BIODIVERSITY
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THE SECRET WORLD OF “JUMPING” DNA

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Transposons are unusual segments of DNA that can affect genes and create new traits, helping to make every living thing special. Transposons have the amazing ability to move around within an organism’s DNA, and they can even travel between organisms! Transposons can be activated by stress, helping organisms to cope and adapt. Researchers are using transposons as special delivery systems to help cure diseases. Also, studying transposons can provide a lot of information on how the biodiversity of life on Earth has changed over millions of years. They can help each other in their journeys, practicing teamwork. The unique features of these “jumping” DNA segments even earned scientists a Nobel Prize for their discovery.

WHAT IS BIODIVERSITY?

The natural world is a big family of life forms, including humans, animals, plants, and many tiny organisms. The incredible variety of living things on our planet is called **biodiversity**. Biodiversity is vital because it keeps our planet healthy. Each type of organism has its

BIODIVERSITY

Biological diversity of living organisms.

own important role. For example, some organisms clean the air, some pollinate plants, and some recycle nutrients. Biodiversity helps the environment to stay balanced, and Earth's diverse lifeforms also provide us with food, medicine, and new technologies. Biodiversity can be influenced by many factors. Sometimes new species evolve, and sometimes species disappear. In this article, we will introduce you to **transposons** and the multiple ways they can influence biodiversity.

TRANSPOSONS

DNA segments that can move around within the genome.

WHAT ARE TRANSPOSONS?

As you may already know, DNA contains information important for the functioning of our bodies and the bodies of all other living things. Every DNA molecule is made of two strands wound together, each built out of chemicals called bases. The four bases are abbreviated A, G, C, and T (Figure 1). All the DNA in an organism is called its **genome**. What is genome made of? Part of this DNA are **genes** and each gene is responsible for a specific **trait**. But our genes make up less than 2% of our DNA. What about the rest of the genome? The function of this 98% "extra" DNA was not immediately clear to scientists. At first, some scientists thought it was useless "junk". But it is not!

GENOME

The complete DNA content of an organism.

GENE

A segment of DNA responsible for a certain function or trait.

TRAITS

Special features or characteristics of an organism, like eye color or height.

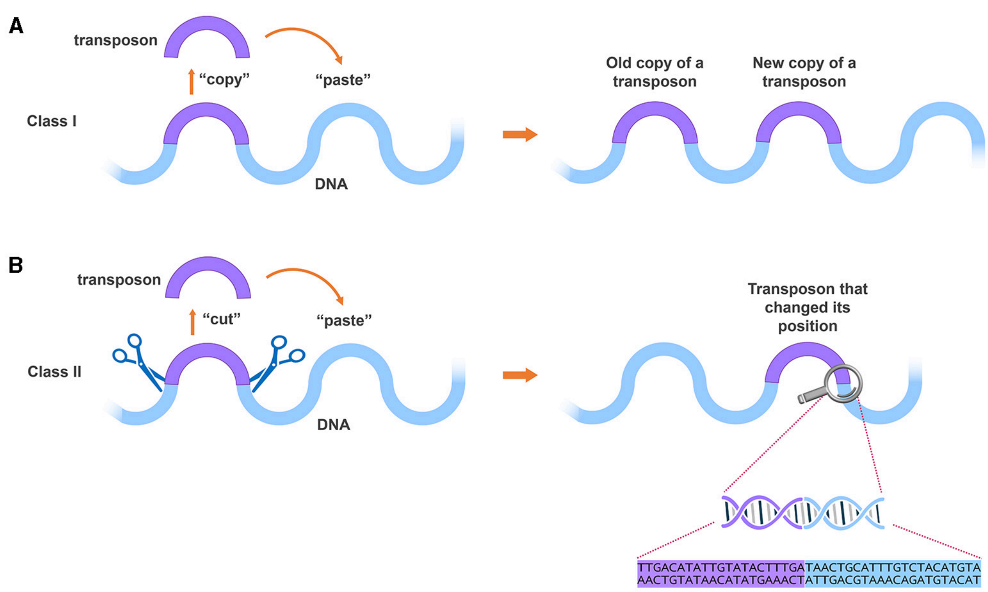

Figure 1

Figure 1

Transposons come in two types: class I and class II. **(A)** Class I transposons copy themselves first, and then the new copy is "pasted" somewhere else in the genome. **(B)** Class II transposons do not use the copy step. Molecular "scissors" snip these transposons out of the genome, and then they are pasted in a new location.

A part of it are DNA segments that have the fascinating ability to move within a genome, called transposons. Transposons make up a sizable portion of the genomes of many organisms, including humans, animals, and plants. Transposons were discovered by a scientist named Barbara McClintock in the 1940s [1]. The scientific community at that time was skeptical about her ideas because many scientists thought that DNA segments could not move from one position to another.

However, decades later, her discovery was confirmed. McClintock's research on transposons even earned her a Nobel Prize in 1983!

Several types of transposons exist. Two main categories are called class I and class II transposons. Class I transposons use a process called "copy and paste" to change positions in the genome. This means they make a copy of themselves and insert it into a new location, resulting in two identical transposons at two locations. Class II transposons use a "cut and paste" mechanism: they cut themselves out of their original position and insert into a new location (Figure 1) [2]. In this case, the number of copies of the transposon does not increase.

When it is time for class II transposons to move, a protein called a **transposase** acts like molecular scissors, cutting the transposon out of its original location (Figure 1). Once the transposon is free, transposase helps guide it to the new location by recognizing specific sequences of DNA. Transposase also helps the transposon insert into the new site. The cell's repair machinery then seals the DNA where the transposon was inserted. In case of class I transposons, other proteins help make additional copies.

TRANSPOSASE

A protein that helps transposons move to new locations in the genome.

Transposons cooperate! Some transposons have all the tools needed to move from one place in the genome to another, while other transposons lack the full set of tools needed to move and cannot move on their own [2]. However, these transposons can "hitchhike" with the ones that have the right tools, borrowing their tools to move around the genome. True teamwork!

TRANSPOSONS AND BIODIVERSITY

So far, scientists have uncovered several important ways that transposons contribute to biodiversity. Each is explained below.

Architects of Diversity

Transposons can act as architects of the genome, moving genes to new locations or even joining segments from separate parts of the genome together. Moving and combining genes can change the instructions telling the organism how to function [2]. Sometimes these changes can lead to new traits that make individuals different from each other, increasing biodiversity. For example, apples come in various flavors, right? Some are sweet and some are sour. The apple's genes are like little recipes telling it to be sweet or sour. Transposons are like sneaky chefs that can change the recipe—they might make a sweet apple taste sour or a sour apple taste sweeter. Sunflowers are another example. Sunflower genes tell the plant how tall it should grow. Transposons can jump into these instructions and change them, so that a sunflower that was supposed to be short might end up growing super tall! Transposons can also affect an animal's coloration. Think about the stripes or spots on tigers or leopards. Transposons can sometimes jump into these pattern genes and create a new pattern. The color of snake's skin can change in the same way. Transposons can also change the fur color of mice, dogs, and wolves. Insects can get different eye colors, and chickens can lay eggs with various shell colors. A similar thing can happen in fish—a transposon can cause a fish to become albino, completely colorless.

Adaptors and Protectors

When transposons move, they can jump *within* a gene. This changes the gene's functioning [2]. In some cases, these changes are harmful and cause diseases. In other cases, they can be beneficial and even make a species *better* adapted to its environment. The story of an insect called the peppered moth is a classic example [3]. In the early 19th century, all peppered moths were a light color with dark spots. However, in 1864, a naturalist in England discovered a completely dark moth. This was quite interesting! During Industrial Revolution, the pollution from factories covered the trees with soot. Dark moths could camouflage on such trees, which reduced the risk that they would be seen and eaten (Figure 2A). Much later, scientists identified that a transposon was responsible for the dark coloration. It jumped inside a moth gene called cortex, which is responsible for wing color, causing more of the dark color to be produced (Figure 2A). Without this change, the peppered moths would not have survived.

Storytellers of the Past

Transposons can help us discover biodiversity that existed in the past, kind of like genetic fossils. Transposons have been around for a very long time. Some were active millions of years ago and have become inactive over time. However, they still remain in organisms' DNA, mostly as broken-down pieces. By studying the presence and types of transposons in the genomes of various organisms, scientists can use transposons to understand how species are related to each other—even extinct organisms found in museums. By studying ancient transposons, scientists can piece together the evolutionary history and relationships between species, like detectives following clues! This way, transposons reveal the story how life on Earth has transformed over millions of years.

Lifesaving Heroes

Transposons have also become useful tools in medical research. Scientists can change transposons in the lab and use them to deliver important genes to specific cells in the body. This can help treat certain **genetic diseases** by replacing or fixing faulty genes. These transposons act like a special delivery system that brings helpful instructions to the right place in the body. They can keep organisms healthy and even save lives!

GENETIC DISEASES

Problems in genes which result in illness.

Figure 2

(A) Transposons help species adapt. Before the Industrial Revolution, moths with light wing color were frequent. Trees changed color due to pollution, so darker-colored insects were better able to hide from predators. The insertion of a transposon (purple) into a gene for wing color changed the gene's activity, making the wing color darker. **(B)** Transposons can protect organisms from dangerous conditions in the environment. In this example, a transposon changed a gene so that less of the toxic metal cadmium was absorbed by plant cells. **(C)** Transposons can keep the genome stable, for example by protecting the ends of chromosomes.

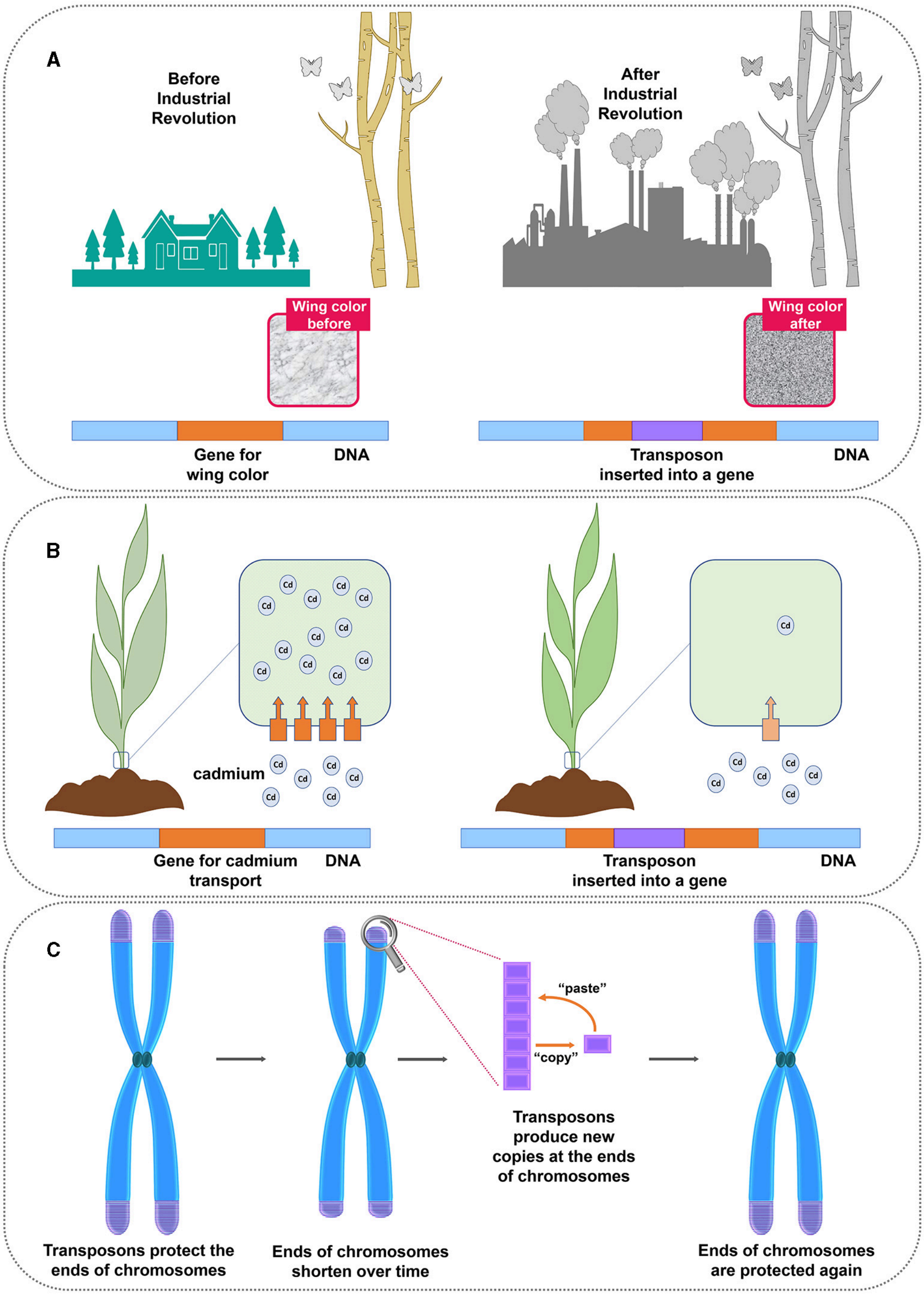

Figure 2

Crisis Response Team

When organisms face stressful situations, like extreme temperatures, dangerous substances, or other challenges, they produce signals that help them cope with stress. These signals can wake up "sleeping" transposons, which then start jumping around the genome. Transposon activation might be a way for the organism to change its genes in an attempt to adapt and survive [4]. For example, a stress-activated transposon is involved in the response of rice plants to a toxic metal called cadmium. Rice plants have a gene responsible for getting cadmium inside their cells. A transposon inserted itself into that gene and disabled it. This reduced the amount of cadmium that the plants took up and helped them stay healthy (Figure 2B). How did this contribute to biodiversity? Now a new type of rice exists, protected from cadmium.

DNA FINGERPRINTING

Identifying individuals by unique DNA patterns.

Biodiversity Trackers

DNA fingerprinting using transposons is an innovative and powerful technique to study and identify different varieties of plants. Transposons can insert themselves at various spots in the plant's DNA so, over time, each plant accumulates its own set of transposon copies. This creates a unique pattern or "fingerprint". By comparing transposon fingerprints in the genomes of different plants, scientists can determine how closely related the plants are. Plants with similar transposon fingerprints are likely to be closely related, while those with very different fingerprints are more distantly related. In this way, transposons help scientists track biodiversity.

"Long-Distance" Travelers

Transposons can even travel between species! For example, a transposon from a plant could find its way into an animal, or the other way around, often carried by viruses or other means of transport. Transposons carry their information to new organisms and make their way into their DNA—becoming a part of the new organism's genome [5]. By changing the genome of the organism they move to, transposons contribute to biodiversity.

Genome Boosters

Remember how class I transposons copy themselves? Well, the more this happens, the larger the organism's genome becomes. For example, an extreme boost in transposons in corn about 3 million years ago doubled the size of its genome [6]. In the genome of a type of farmed wheat, 96% of the DNA is composed of transposons. The formation of many cultivated varieties of plants is related to transposon activity.

Safeguards

Transposons can sometimes serve as guardians of the genome, keeping it stable. One example is when transposons replace the normal sequences found at the ends of the DNA molecule, protecting them from shortening and degradation. This happens in the fruit fly, for instance (Figure 2C). By producing new transposon copies, DNA ends remain intact over time, which helps to ensure that important genetic information is not lost. If genetic information is lost, organisms may not survive and biodiversity is reduced.

CONCLUSIONS

Today, transposons are recognized as important builders of the genome and drivers of its evolution. As you have seen, their contributions to biodiversity are various and significant (Figure 3). They act as architects, storytellers, travelers, healers, guardians, hitchhikers, and much more. Transposons are involved in many important processes that change and shape the genome. There are still many mysteries to be revealed about transposons. How is their movement within and between genomes regulated? How they can be further used in medicine? How will transposons behave as the environment on Earth changes? Are there other ways that they affect biodiversity? We already know that transposons are important, but we believe there is much, much more to come!

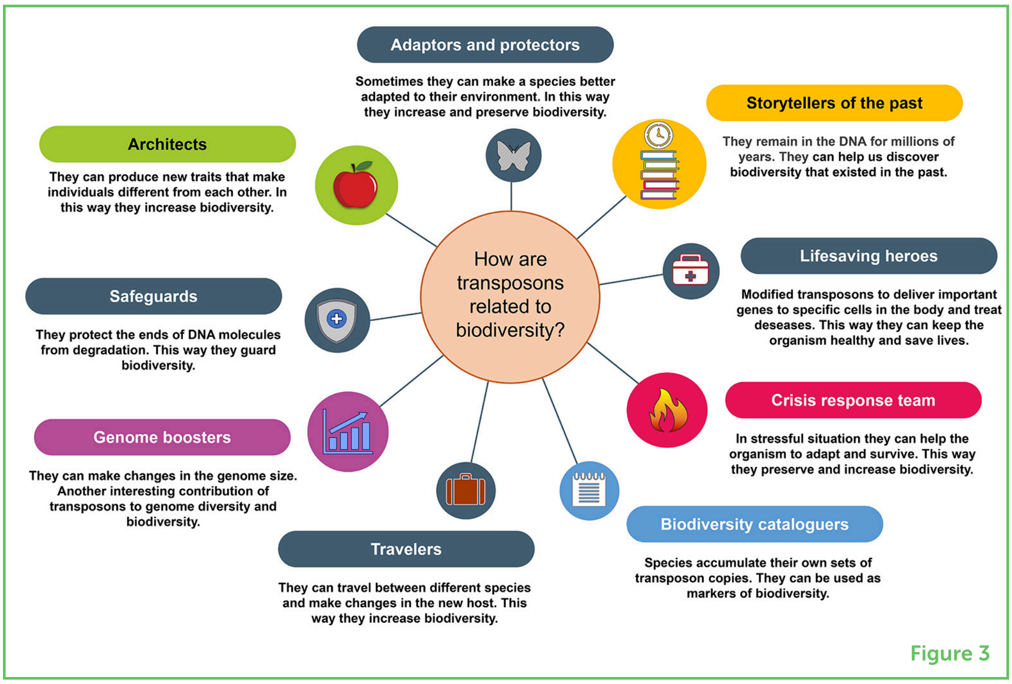

Figure 3

Transposons contribute to biodiversity in many ways.

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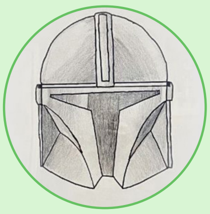

SAMARTH, AGE: 13
I am interested in science and math. One of my favorite things to do is to read and play music. I play piano and trumpet in the school band. I also love history, sports, and cooking!

Y8 LAURUS INTERNATIONAL SCHOOL OF SCIENCE, AGES: 11–12
We are the Y8 of Laurus International School. We are all about diving into cool science stuff and figuring out how things work. We also love gaming and sports. Let us explore the world and uncover some awesome mysteries!

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I am a molecular biologist working as a researcher at Ruđer Bošković Institute in Croatia. My primary research focus is repetitive DNA sequences in the genomes of various organisms. I have characterized various transposable elements and satellite DNAs, and investigated their structure, function, localization, organization, evolution, and influence on genome architecture. Repetitive sequences like satellite DNAs and transposons were once accused of being "junk DNA", with no relevant biological function. This has been proven very wrong, and I enjoy contributing to the debunking of this myth. *Eva.Satovic.Vuksic@irb.hr

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I am a senior scientist at Ruđer Bošković Institute in Zagreb, Croatia, emeritus of the Institute since 2022. For over 30 years, I focused on exploring the structure and evolution of non-coding repetitive DNA sequences that build the major fraction of our genomes. My main goal is helping people to understand the usefulness of these sequences, particularly, by explaining the functions of these sequences. I was principal investigator or participant in many projects that included international collaborations with scientists with similar interests.