bleaching was mainly done using chlorine compounds, which led to the formation of toxic chlorinated compounds and acidification of water. Due to their complex composition and proven toxicity, wastewater from the pulp and paper industry represents a serious threat to aquatic ecosystems as well as the environment as a whole. Thermal pollution of water, resulting from the discharge of process wastewater at higher temperatures, can also have a multiple impact on aquatic organisms. Sudden temperature changes occurring near the discharge can cause immediate death (lethal effect) or induce stress and physiological disturbances (sublethal effects). Warmer water contains less dissolved oxygen, accelerates the metabolism of living organisms, and depletes oxygen faster, resulting in

reduced oxygen concentration. This changes the living conditions of the habitat, gradually eliminates organisms that require more oxygen, and triggers anaerobic degradation of dead organic matter. The problem with process wastewater from the pulp and paper industry is also related to its coloration. Paper industry contributes to the coloration of water by using synthetic dyes to suppress the yellowish color of paper (optical brighteners) or produce colored paper. Even low concentrations of dyes in water (> 1 mg dm-3) are intensely visible. The presence of dyes in natural waters reduces water quality, disrupts the aesthetics of ecosystems, and prevents the penetration of light into deeper water layers. This disturbs photosynthesis, resulting in reduced oxygen concentration and lower productivity of the aquatic environment. Many dyes and their degradation products are carcinogenic, mutagenic, and/or toxic to organisms. Due to their high chemical and thermal photostability, dyes persist in the environment for a long time and disrupt metabolic processes in the cells of microorganisms, plants, and animals present in the ecosystem.

In the first half of the 20th century, a highly modern thermal power plant with a capacity of 3200 HP was built in the Rijeka Paper Factory, which polluted the air with coal combustion by-products during electricity production.

At different stages of its operation, the Rijeka Paper Factory also mechanically affected the flow of water in the Rječina River. Additionally, the reduction of river water flow due to water use in various production processes leads to the upstream intrusion of saltwater in the estuarine area, altering the living conditions and species composition in that part of the river.

Hartera paper plant today – natural features of an abandoned industrial site

Hartera, once an industrial complex now abandoned, is dominated by urban flora consisting of ruderal plant species. These species, often annual, employ an r-strategy for survival, characterized by a high growth rate but low survivability, meaning they produce many "cheap" offspring. In contrast, K-selected species, typically prevalent in climazonal vegetation types (representing the final stage in vegetation succession for a given climate and period), exhibit a low growth rate but high survivability, producing fewer but "expensive" offspring.

Abandoned sites as Hartera former plant area, and ruderal sites, are largely taken over by adventive, often invasive species. Since the available spaces and roles in ecosystem (ecological niches) at this sites are not occupied, once highly urbanized and disturbed sites represent spaces where newcomers find their place to grow. Many of these alien plant species turn out to be invasive ones at their new habitats.

Notably, in close proximity to these industrial sites, well-preserved flora and vegetation thrive in more or less natural areas. These serve as a species pool and offer significant potential for recolonizing the abandoned industrial sites.