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STORIES WITH MICROORGANISMS…

HISTORIE Z MIKROORGANIZMAMI…

Abstract: Microorganisms, usually invisible for us, accompany us always and everywhere. Often we do not realize how decisive its impact on our lives is, how much we use their presence, which of our troubles are the result of their actions, and also how surprising effects result from their activity. Microorganisms also very often play a decisive role in the development of societies, politics and history. One of the most spectacular interventions of micro-organisms in human history include the example of a false "oil fever" that exploded in Australia in the second half of the nineteenth century. It was even more significant to redirect Europe's history in the new direction as a result of the "black death" epidemic in the fourteenth century. Microorganisms have created social conditions for the transition to the next epoch - renaissance, which forms the basis of today's shape. Because of the microorganisms J.F. Kennedy could have been in the 1960 President of the United States of America and to direct her development in the new direction and to stop Khrushchev's expansion into the second hemisphere. Microorganisms, not leaders and generals, won battles and wars. It was *Rikketsia prowazeki*, not the genius of the opponents, that broke Napoleon's power in Europe. Microorganisms fight disease, improving quality of life and prolonging its period. They allowed to control rabies and numerous infectious diseases. In the economy for the cause of microorganisms, powerful monopolies fell. Bacteria were also used to protect civilians in Poland during World War II. There are many similar stories to tell, stories in which microorganisms play an essential role. But would these stories be about microorganisms only? Or perhaps about people who were fascinated by the microscopic world of microbes discovered his secrets, meaning and ... beauty.

Keywords: microorganisms, history, society, medicine

At the beginning

Microorganisms, normally imperceptible, accompany us always and everywhere. Often we do not realize how decisive the impact they have on our lives, how much we use their presence, which of our troubles arise from them, and how surprising results are from their activity.

Food production, health, environmental cleanliness, waste disposal, energy generation, all those problems essential for life, society and civilization, are primarily or directly related

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to the microbes. Microorganisms have also played a decisive role in the development of societies, politics and history.

Let's take a look at some examples illustrating the impact of microorganisms on our environment and ourselves.

Disappointed hopes for the oil business

Oil is now the basis of our economic system, it is difficult to imagine a modern world without this raw material. Here is an example of a false "oil fever" that exploded in Australia in the second half of the 19th century [1]. History began in 1852, when a police escort, protecting the transport of gold from Victoria, discovered a strange substance. On a flat ground, near the freshwater lake in the Coorong District in the south of the continent, which was only periodically filled with water, as it often happens, a layer of slippery, oily material was noticed. It was black, and under the light it looked yellowish. Despite its hardness, the material was cut or torn. None of the cops saw anything like it before. In the following years, similar substances were found in other parts of Coorong. It was usually found in coastal areas of lakes and floodplains, in 1-2 cm thickness layers, but sometimes even 30 cm.

A substance called coorongite was of interest to chemists. During the distillation, the hydrocarbons, like from the oil, were released. So the solution of the mystery seemed obvious: oil was extracted from the underground deposits and formed the layer on the surface. Around 1860, the fever of exploration exploded. Speculators have redeveloped areas throughout the region, and drilling has started, even in solid rocks, which was covered with coorongite but geologists did not indicate the presence of oil deposits. However, all efforts have proved futile and oil has not been found, which was a great disappointment for many prospective mine owners.

In the meantime, biologists became interested in coorongite. It turned out that the material contained spores, which could indicate its biological origin. This hypothesis was long overwhelmed by the hypothesis of the oilfields supporters who claimed that of coorongite, 318 liters of paraffin, 59 liters of paraffin oil and 32 liters of varnish can be obtained by distillation.

Finally, when in 1892 even drilling to a depth of 275 m did not give results, the hypothesis of the oil deposits existence was dropped. True surprise came after discovering the real origin of coorongite. Researchers have discovered that it is made up of a thick, greenish layer of foam, found on water tanks, which over time has precipitated in the form of this mysterious, rubbery material. It is formed predominantly of hydrocarbons derived from *Botryococcus brauni*, which are subject to polymerization and other chemical transformations.

So are not we dealing with the phenomenon of the first stage of oil production? And in the future could not it be a way to produce energy material? Perhaps, landowners in the state of Coorong will still have their oil fields if they have the patience to wait long enough?

How the bacteria changed the history of the continent - black death over Europe

In 1347, a plague broke out in Europe, which in the course of four years caused the death of 1/3 of 75 million population on our continent. In the following decades, it receded at intervals of at most 8 years, which reduced the population to a quarter of the original amount [2, 3]. Black death, or plague, was caused by *Yersinia pestis*.

Plague is a terrible disease; it begins with swollen lymph nodes, high fever followed by extensive bleeding blackening the skin. Patients complain of chills and headaches, vomiting and diarrhea. After the lung infection, the disease enters the infectious phase and spreads at enormous speed.

Historians agree that the plague comes from Asia. The first known pandemy was it ancient Rome [4] By the fourteenth century, it had reached east through rats. Diseases are documented in the caravanserai on the silk route in 1345 in Astrakhan, in the Delta of the Volga river and in the lower Seraglio river. Probably this way a new strain of *Yersinia pestis* [5-7] reached Europe. The marmots of Central Asia played a major role. They died in a large numbers, and local hunters were picking up animals and removing peels, which they later sold to Westerners. As soon as some bundles of skins were opened in Astrakhan and Seraglio, the hungry fleas carrying the disease spread. Following way of *Yersinia pestis* led through Don river to Black Sea ports. In the ports, rats on the ships were the ideal environment for the spread of the disease. In December 1347, it reached Messina in Sicily, Constantinople and most other ports, like Jaffa and Genoa in northern Italy.

In the following year, the plague reached France and from there, probably on a ship with a load of red wine, it reached England. In May 1349, a merchant ship departed from London heading for Bergen, Norway. A few days later, the inhabitants of Bergen, who had flocked in boats to the ship in coastal area, reported that the entire crew was dead. As they returned to land, they took some bales of wool from the ship's load with fleas infested with lethal bacteria that spread rapidly on land. From Germany and Denmark, the plague broke into Poland in 1351, and the following year, a circle of death closed when the plague hit Russia again.

Already in 1893, French historian Aidan Gasquet [2] pointed to the effects of religious and political changes by plague. Other scholars later confirmed his opinion. The devastation caused by *Yersinia pestis* has created conditions in Europe, where much less has been fought for food, work and security. Even people from lower social strata could, as never before, improve the conditions of their being, while the wealthy, by getting the possessions of the dead relatives became even richer. In this way social conditions were created for the transition to the next epoch, which gave rise to the present shape of it - to Renaissance.

Why J.F. Kennedy became president of the United States of America

Over the years, landowners in Ireland, who have been farming wheat, have donated whole grains for sale outside of this green country. Small farmers left little land where they had to cultivate crops that would produce high yields and allow them to collect enough supplies to survive the whole year. Potato was such a plant. The constant concern of the farmers was the crop size, which was further reduced by mysterious potato disease infecting leaves and tubers. In 1844, the disease struck with a special strength [8]. In a cold

and humid weather, the crops have been destroyed throughout the country. Because potatoes were the basis of most families' food, hunger was worsening and many people died in the winter. The next year was even worse. Diseases, typhus, fever and dysentery have plagued the weakened population.

Specialists looking for causes of disaster gave different reasons. Some talked about the soil exhaustion, others thought it was the work of Satan and the punishment of God for the profligacy during the period of abundance. Others claimed that steam locomotives, speeding through the country at dizzying speeds of 30 km/h send damaging electric pulses towards the fields. There were those who believed that misfortune was a matter of gnomes and kobolds, hostile for human tribes.

Trying to find ways to save, E.C. Lange advised: *potatoes should be drained with lime or put into salt, cut them into slices and dry them on the stove* (...) *people should stock up with vitrol, manganese oxide and salt and subject their potatoes to chlorine that is generated by mixing these substances.*

The true cause of the disease was discovered by English pastor and naturalist-amateur, Miles Berkeley of King's Cliffe parish in Northamptonshire. Looking at the potato leaves under the microscope, he noticed the mycelium that we now know as *Phytophtora infestans*. He considered that large amounts of the fungus make plants to suffocate. At first, he was his theory was ridiculed and only in 1860/61 German phytopathologist Anton De Bary confirmed the validity of this discovery. And today it is commonly known [9, 10].

Before the famine in 1845, Ireland was one of the most densely populated countries in Europe. There were 8 million people living there. A few years later, there were only five million. A million died of hunger and disease, the other two left the country and gone to Australia and America. Among those who went to the New World was the Fitzgerald family from Kerry and the Kennedys from Wexford County. And that is why J.F. Kennedy could have been elected President of the United States of America in 1960 and direct its development into new paths.

About the relative uselessness of generals

Here is a motto of one chapter in Hans Zinsser's 1935 book *Ratten, Lause und die Geschichte*, i.e. *Rats, Lice and History* [11]. This beautiful statement puts people and microorganisms in the right place. The author was the first to point out, on the example of the typhus, that microorganisms in many cases had a far greater impact on the course of war campaigns than some generals with all their strategies and concepts.

Typhus is caused by *Rikkettsia prowazeki* [12] and carried by fleas. Infestations are favored by large gatherings of people who are just emerging during wars, with concentration of troops, among refugees. Disease is common in situations of malnutrition and bad hygiene conditions.

Rikkettsia is similar to bacteria, e.g. it is susceptible to antibiotics but also to viruses, not only by its small size but also by the fact that it reproduces only in living cells. *Rikkettsia provozeki* was named in honor of two researchers: the American Howard Ricketts and the Czech, Stanislaus von Prowazek, who both died of typhus, which they got infected during their work.

The cause of the disease gets into the host's body together with the infected lice. They cause itching, and as a result of scratching, conditions to penetrate are created. Symptoms

of the disease are high fever, headache, spotty rash, chills, vomiting and muscle aches. The final stage is coma and death, which occurs at 5-15% of patients, depending on their age.

Rikettsia most spectacularly influenced on the events of the Napoleonic Wars. During the marches of troops along and across Europe, more people died from typhus and some other diseases than from fighting in the hand of the enemy.

Detailed observations of typhus effects during Napoleon's expedition to Russia in 1812 are owed to military physician J.R.L. Kerckhove. He describes that the military hospitals of Magdeburg, Berlin and other cities had no problems despite the concentration of about 500,000 soldiers. As soon as the march was started, the conditions deteriorated. The bad conditions for the army, lodgings in insect-filled cottages, hot days and cold nights, and bad food created ideal conditions for *Rikkettsia prowazeki* to develop. The first cases of the disease occurred after crossing the Nemunas river at the end of June. After the battle at Ostrava in late July, more than 80,000 people were infected. The 42,000-soldiers Kerckoves Corps had only half the capacity of service when it reached Moscow in September. Since then, typhus and diarrhea have become Napoleon's main enemies. At the beginning of the retreat from Moscow on October 19, 1812, only barely 80,000 able men of the entire army remained healthy. The retreat became an escape; Hans Zinsser writes: (...) *exhausted and sick soldiers were constantly being persecuted and attacked by the enemy. It was very cold and many people - devoid of strength by disease and effort - frozen* (...) *the hospitals in Vilnius were overcrowded, people were laid on rotting straw, in their own dirt, hungry and cold, unattended. They were forced to eat skin and even human flesh. Diseases and, above all, typhus spread throughout the cities, villages and neighborhoods* (...) *The soldiers who survived and returned from Russia were almost without exception sick of typhus.*

Despite such heavy experience, Napoleon re-assembled 500,000 people the following year and re-conquered. However, this time the story was repeated again.

It was *Rickettsia prowazeki*, not the genius of the opponents, that broke Napoleon's power in Europe.

Rabies, or how lucky you are

A non-medical person uses material of unknown composition and toxicity, giving it to the patient, including child, perhaps sick of a fatal disease. He does not even try to get patients' consent, but publishes their names and addresses to announce his amazing suppositions. In addition, as the various charlatans do, he keeps the details of the cure in secret so that its meaning and value cannot be judged. And the worst of all is that this unscrupulous man is injecting extremely virulent microorganisms to people, without having previously tried animals. Some patients die and the doctor, initially involved in the project, is distracted from the healer's actions [13, 14].

You guess what we are talking about. Ludwik Pasteur, father of microbiology. The great chemist had, like in other cases, been very lucky in his research on rabies. By the way - he broke all possible ethical rules. But it can be said that if he did not do it, for a long time people would still die of this terrible disease. Today, in regulated and bureaucratic world regulations, it would be impossible. How many valuable discoveries did not see the light of day?

Pasteur supposed that the cause of the disease must be localized in the spinal cord, although the cause of the disease was not yet known. According to him, it was possible that

the cause of the disease would be somehow *weakened* if the cord of sick rabbits was isolated and undergone *aging*. The modified pathogen from such tissue, as he hoped, would protect against the disease when administered to patients.

In July 1885, Pasteur applied *aged* cord, which according to him contains weakened germs, to a small boy Joseph Meister. It was only a month later that he checked the same material in animal tests. The experiments were only partially positive. Pasteur was not even sure that the material contained the virus at all. On the other hand, he briefly denied treatment for a bitten child, stating: *The results must first be confirmed by experiments on different animal species before such preventive therapy can be used in humans*.

To justify him may be added that rabies is a particularly hideous disease that destroys the victim physically and spiritually and leaves only the shimmering, animal-like shadow of a man. The fear of it in Pasteur's time was so great that people were voluntarily ready for any hopeful treatments, including painful ones like firing with fire or acid.

But Pasteur was not wrong and succeeded. His work has become the basis for the development of vaccination against many diseases. International recognition for his work upon rabies led to the creation of the Pasteur Institute in Paris and increased funding for medical microbiology research worldwide. Since then, vaccination with weakened or killed microorganisms has become one of the most effective methods of modern medical science.

Penicillium notatum - beginning of a new era

Constable Albert Alexander has been in London for two months in a Radcliffe hospital fighting a severe infection. It started with a small wound in the corner of the mouth, and then spread to the entire face, eyes and skin. The left eye was amputated a month ago and now the bacteria - two strains of *Streptococcus* and *Staphylococcus*, reached the left arm and into the lungs. The sulfonamides used at that time remained without effect [15, 16].

On February 12, 1941, a young researcher, Charles Fletcher, associate professor of medicine at Oxford, L.J. Witts, found the policeman in this hopeless state. Just a month before, Fletscher witnessed the conversation of Professor Witts's and his colleague, Howard Florey's pathology professor. Florey and his coworkers, Norma Heatley and Ernest Chain, have accomplished which failed 10 years ago to Alexander Fleming. They isolated a substance from the mold fungus *Penicillium notatum* and cleaned it, which they considered a wonderful weapon for the fight against bacteria, including pathogens.

We all know the story of Fleming, who, working at St Mary's Hospital in London, noticed that *Staphylococcus* sp. growing on a left dish, had been inhibited by an unknown substance diffusing from *Penicillium notatum*. However, he did not succeed in his observation, which he published, turn into a useful medicine. This was done by Florey at the turn of 1940/41 and now, in February 1941, after an animal experiment, he looked for a patient who would be fit to perform trials. The same day, he injected a policeman for whom there was no other hope, 200 mg of substance and subsequent smaller doses at intervals of 3 hours.

The effect was astounding. Within 24 hours, the patient's condition improved significantly. The fever fell, external wounds began to heal, appetite returned, and 5 days later his right eye was almost normal. Everyone seemed to have a miracle. But this story did not have a happy ending. Florey, Heatley and Chain had only a limited amount of penicillin, which soon ended. They desperately tried to isolate it from the urine of the patient to re-inject, which allowed them to gain some time. There was further improvement,

until penicillin was no longer left and the treatment had to be stopped. Finally *Staphylococci* won and constable Albert Alexander died on March 15, 1941.

It was only a losing battle, but not war. Thanks to penicillin and other antibiotics that have been discovered, the average life expectancy has increased by 10 years. Today, although used too often, leading to the emergence of resistant strains, antibiotics are a powerful tool to fight diseases. The story of the unfortunate London police officer Albert Alexander has opened a new era of antibiotic revolution [17].

And the small note at the end: anyone who reads the Trilogy of Henryk Sienkiewicz knows, that in the former Poland wounds were treated with bread kneaded with spider's web. And on spider's web, of course, there are plenty of fungal spores, also *Penicillium*. So antibiotic treatment has been used in our country for centuries ...

The end of Italian monopoly

How can a small, almost invisible organism knock down the entire industry, break the monopoly and have a profound effect on the economy of the country? This is what happened when J.N. Curie in 1917, published an article dealing with some of the characteristics of *Aspergillus niger* fungus metabolism in the Journal of Biological Chemistry. He discovered the method of obtaining the citric acid using this fungus [18].

Citric acid, thanks to its poorly acidic, pleasant taste and lack of toxicity, is readily used in the kitchen as a supplement to juices, marmalades, sweet food and other dishes.

The history of citric acid production began in 1826 in England, in Selby. There, Jon and Edmund Sturge started the production of calcium citrate from lemon juice imported from Italy. The business went well. However, in the first two decades of this century, also Italian companies began to produce citric acid. They quickly reached the position of monopoly, and as a result, as predicted, prices quickly went up. Italians have mastered the world markets.

The discovery of Curie coincided with a breakdown of citric acid production after World War I, when lemon and orange plantations were neglected. An investigator who not only described the production of citric acid but, as we would say today, has optimized the whole process, determining under what conditions the production is maximized, has developed together with firm Pfizer an industrial production method. It started in 1923 in Brooklyn. Other factories have also been established in Great Britain, Germany, Belgium and the Czech Republic. Instead of sugar - molasses began to be used. New plants were built, technological improvements were made, although the main features remained the same as in the beginning. Today, citric acid is only produced by *Aspergillus niger*. With an annual production of half a million tons, it would not be possible to obtain this product from lemon juice [18].

Aspergillus niger is a special species. In addition to citric acid, it can be used to produce gluconic acid, used in pharmacy - calcium or iron gluconates are used to deliver these elements in case of deficiency. It is also used for extinguishing the foam in installations of food industry facilities. The fungus can also be used to produce vitamin B_{12}, starch hydrolyzing enzymes in beer production, as well as itaconic acid used in the paint, adhesives and fibers industry.

This was the result of the publication of an article in the scientific press, it would seem to be interesting only to specialists and as a result of pure curiosity, as we today say - basic research. Today, when writing a research project proposal, we need to accurately describe

what will be done and what results will be obtained, who and how much will benefit from the research, and when the first euro will be affected as a financial result, we should remember the story of the discovery, that began from the curiosity of the researcher and ended with the overthrow of a powerful industrial monopoly on a global scale.

OX19, i.e. an epidemic that did not occur

Finally the Polish accent. Let's go back a few decades, until the German occupier took control of our country (World War II). First, however, we disseminate the mysterious OX19 cryptonym.

Infectious agent causes the formation of antibodies in the body that are specific to the organism causing the infection and do not react to the presence of other pathogens. This is one of the important diagnostic methods. With specific antibodies, we can recognize a 100% certain pathogenic factor. However, there is an exception. In the case of typhus, as a side effect, antibodies that react with *Proteus vulgaris* strain OX19 are also produced in the blood. The reason is that this strain has a same surface antigen like *Rikkettsia prowazeki*, causing a typhus. The immune response is so unequivocal that this side-effect is used in tests to detect typhus infection in pathological laboratories. Why should we use dangerous microorganism, *Rikkettsia prowazeki*, for the pathogenic test, if the same effect can be achieved with the completely harmless *Proteus* OX19? This is the so-called *Weil-Felix reaction* [12].

Two physicians, Eugeniusz Laskowski and Stanislaw Matulewicz, who worked during the German occupation in Rozwadow and Zbydniow, knew the Weil-Felix reaction from his studies [19]. They were not needed it in a daily work, but remembered it after visit of a friend who had been sent to Germany for forced work and just arrived for a short two-week stay in the country. He was determined not to return to Germany and stay at any price. It was not easy; only a serious illness confirmed by research results, could help here. Then the idea came up: if they inject the friend with *Proteus* OX19 bacteria, they would produce antibodies in the blood, which would simultaneously indicate the patient's infection with a typhus. As they thought, so they did. Within a short period of time, antibodies developed in the blood of the friend, but of course he remained healthy. His blood was sent to the German laboratory and the official result was: Weil-Felix reaction - positive. The man had not to go to Germany. This success did not satisfy brave doctors, however. Once succeeded, why not try once more? The idea was very favored by the Germans fear of a typhus. It was so large that in the German death camps, all prisoners were undergoing a 6-8 week quarantine and people who had been diagnosed with the disease were murdered. So both doctors gave the other patients injections with *Proteus* OX19 bacterium and sent their blood for testing. Multiplication of disease cases has seriously disturbed the Germans. They were convinced that the typhus epidemic broke out. The district in which Laskowski and Matulewicz practiced, covering a dozen or so villages, was declared a closed area due to an epidemic. For a long time, the inhabitants had peace - Germans did not show up almost at all.

Only once, the deception was almost discovered. A denunciator informed the occupant that there was no epidemic at all. But without knowing it exactly, he assumed that the blood of one sick person was being used, sending it under different names for analysis. The investigation was implemented, but it was also contaminated with fear of disease. Instead of thoroughly investigating all allegedly ill people, which would show that they are not

infected, the Germans took blood again. The result was same, the Weil-Felix reaction was again positive.

Many years later, English surgeon Jon Bennet of the British military hospital at Rinteln, describing the whole story, wrote that it was strange that the absence of death cases, which is the often end of the disease, had not alarmed German specialists, along with the equal level of antibodies in all patients' blood, which is also abnormal. But they were paralyzed by their fear of disease and all the research was done without contact with the sick persons. Also the percentage beverages played a role here. English doctor gives an example: "The German commission, consisting of a senior physician and two young assistants, was sent to check the diagnosis of Matulewicz and Laskowski. According to Polish custom, they were welcomed, and given with food and drink, and especially drink. The older doctor preferred to spend time for libation and sent his assistants to the village for inspection. They looked superficially, but the fear of infection kept them from checking more closely. They were shown to an older man suffering from pneumonia claiming to be ill with typhus. As the Germans say, repeating after Goethe "wir sehen, was wir wissen" - "we see what we know". So the Germans saw, they were convinced and they went away".

It is said that one fifth of the population of Poland died as a result of the occupation, and many more were deported to extermination camps abroad. The fact that one small municipality suffered so little resulted largely in the ingenuity of two doctors and the *Proteus* OX19 bacteria.

Epilogue

There are still many stories to tell, in which microorganisms play an indispensable role. It would be very interesting to listen about the life of microorganisms in libraries and in old books, about microorganisms that metabolize PCB's, the most stable substances in nature, or living entirely without food; about the ones that provide the most sophisticated tastes to gourmets; about cleaners of our waste; about those saving the ozone layer in the atmosphere; about those that wash our clothes; about biodegradable plastics producers; about those that can be used to monitor the quality of the environment and to control pests and diseases of plants; and also about such that protect Earth from global warming.

But would these stories would be about microorganisms only? Or perhaps about the people who were fascinated by the microscopic world of microbes and discovered their secrets, meaning and ... beauty?

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Abstrakt: Mikroorganizmy, niedostrzegalne na co dzień, towarzyszą nam zawsze i wszędzie. Często nie zdajemy sobie sprawy, jak decydujący wpływ wywierają na nasze życie, jakie korzyści przynosi ich obecność, które z naszych kłopotów są skutkiem ich działania, a także jak zaskakujące rezultaty wynikają z ich aktywności. Niejednokrotnie mikroorganizmy odegrały też decydującą rolę w rozwoju społeczeństw, polityce i historii. Do najbardziej spektakularnych ingerencji mikroorganizmów w historię ludzkości należy między innymi przykład fałszywej „gorączki naftowej", która wybuchła w Australii w drugiej połowie XIX wieku. Jeszcze bardziej znaczące było skierowanie historii Europy w nowym kierunku na skutek epidemii „czarnej śmierci" w XIV wieku. Mikroorganizmy wytworzyły warunki społeczne do przejścia do kolejnej epoki - odrodzenia, stwarzającej podstawy dzisiejszego kształtu kultury europejskiej. To dzięki mikroorganizmom J.F. Kennedy mógł zostać w roku 1960 prezydentem Stanów Zjednoczonych Ameryki i skierować jej rozwój na nowe tory. Mikroorganizmy, a nie przywódcy i generałowie wygrywali bitwy i wojny. To *Rikketsia prowazeki*, a nie geniusz przeciwników złamała potęgę Napoleona w Europie. Drobnoustroje walczą z chorobami, powodując poprawę jakości życia i przedłużenie jego trwania. Pozwoliły na opanowanie wścieklizny oraz licznych chorób zakaźnych. W gospodarce za przyczyną mikroorganizmów upadały potężne monopole. Bakterie zostały też użyte do ochrony ludności cywilnej w Polsce podczas drugiej wojny światowej. Jeszcze wiele podobnych historii można by opowiedzieć, historii, w których mikroorganizmy odgrywają niepoślednią rolę. Czy jednak byłyby to historie tylko o mikroorganizmach? Czy może też o ludziach, którzy zafascynowani mikroskopijnym światem drobnoustrojów odkrywali jego tajemnice, znaczenie i … piękno.

Słowa kluczowe: mikroorganizmy, historia, społeczeństwo, medycyna