WHAT WE HAVE LEARNED FROM ANIMALS

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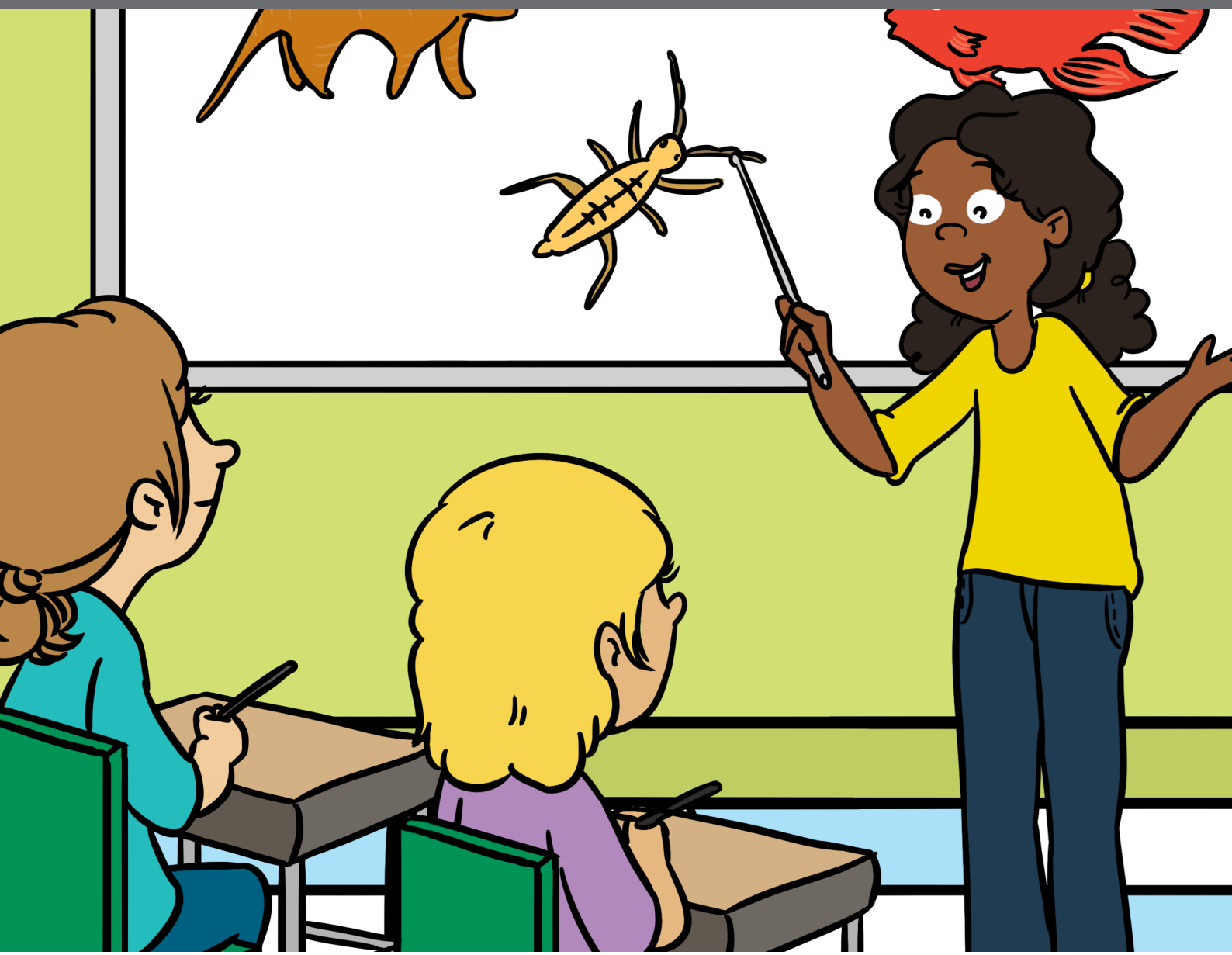

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WHAT WE HAVE LEARNED FROM ANIMALS

Topic Editors:
Stuart Semple, University of Roehampton
Anne Robertson, University of Roehampton

Did you know that we can learn things about ourselves (humans) and our behaviour without directly studying ourselves? Scientists have for years studied all kinds of animals, to gain a better insight into their strategies for survival, both alone and together. And we are now finding out that these studies can teach us a lot about us and our world – from ecosystem functioning, to behaviour, to health.

This Collection examines what we have learned from animals, ranging from microscopic invertebrates to fish and mammals. We look in particular at what different animals can teach us about human behaviour, about how life has evolved and its diversity, and about how the ecosystem on our planet functions. We hope you enjoy reading about all the fascinating things we can learn from the animals we share out planet with!

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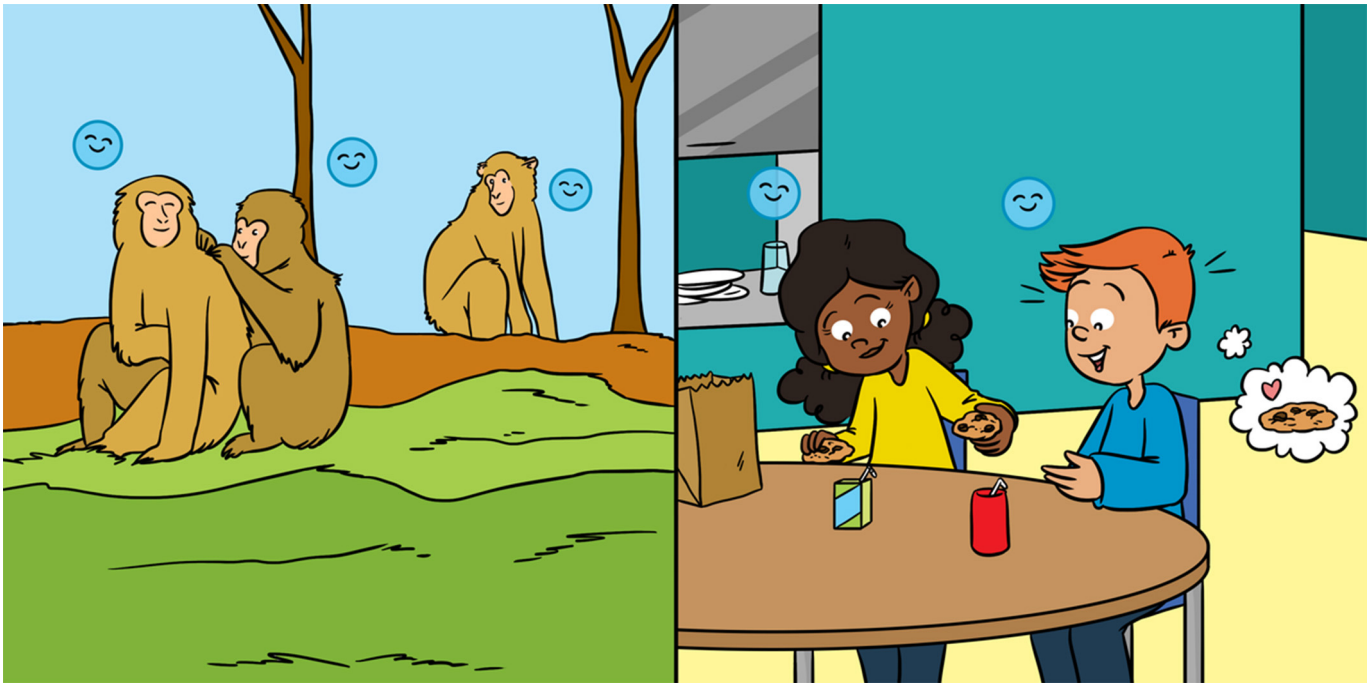

GOOD VIBES: WHAT HAPPENS WHEN MONKEYS ARE NICE TO EACH OTHER?

Stuart Semple *

Department of Life Sciences, Centre for Research in Evolutionary, Social and Interdisciplinary Anthropology, University of Roehampton, London, United Kingdom

YOUNG REVIEWER:

MICHAEL

AGE: 13

Humans belong to a group of animals known as primates. This group includes the lemurs, monkeys, and apes. Scientists have studied the behavior of primates for many years, and one reason for doing this is to find out how similar—or not—primates are to us. This article will tell you about research we have carried out into the social behavior of a monkey known as the Barbary macaque. We looked at a special behavior, grooming, where one animal does a favor to another by cleaning its fur, removing dirt, ticks, and fleas. We discovered that doing grooming makes monkeys feel relaxed, and that even observing others groom has the same effect. These findings suggest that for monkeys, being nice—or just watching others being nice—makes them feel good. This is also true for humans, so our lives and those of the other primates are more similar than we previously thought.

Figure 1

Examples of primates—a lemur, a monkey, and a great ape.

Ring tailed lemur
(picture by Matthias Appel, from https://en.wikipedia.org/wiki/Ring-tailed_lemur)

Black-headed spider monkey
(picture by Petruss, from https://en.wikipedia.org/wiki/Spider_monkey)

Orangutan
(picture by David Arvidsson, from https://en.wikipedia.org/wiki/Orangutan)

Figure 1

STRESS AND GROOMING IN PRIMATES

PRIMATES

A group of animals that include the lemurs, monkeys, and apes (including humans); the primates are part of a larger group called the mammals.

The **primates** are a group of animals that includes the apes, the monkeys, and the lemurs (Figure 1). Humans are primates—we are one of the great apes, along with chimpanzees, bonobos, gorillas, and orangutans. Scientists have learned a lot about what makes us human by studying the behavior of the other primate species. In particular, studies of our primate relatives have helped us to understand the importance of being nice to others.

GROOMING

Picking through the fur of another animal, not just to clean away dirt and parasites but also to gain favors later.

Our work in this area has focused on the Barbary macaque, a monkey species that, in the wild, lives in the mountains of Morocco and Algeria in northern Africa. There is also an introduced population on the Rock of Gibraltar, in the Iberian Peninsula (Europe). We have looked specifically at a behavior known as **grooming**. Grooming involves one animal carefully picking through and cleaning the fur of another group member, and is a very common behavior among social primates [1]. It was originally thought that the purpose of grooming was solely to remove dirt, ticks, and other parasites from the fur, but it has become clear that there is much more to it than that. Animals being groomed benefit not only from the cleaning service they receive but also because being groomed is really relaxing and makes them feel good [2]!

BETA ENDORPHINS

Chemicals in the body which have the effect of making you feel good (the great feeling you get after doing exercise is due to these).

There is evidence from several different kinds of monkeys that being groomed lowers heart rate [3], reduces the levels of stress-related hormones [4], and leads to the release of feel-good chemicals known as **beta endorphins** [5]. All these relaxing effects mean that being groomed is like receiving a monkey massage (Figure 2). Because of the pleasure monkeys feel when they are groomed, this behavior appears to be a type of social currency that can be traded by monkeys for future benefits. For example, grooming can be traded for support in fights—if one monkey grooms another and the one that did the grooming later gets involved in a fight, the one that received the grooming is more

Figure 2

Two adult female Barbary macaques involved in a grooming session.

likely to come to their aid [6]. This is the typical case of "if you scratch my back, I will scratch yours."

GROOMING, GOOD TO GIVE AS WELL AS TO RECEIVE?

We decided to look at grooming in a new way—to find out if giving grooming is also relaxing [7]. We worked with the Barbary macaque population in Gibraltar and wanted to measure the stress levels of animals that we saw grooming. The goal was to know if those Barbary macaques that did more grooming were more relaxed as a result. To do this, we used methods that did not involve capturing the monkeys, for example to collect blood samples, as doing so would of course cause them to be stressed.

So, what we did was collect poo (or as scientists say "fecal samples"). While this may seem a strange thing to do, fecal samples can give an insight into what monkeys are feeling. When a monkey feels stressed, its body releases hormones called **glucocorticoids**. Once the glucocorticoids have served their purpose, they are broken down by the liver and some of what is left—these are called **metabolites**—pass out in the feces. By collecting fecal samples and then using some neat chemical processes to measure the concentration of stress hormones, scientists can know which monkeys are stressed, and which are chilled out.

GLUCOCORTICOIDS

Chemicals released in the body when something stressful happens.

METABOLITES

When your body breaks things down (this is called metabolism), what is left are the metabolites.

In total, we collected between three and six samples from each of 12 adult female monkeys. We also measured how much time each animal spent being groomed and grooming others. Male monkeys groom too, but a lot less than females, so we decided not to study males. When the data on grooming and glucocorticoid metabolite levels were analyzed, something really surprising was found: the quantity of glucocorticoid metabolite was not related to the time spent being groomed but was related to the time spent grooming. This means that monkeys that did more grooming had lower stress. For this species, it seems it is better

to give than to receive! Another important finding was that the number of grooming partners was also important. We found that animals that gave grooming to a larger number of others had even lower levels of these metabolites. In other others, they were less stressed.

So what might be going on here? We think that by doing a lot of grooming—and spreading grooming among lots of their group mates—Barbary macaques build up a large network of potential supporters. This means that when one macaque gets into a stressful situation, it can count on being backed up by those friends it has groomed before. This means that, on average, Barbary macaques that built up a group of potential allies are more relaxed than animals that have not.

FRIENDLY BEHAVIOR IS CONTAGIOUS

We also wanted to know what happens to those Barbary macaques that just watched others grooming and being groomed [8]. This idea was inspired by research in humans that showed that seeing others act in a friendly way not only makes people feel good, but also encourages them to pass the good feelings to others. This is known as **positive visual contagion** and was thought to be unique to humans. Probably, monkeys experience positive visual contagion too.

POSITIVE VISUAL CONTAGION

When you see someone being nice, that makes you be nice to others.

DISPLACEMENT BEHAVIOR

A group of behaviors—like scratching, touching your face or hair—that in humans we call fidgeting.

So, we decided to compare the behavior of female macaques in two situations: after they had and after they had not watched others grooming. We measured a particular type of behavior known as **displacement behavior**. Displacement behavior includes scratching and self-grooming—the sort of thing that called fidgeting in humans. We knew that displacement behavior provides a measure of primates' emotions: when animals are in a stressful situation, they show more displacement behavior, while a reduction in displacement behavior indicates that animals are relaxed.

The results of the study revealed that macaques showed much less displacement behavior after watching others groom. It seems that it is relaxing to watch others relaxing! Also, animals that watched others groom were also more likely to later groom others. So, friendly behavior does indeed appear to be contagious for these monkeys.

HUMANS, BE NICE TO EACH OTHER

Humans do not openly groom each other on the street or at work to reduce stress, although you could see a trip to the hair salon or going for a massage as forms of grooming. While we certainly do not spend as much time grooming as monkeys do, these two studies of Barbary macaques could help us understand why, with a few exceptions, we

tend to be a friendly species. During our evolutionary history, making others feel good may have been rewarding in itself, and even just watching others being nice to each other may have led to positive feelings. This is likely to have been very important throughout human evolution, maintaining friendliness and a desire to help others in the societies in which our ancestors lived.

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YOUNG REVIEWER

MICHAEL, AGE: 13

I am a video game fanatic, and I also study very hard to keep up with my school work. My favorite topic in school is Biology followed by History. I keep up with the political news and 1 day I aspire to be a doctor, but not sure yet what type of doctor I want to be. I live with five cats and two dogs.

AUTHOR

STUART SEMPLE

I am a Professor of Evolutionary Anthropology at the University of Roehampton in London. I started out in science studying coral reefs, but soon became fascinated with the behavior of monkeys. I have been studying these animals for over 25 years, working with baboons in Kenya, and Barbary macaques in Gibraltar and Morocco. The work I talk about in this piece involved my colleagues, Kat Shutt, Juliette Berthier, and Ann MacLarnon. *s.semple@roehampton.ac.uk

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THE AMAZING DIVERSITY OF CICHLID FISHES

Isabel Santos Magalhaes [*†] *and Antonia Geraldine Patricia Ford* [*†]

School of Life and Health Sciences, University of Roehampton London, London, United Kingdom

YOUNG REVIEWERS

BLINDERN IB SCHOOL

AGES: 15–16

Imagine swimming through warm, clear-blue water where, all around you, you see brightly colored fishes of all shapes and sizes. Does this sound like a tropical coral reef? Maybe so, but it could also be a tropical freshwater lake, with hundreds of different types of cichlid fishes. Cichlids live only in freshwater and are found in lots of different lakes and rivers across the world. Their bright colors and interesting behaviors mean that they are popular to keep as pets in fish tanks, but they also are incredibly interesting to scientists and are a valuable food source. Scientists study cichlids because they want to understand how different types of cichlids have evolved to suit their different environments. Cichlids are important for food in many countries, both through fishing of wild populations and fish farming (aquaculture), in specially built ponds or tanks.

CICHLIDS

Freshwater fishes of the family Cichlidae that can be found in warm climates, in many types of water bodies across Africa, Central and South America, and Asia.

WHAT ARE CICHLIDS AND WHERE CAN WE FIND THEM?

Cichlids (pronounced sik-lids) are freshwater fishes that can be found in warm climates, in many types of water bodies such as lakes, ponds,

Figure 1

Cichlid fish species in Lake Malawi exhibit great diversity in shape, size, and color (Image credit: Isabel Magalhaes).

rivers, and streams. There are lots of different species of cichlids. They come in an amazing range of sizes, colors, and patterns (Figure 1). Most cichlid species alive today are found in Africa, with almost 2,000 known species in African lakes alone. In Central and South America there are 560 known species, and 32 in Madagascar (reviewed by Kocher [1] and Turner [2]). Three species can be found in southern Asia and seven in the Middle East. Because cichlids are found in so many countries in the southern hemisphere, some scientists believe that they existed on the ancient southern supercontinent known as Gondwana. Gondwana was a huge land mass which, around 120–160 million years ago, broke up into the pieces that we know today as South America, Africa, Arabia, Madagascar, India, Australia, and Antarctica. However, other scientists have a different idea: they think that cichlid fishes may have moved between continents by swimming across oceans. We may never know for sure which one of these ideas is correct, but what scientist *do* agree on is that cichlids have been around for a long time, with the oldest cichlid fossils being 45 million years old. We also know that cichlids are capable of very rapid **speciation**. This is the evolutionary process by which one species gives rise to a new, closely related species.

SPECIATION

An evolutionary process that leads to the formation of new, distinct species that can no longer breed with the original species.

The cichlid species in the Great Lakes of East Africa have attracted the most attention from researchers [2]. In these lakes, almost 2,000 species of cichlids have evolved over the last 100,000 years, which is considered the very recent evolutionary past. Scientists are interested in understanding exactly how the new species arise, and why speciation occurs more quickly in cichlids than in other types of vertebrates. The three Great Lakes of Africa have the highest number of described species: around 1,000 species in Lake Malawi[1] , 500 in Lake Victoria, and 250 in Lake Tanganyika. In each of these lakes, cichlid

[1] To learn more about Lake Malawi life, see `https://www.bbc.co.uk/programmes/p00379zw`

species form what is known as an **adaptive radiation**, which is a group of many species that have rapidly evolved from a single species called the common ancestor. These species have lots of variety in their size, shape, and color, as well as in what they eat and where in the lake they live. As such, cichlid fishes are important for understanding how evolution gives rise to biodiversity.

ADAPTIVE RADIATION

Rapid increase in the number of species descended from a common ancestor, characterized diversity in diet and habitat.

There are several theories to explain how so many species of cichlids emerged in the African Great Lakes in a relatively short time. However, in this article, we will focus on two theories: ecological selection and sexual selection.

ECOLOGICAL SELECTION

Ecological selection is the adaptation of species to different food sources or habitat niches. Different species of cichlids have different mouth, tooth, and body shapes that are adapted to different ways of feeding. Some species sift through sediment for food, some feed on zooplankton, and some feed by scraping the algae off rocks. Other species are predators of fish, eggs from other fish, and insects. There are specialized crab-eaters and many snail-eating species. Some cichlid species specialize on very specific types of food, such as sponge-eating species and species that remove parasites from the skin of catfish. One species feeds mainly on flies that rest on rock surfaces near the water.

ECOLOGICAL SELECTION

The process by which populations of organisms adapt to new environments or resources. Their ecology (diet or body shape, for example) changes as a result of this process.

Cichlid species have also adapted to live in different habitats. There are streamlined species that inhabit offshore sandy areas, and rock-dwelling species that live their lives on rocky shores. Some species inhabit empty snail shells and others live up to 100 m below the surface and have evolved huge eyes to enable them to see in the dim light.

These varied behaviors are associated with structural changes to body and head shape, jaw size and shape, and the size, shape, and number of teeth. Cichlids in different lakes have independently evolved the same changes. When species in similar environments adapt to resemble each other, it is called **convergent evolution** (Figure 2). All these differences in diet and niche have led to the hypothesis that there are many cichlid species because they have adapted to different food sources and habitats. If fish only mate with other fish that feed on the same food or live in the same habitat, then these groups can eventually become separate species.

CONVERGENT EVOLUTION

independent evolution of similar characteristics in distantly related organisms.

SEXUAL SELECTION

Another possible theory to explain the diversity of cichlid species is called **sexual selection**, which basically means individuals of one sex

SEXUAL SELECTION

An evolutionary process resulting from a preference by one sex for certain characteristics in individuals of the other sex.

Figure 2

Figure 2

The Convict Julie **(A)** and the Golden Mbuna **(B)** live in similar habitats but in different lakes, and they have evolved similar body size and characteristics, such as a streamlined body shape, golden body colour and dark horizontal stripes. Despite the similar appearance, the Golden Mbuna is not very closely related to the Convict Julie. In fact, it is more closely related to the Blue Moorii cichlid **(C)** which lives in the same lake but has evolved to live in a different habitat. This is an example of convergent evolution, where the evolution of the Convict Julie and the Golden Mbuna have converged on a similar set of evolutionary adaptations, despite not having a recent common ancestor. Individual images compiled to create the panel. **(A)** https://commons.wikimedia.org/wiki/File:Julidochromis_regani.jpg (image copyright Regani; image in public domain); **(B)** https://commons.wikimedia.org/wiki/File:Melanochromis_auratus_(female).jpg (image copyright Vlad Butsky, licensed under CC BY 2.0); **(C)** https://commons.wikimedia.org/wiki/File:Cyrtocara_moorii_male_2.jpg (image copyright Brian Gratwicke, licensed under CC BY 2.0).

show preference for certain characteristics in individuals of the other sex. A striking characteristic of cichlids in the African Great Lakes is that the males of many species are brightly colored. This is similar to bird species like the peacock and pheasant, in which males have extravagant plumage and colouration to attract potential mates. Male cichlids are also thought to display bright colors to attract females. Many cichlid species can be identified by the color of the males' bodies, but females are mostly brownish- or grayish-colored and harder to distinguish. The sexual selection hypothesis states that the preference of females for males with differently colored bodies has led to the emergence of species that have different colors.

Most male cichlids put a lot of effort into trying to attract females. As well as having brightly colored bodies, males from some species have developed interesting strategies. For example, some males build huge and complex sandcastles, called bowers (Figure 3). They build and maintain these bowers for several weeks and females have been shown to prefer males with bowers of certain sizes and shapes. Because female cichlids often choose males to mate with based on their appearance (body colouration) or behavior (bower-building), these choices lead to evolution of different species of cichlids based on the characteristics that females prefer.

WHY STUDY CICHLIDS?

Cichlids are useful for studying the process of how new species evolve, because 2,000 unique species have evolved in the last 10 million years. Few other animals offer the opportunity for scientists to study speciation in this way. But cichlids are not only important for understanding how species emerge. Many cichlid species live in areas that are poor in food resources, and they provide an important food source for local communities. For example, tilapia cichlids are one of the most important freshwater food resources in tropical regions, and they are even farmed extensively in other parts of the world for human consumption.

Unfortunately, many cichlid species have recently become endangered, often by over-fishing. Another problem for cichlids comes from habitat changes caused by humans, including the building of dams or the development of lake shores. Because many cichlid species are only

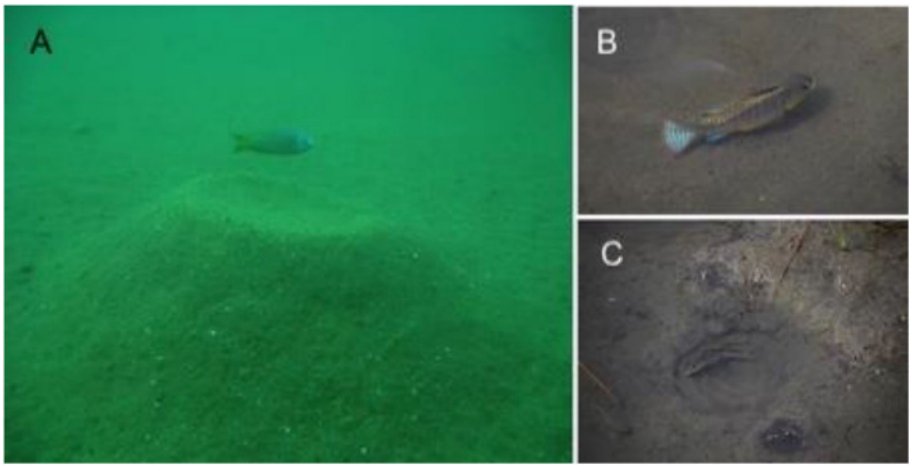

Figure 3

(A) A male of a bower-building cichlid species from Lake Malawi defending their territory around a bower built to attract potential mates (Photograph credit: Isabel Magalhaes) **(B,C)** Soda cichlids on bowers (Photograph credits: Antonia Ford).

found in one lake or a small geographical area, even small areas of development can negatively impact some species. Also, introduction of **invasive species** to some African lakes has threatened many native cichlid species, some to the point of extinction. In Lake Victoria, once called "Darwin's dream pond" for the number of cichlid species it contained, the introduction of the Nile perch in the 1970s caused a drastic reduction in the number of cichlid species. Nile perch are predatory fish that can grow up to 2 meters long. They are extremely voracious and grow very quickly. Unfortunately, Nile perch feed mostly on cichlids, and some cichlid species have been drastically reduced. Another problem for cichlids comes from chemicals entering the water through runoff from farm fields. These chemicals fuel the growth of algae, which make the water murky, and in some locations females cannot see the colors of males. Since they can not distinguish males based on color, females may mate with males from a different species, a process called **hybridization**. Hybridization can lead to species losing their unique characteristics and becoming less well-adapted to their environments.

INVASIVE SPECIES

A species that finds a new place to live, away from its native area, and increases in number, sometimes causing negative impacts on native species and the ecosystem.

HYBRIDIZATION

Interbreeding between animals or plants of different species.

Some cichlid species, such as the Nile tilapia (*Orechromis niloticus*), are also invasive species themselves! Nile tilapia, native to North, East, and West Africa, have been widely introduced and farmed in Africa and many countries in Asia, Europe, and North and South America. In these new places, Nile tilapia often threaten the native ecosystems and species.

PROTECTING CICHLIDS

Several conservation projects aim at protecting the amazing biodiversity of cichlid species across the world. These include policies to reduce the impact of overfishing and breeding programmes to ensure that the rarest of species do not become extinct. For

example, the Pangani tilapia is an important species found only in the Pangani River basin in East Africa. A combination of factors, including habitat degradation, heavy fishing pressure, and competition from the invasive Nile tilapia, have led to the Pangani tilapia becoming critically endangered. A conservation project led by Sokoine University in Tanzania aims to restore degraded habitat and map the habitat of the species to protect it[2]. Other conservation projects may use breeding programmes to try to rebuild species numbers. In 2013, the Zoological Society of London asked people to help find any remaining Mangarahara cichlids, of which only 3 individuals were known, all in captivity. Thanks to their request, a wild population of the species was found in Madagascar, thought to include only 18 individuals, and a breeding programme was started at a local aquaculture facility to try to restore their numbers[3]. Hopefully, future conservation projects will continue to help preserve these important species, so that scientists can continue to learn about the fascinating evolutionary process of adaptive radiation and future generations can enjoy them.

[2] https://www.speciesconservation.org/case-studies-projects/pangani-tilapia/5314

[3] https://blogs.scientificamerican.com/extinction-countdown/fish-found-the-greatest-conservation-success-story-of-2013/

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YOUNG REVIEWERS

BLINDERN IB SCHOOL, AGES: 15–16

We are the MYP5 class: a bunch of energetic and engaged teens. We already knew about conservation and climate change issues. We are a diverse group coming from all over the world!

AUTHORS

ISABEL SANTOS MAGALHAES

My research focuses on understanding how species evolve, change and adapt to new and changing environments. I am a lecturer in the School of Life and Health Sciences at the University of Roehampton, London, UK. *isabel.magalhaes@roehampton.ac.uk

ANTONIA GERALDINE PATRICIA FORD

I am an evolutionary biologist, and I investigate patterns of evolution in freshwater fish. I am particularly interested in how new species evolve and how they adapt to variable environments. I am a lecturer in the School of Life and Health Sciences at the University of Roehampton, London, UK. *antonia.ford@roehampton.ac.uk

†These authors have contributed equally to this work

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WATER BEARS—THE MOST EXTREME ANIMALS ON THE PLANET (AND IN SPACE!)

Skander Elleuche *

EUROIMMUN Medical Laboratory Diagnostics AG, Lübeck, Germany

YOUNG REVIEWERS:


CATHERINE
AGE: 15


HARRISON
AGE: 11


ISABEL
AGE: 11


MARGARIDA
AGE: 13


MEGAN
AGE: 15

Can you imagine that there is an eight-legged bear that tolerates colder temperatures than the polar bears do in the Arctic? Can you imagine that this bear is able to grow older than the grizzly bears in North America? And can you imagine that this bear grows by molting, like spiders or snakes? These so-called water bears, scientifically named tardigrades, are the most extreme animals on our planet. They not only survive in ice, but also in boiling water. Moreover, they can stop breathing for long periods and they have even traveled to outer space, surviving without an astronaut's suit. Since water bears can withstand the harshest conditions on earth and beyond, they may teach us how we can protect ourselves from extreme environmental conditions.

ARE WATER BEARS TRUE BEARS?

What are water bears? Are they really bears? This question is easy to answer: no, the only thing that water bears and bears have in common is the fact that both are animals. The shape of a water bear slightly

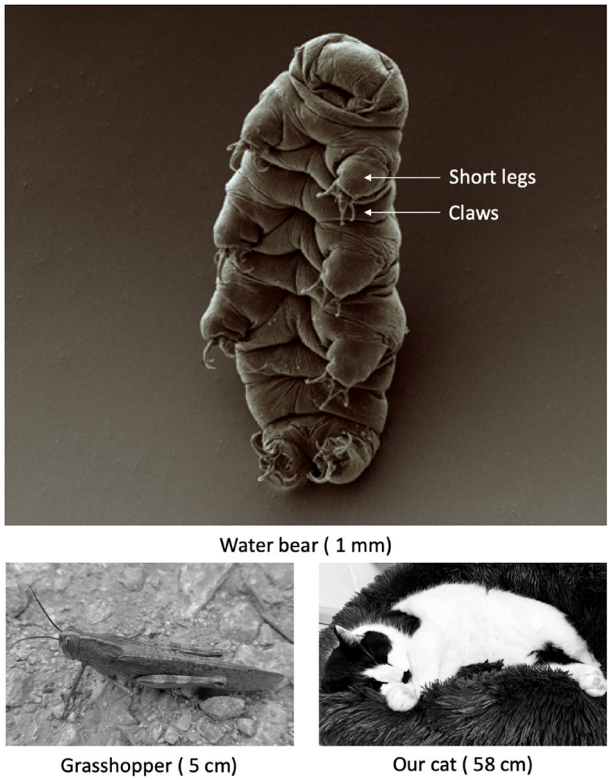

Figure 1

Water bears, also called tardigrades, are extremely small compared to other animals. This image of a water bear was taken with a scanning electron microscope. The water bear micrograph by Bob Goldstein and Vicky Madden (https://en.wikipedia.org/wiki/Tardigrade#/media/File:Waterbear.jpg). Photographs of the grasshopper and the cat by S. Elleuche.

ARTHROPODS

This group of animals is characterized by the outer skeleton and includes insects, spiders, millipedes, and crabs.

WETLAND

A living space for multiple organisms that is temporary or permanently flooded by water and inhabited by aquatic plants.

resembles that of true bears, such as the polar bear or the grizzly, but they are most closely related to the huge group called the **arthropods**, which includes insects, spiders, millipedes, and crabs. However, you cannot see a water bear with the naked eye, because these animals are very tiny. They usually grow to <1 mm (Figure 1). Water bears were discovered more than 200 years ago [1]. The German pastor and biologist Johann Goeze initially named them "little water bears," because of their size and their preference for wet living spaces.

Water bears love wet or at least humid environments where they can remain covered by a layer of water. They are among the most successful lifeforms known and are widely distributed all over our planet. We can observe water bears in all oceans, rivers, seas, and lakes, and in **wetlands**, but they are mainly found in mosses or swamps. Water bears have even conquered the highest mountains, rainforests, and Antarctica. Many different types of water bears have been found and described. They even conquered Hollywood, where you may have encountered water bears in the Marvel superhero movies "Ant-Man" and "Ant-Man and the Wasp," when Scott Lang disappears into the quantum realm.

Water bears have a strange shape—they are of stout build with four pairs of short and stubby legs, ending with four to eight claws, and they appear to lumber along as they move (Figure 1). The first three pairs of legs are used for moving, while the water bears use the last pair of

legs to hang on to the surface on which they walk. Even with so many legs, water bears usually do not walk but instead passively slide, using the flow of water or wind. The way they move is also reflected by their scientific name: **tardigrades**. Tardigradum means "slow walker," and this name was given to water bears by Loredano Spallanzani, a former Italian biologist, due to the slow and sedate behavior of these animals, which might look like laziness.

TARDIGRADE

A scientific nomenclature for a group of animals that are also known as water bears or moss piglets.

HOW DO WATER BEARS GROW?

Just like almost any other creature on our planet, water bears must eat food and breathe air to generate the energy needed for their cells to divide and their bodies to grow. In contrast to true bears, water bears are just too tiny to eat salmon or seals. Honey is also not on their menu. Nevertheless, water bears basically eat everything. While they mainly prefer vegetarian foods like plants and algae, they will also eat microscopic animals.

Unlike most other animals, the bodies of water bears are created following a specific plan. Every type of adult water bear even has exactly the same number of cells. Their cells are continuously dividing, but the water bear is covered by a non-growing and non-flexible sheath, or protective outer covering. As soon as the sheath becomes too tight, water bears will shed the sheath in a process called **molting**, similar to spiders and snakes. Although both humans and water bears need oxygen to survive, water bears do not breathe the way we do. In fact, they do not even possess respiratory organs like lungs. Water bears take up air through the surfaces of their bodies, just like insects. Water bears can even stop breathing and eating for some time, similar to the process of hibernation that allows other animals, such as polar bears, to slow down their bodily processes to survive the winter months. However, water bears are even more impressive, because not only can they sleep for a couple of months, but they can also become extremely old and thrive in the most extreme places on earth.

MOLTING

Some animals, such as water bears, insects, spiders and snakes do not grow continuously. They have to replace their outer sheath when it became too tight.

WHAT ARE THE MOST EXTREME LIVING SPACES FOR WATER BEARS?

Water bears are the most extreme animals that we know—they basically tolerate almost every extreme condition that we can think of. They can survive in the Arctic alongside polar bears, or in Antarctica, where penguins feel at home (Figure 2A). Water bears even survive in the laboratory at temperatures below −200°C, which is more than twice as cold as the coldest temperature that was ever observed in nature. Under such extreme conditions, the water bears enter a stage that resembles death. During this death-like resting stage, called **dormancy**, water bears stop all functions that usually define life: they stop breathing, they stop moving and growing, and they even stop

DORMANCY

Death-like resting stage during which each kind of activity such as growth or ingestion is temporarily stopped.

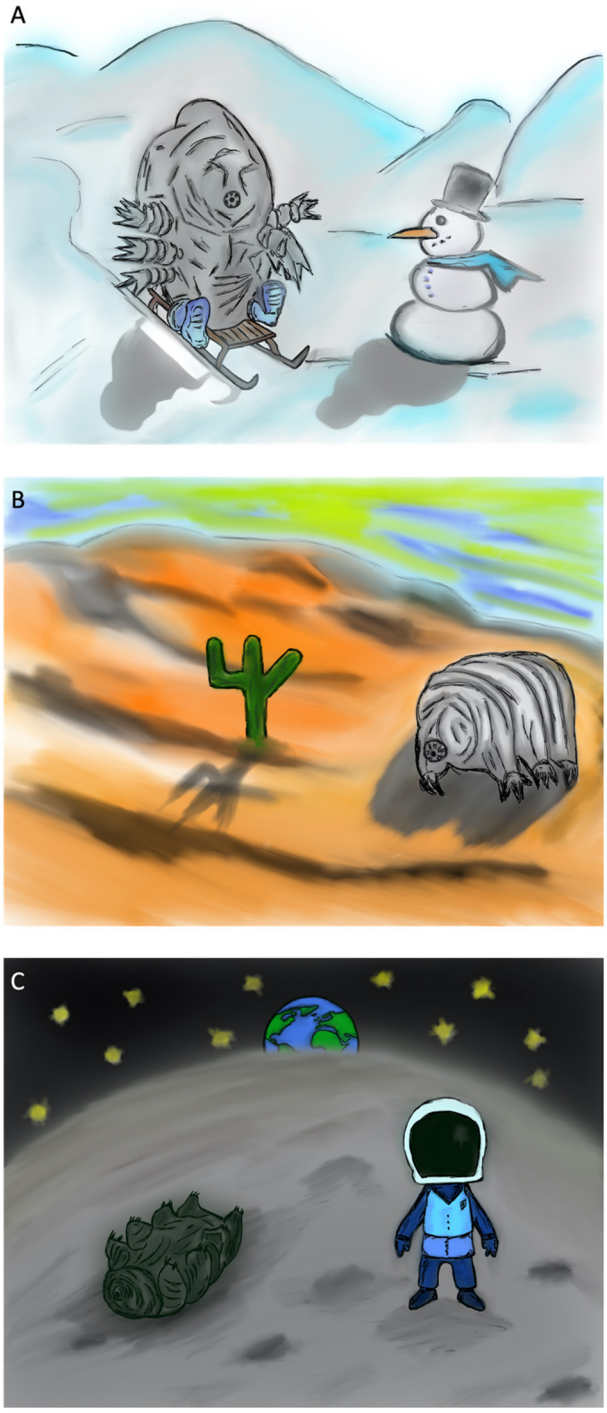

Figure 2

(A) Water bears can survive in extremely cold habitats, like the icy Himalaya mountains, and at temperatures as low as −150°C. **(B)** Water bears can survive in extremely hot habitats, like the hottest deserts, and at temperatures as high as 100°C. **(C)** Water bears can even survive in the vacuum of space!

digesting their last meal [2]. Depending on how long they are in dormancy, it can take several hours to wake them up. Some water bears have even been seen to last for a century in dormancy.

On the other end of the temperature scale, there are microbes that can grow at temperatures around 120°C. These heat-loving microbes are called **extremophiles** [3, 4]. Water bears do not love the extreme

EXTREMOPHILES

Microorganisms that love to live in the most extreme environments on the planet. Water bears are no true extremophiles because, although they can tolerate extreme conditions, they do not prefer such environments.

heat, but not only can water bears survive in the desert, they can even tolerate temperatures around 150°C (Figure 2B)—temperatures that would kill most extremophiles. Even more impressive is the fact that water bears can be repeatedly heated up and frozen without dying. These abilities have allowed water bears to become unrivaled in their success over the course of evolution. More than 1,000 different types of water bears are known, with the oldest species dating back more than 500 million years.

Water bears do not only survive the coldest cold or the hottest heat without food and without air to breathe, but they can also go without water and they are resistant to radiation. Since those extreme conditions exist in space, scientists asked themselves whether water bears might even be able to travel in space (Figure 2C). Scientists knew that the high pressure present in the deep sea could be tolerated by water bears, but in space there is a vacuum, with lower pressure compared to earth. Nevertheless, several species of water bears were sent into space and all of them returned home in healthy condition. Moreover, more than 1,000 water bears in dormancy were crash-landed on the moon as passengers of a spacecraft in 2019. It is expected that most of these robust animals have survived the crash and could be revived by water and oxygen in the future.

COULD WATER BEARS BE USED TO HELP HUMANS?

For a long time, scientists have been trying to understand the water bears' resistance to radiation. Although radiation in the form of X-rays can be used by doctors to examine broken bones, radiation can also cause the destruction of the body's instruction manual. This instruction manual is called the **genome**, and it is similar in every living organism on earth, including water bears. There must be a reason for the immense resistance to radiation seen in water bears, which is more than 1,000 times higher than humans' resistance.

GENOME

A kind of construction plan that is included in every living cell in all organisms (Bacteria, Fungi, Plants, Animals etc.), which determines the look and composition of most cellular compon.

One part of the genome of water bears has recently been identified and reproduced in a laboratory [5]. When this factor was added to human cells grown in the same laboratory, the human cells tolerated more intense radiation than did human cells without the water bear factor. These early experiments may lead to future applications of water bear factors that could not only be used to protect the human cells against radiation, but possibly also to stabilize drugs or to increase the resistance of crop plants to environmental conditions like drought.

WHAT WE HAVE LEARNED FROM WATER BEARS

So, now you can see that those little water bears are quite different from the bears we know well. We have learned from these animals

that they not only tolerate the most extreme conditions on our planet, they are even capable to survive in Space. Because of these unique properties, water bears are fascinating and among the most interesting model organisms for us to further study.

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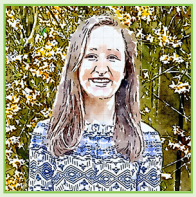
YOUNG REVIEWERS



CATHERINE, AGE: 15
I love music and singing, I play the violin and guitar and I also enjoy writing! I am part of a highland dance troup and volunteer with children at local kids clubs and guides. I enjoy attending youth events at my church and doing fitness. I hoped that by reviewing these articles I could learn about new and interesting stuff!

HARRISON, AGE: 11
I love playing sports such as hockey and going running and chasing my dog! I also love discovering new things, but not new foods! Because I currently go to primary school I am excited to start my new secondary school and try lots of new subjects. My favorite subject at the moment is math.

ISABEL, AGE: 11
Hello, I am Isabel. I am 11 years old and I really like writing stories. I also like reading. I am really interested in diplomacy.

MARGARIDA, AGE: 13
My name is Margarida, I am 13 years old and I like reading, climbing, and writing. I love science, especially anything about black holes and I have absolutely no idea what I want to do when I grow up. I also really like biology.

MEGAN, AGE: 15
HI, I am Megan, my hobbies include musical theater, baking, and surfing (only during summer though!). I got involved with Frontiers for Young Minds as I really want to learn more about science and the world around me, so I thought reading these articles would be a good start!

AUTHOR

SKANDER ELLEUCHE
I am microbiologist/molecular biologist by training with an innate curiosity for all fields of biology. I have more than 10 years of experience working with microbes from extreme environments. I have designed comic book stories on science and have just written a popular science book on extreme environments, which is illustrated with cartoons (in German). Since 2020, I have worked as a scientist in a company that is developing assays for the detection of diseases and infections. Outside of work, I enjoy reading science stories and comic books and spending my leisure time with our cat, Leon. *skander.elleuche@rub.de

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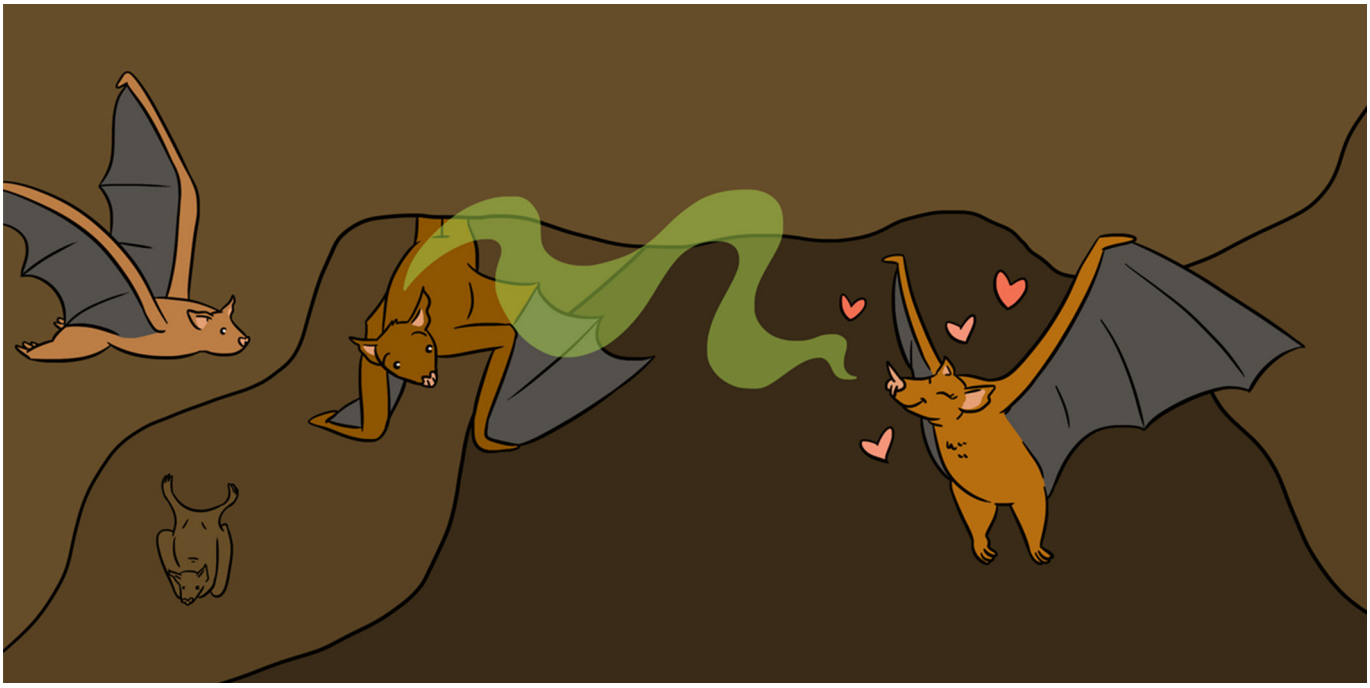

THE AGAVE BAT AND ITS STINKY BACK PATCH

Osiris Gaona[1] *and Carla Ximena Neri Barrios*[1,2*]

[1] *Laboratorio de Ecología Bacteriana, Instituto de Ecología, Universidad Nacional Autónoma de México, Mérida, Mexico*
[2] *Conservation Management, Soluciones Ambientales Itzeni AC, Mexico City, Mexico*

YOUNG REVIEWERS:

JACK
AGE: 10

NADIA
AGE: 9

Have you ever wondered how bats choose their mates? It turns out that some male and female bats meet in dark caves, with thousands of bats around them. Despite their good eyesight, it can be challenging to find "Mr. Right" in these conditions! Female bats have resorted to using their noses and, surprisingly, they prefer the stinkiest of males. Male long-nosed bats develop a stinky patch between their shoulder blades that they use to attract females, with the aid of bacteria.

BATS: WHAT IS THEIR DEAL ANYWAY?

Bats are neither birds nor mice, although they may look a bit like both. They are a special kind of **mammal**. All mammals give birth to live babies, have bellybuttons, are covered in fur, and feed their offspring with milk. **Chiroptera** is the scientific name given to bats, which are the only mammals capable of true flight. This name is made of two Greek words: "cheir" which means hand, and "pteron," wing. Therefore, Chiroptera translates to "winged-hands."

MAMMAL

Animals that feed their babies with milk produced by their mothers, their skin is covered in fur completely or partially. Humans, dogs, and bats are some examples of mammals.

CHIROPTERA

It is a Greek word composed of two elements, the first one is "cheir" that means hand, and "pteron" that translates to wing. Chiroptera literally means winged hands. The wings of bats are actually their hands, with membranes between their fingers that help them fly.

The winged hands of bats evolved over thousands of years to have bones that are as long as their bodies and a thin membrane that connects their fingers, forming the wings that allow them to fly. Bats are only active at night to avoid predators that hunt during the day, and contrary to common beliefs, they have good eyesight. Bats sleep in caves, hollow trees, under large leaves, in termite nests, in large city buildings, and under the roofs of many houses. They can be found everywhere in the world, except in the coldest areas, such as the polar regions.

There are 1,200 species of bats in the world and scientists have studied only a tiny proportion of them. Bats can be gray, brown, or white, with yellow stripes, black masks, or marbled fur. They can be as small as a hummingbird or as large as a cat, like the fruit-eating flying fox of Asia. Bats feed on many things depending on the species. They can eat fruits, nectar, small animals, insects, fish, and even blood. But only 3 out of 1,200 existing bat species eat blood, and those can only be found in the wildest places of Central and South America.

BATS ARE OUR FRIENDS

Speaking of eating blood, some people believe that bats are dangerous or scary. Like any other mammal, bats can transmit diseases to humans, including the rabies virus. Also, a certain fungus can grow in bat feces, which can cause an illness known as histoplasmosis if it is breathed in. However, this does not mean bats are any more dangerous than any other wild animal. We should avoid touching all wild animals, including bats, without protective equipment like gloves and face masks. Instead of thinking of bats as scary creatures from horror movies, we should view them as our nocturnal allies! Just like bees, bats help pollinate thousands of flowers, help to keep insect populations down so that farmers can use fewer pesticides, and help to disperse seeds when they poop, eventually restoring forests.

THE AGAVE BAT, A.K.A MR. STINKY

We will now focus on just two bat species, the lesser long-nosed bat, and the Southern long-nosed bat. Their scientific names are *Leptonycteris yerbabuenae* [pronounced lep-toh-nick-ter-is yerb-a-buen-ah] and *Leptonycteris curasoae* [pronounced lep-toh-nick-ter-is coo-rah-so-ah], respectively. These two species are known as agave bats because they pollinate agave plants. The lesser long-nosed bat is the smallest of the agave bats. As you can guess from its name, it has a long snout with an even longer tongue to reach the sweet nectar that hides at the bottom of flowers (Figure 1).

Agave bats travel hundreds of miles every year, from their birthplace to their feeding grounds and back, a behavior known as migration.

Figure 1

Agave bats have long snouts and tongues to fed on the nectar of flowers. Males have a bald patch on their backs called a dorsal patch. With the help of bacteria, the male bats use this patch to produce a stinky perfume that attracts females.

Figure 1

Females look for warm, humid caves in which to give birth to their offspring and feed them with milk. Because there are hundreds of mothers and babies in one place, scientists have named these special places maternity caves. Another amazing fact about bats is that mothers can fly with their cubs holding tightly to them, just like monkeys. Maternity caves are left empty when pups grow into adults.

Young adults start foraging for food on their own and begin migrating like their parents. When the time comes, males who are ready to find a mate congregate in roosts known as bachelor caves, where they meet females. A dark, busy cave full of potential mates flying around is a difficult place for females to choose a male. So, female agave bats resort to one of the most developed senses in mammals: smell. With their long snouts, females start sniffing for healthy, strong males, but a male's normal scent alone is not enough to attract females; the males need something stronger—a stinky perfume. Male agave bats attract females with a gross perfume that they create.

HOW DO MALE BATS GET SO STINKY?

In a quest to become the stinkiest male in the cave, male bats scratch at their backs, right between their shoulders, until they get rid of the fur in that spot, creating what is called a **dorsal patch**. Then they lick their feet and smear saliva and other body fluids on this bald patch, to create a gross soup [1, 2]. This nasty mess feeds the bacteria that live in the bald patch [3, 4]. In turn, some of these bacteria, called **fermentative bacteria**, produce a stinky fragrance that females find irresistible (Figure 2). Agave bats are not the only bats to use this smelly technique. Other bats, like the brown bat, also use scent cues to identify their kin and probably also use bacteria to help them produce these smells [5].

DORSAL PATCH

This is a gap of bare skin, the size of a fingerprint that develops between the shoulder blades on agave bat males during reproductive season. Dorsal means that something is situated near or on the back of animals.

FERMENTATIVE BACTERIA

These bacteria transform the molecules they find in their environment to create new ones. During this process, smelly gas is produced.

Figure 2

Bacteria help male agave bats to develop the dorsal patch. The dorsal patch releases a stinky perfume that attracts females. Thus, the bacteria in the dorsal patch help the male bats to find mates.

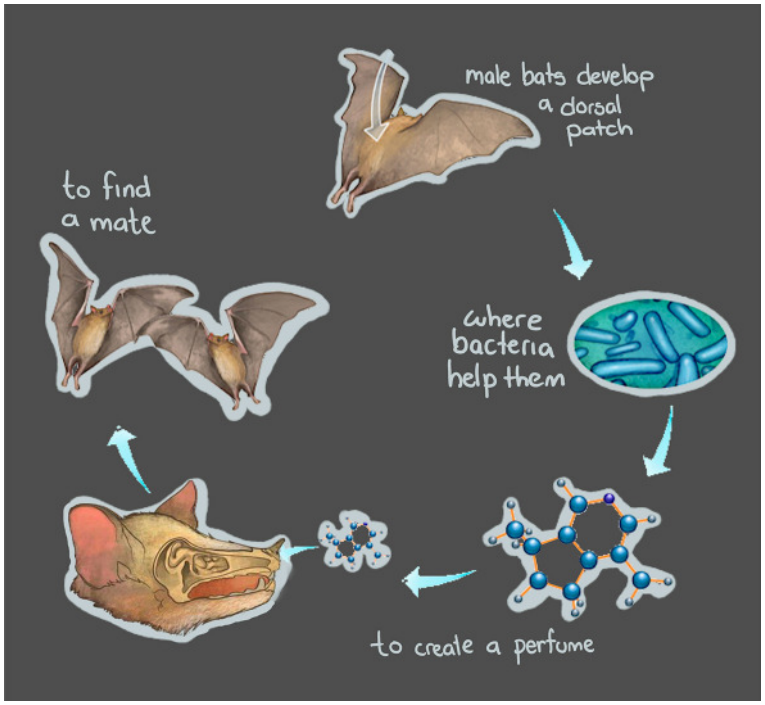

Figure 2

It is known that bats, just like all other animals including humans, are home for lots of microorganisms, such as bacteria and viruses. Some of these bacteria are good and help the animals to thrive, and these helpful microorganisms are known as the **microbiota**. We know from other studies that bacteria help produce odors, for example in human armpits. So, we wanted to test whether the skin microbiota of bats was responsible for the male's scent.

MICROBIOTA

It refers to all the living organisms that can only be seen through the lens of a microscope. All bacteria and viruses, and some fungus, are part of the microbiota.

OUR STINKY BAT STUDY

Our group of bat experts headed out to capture a group of male agave bats during the reproductive season. We used sterile tools to sample the dorsal patches of 11 male bats and then safely released them back to the wild. Back in the lab, we used **molecular biology tools** to identify the bacteria growing in the bats' dorsal patches [4]. We were excited to find that all males shared 26 types of bacteria in their dorsal patches (Figure 3). Interestingly, 16 out of these 26 kinds of bacteria were fermentative, which means that they are bacteria that produce the chemicals responsible for scents [4].

MOLECULAR BIOLOGY TOOLS

Are the techniques and lab tools that biologists use to study molecules, like proteins and the DNA, within cells.

Our results helped us demonstrate that Mr. Stinky uses bacteria to make the nasty cologne that attracts Mrs. Right! In summary, bats make their own perfumes with the help of bacteria. Much more work is needed to study these bats scents in more detail, but our research demonstrated that bacteria are in fact present in the dorsal patch and probably help males to attract females (Figure 3).

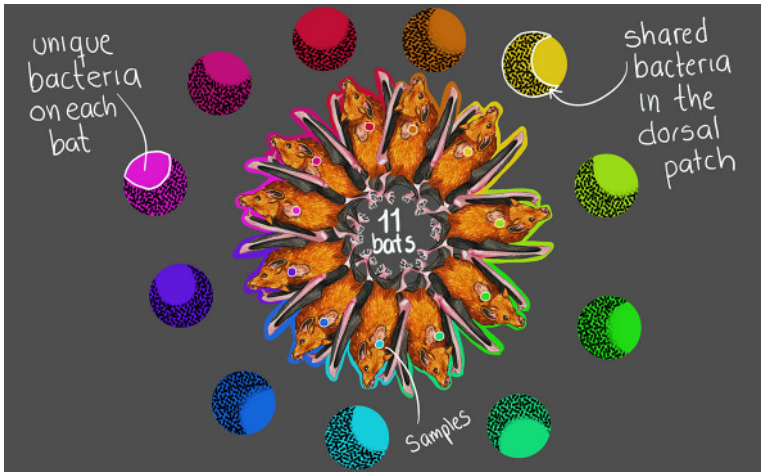

Figure 3

We sampled dorsal patches from 11 male bats and analyzed the bacteria present in the patches. All 11 bats shared many of the same types of bacteria (represented by the dots in the colored circles), most of them fermentative bacteria, which are those that produce odors. Each bat also had some bacteria that were unique to that individual bat (represented by the different colored circles).

MR. STINKY AND MRS. RIGHT—THE SHORT STORY

Bats are fascinating mammals and very important for a healthy ecosystem. So, they are worthy of more scientific study. In our work, we found that male agave bats use fermentative bacteria to create a really strong perfume that attracts females. It seems that bacteria can help mammals in many ways—even in finding Mr. Stinky! The next time you use a perfume or deodorant, remember bats and how they use their bacteria to help them to be stinky in an attractive way!

ORIGINAL SOURCE ARTICLE

Gaona, O., Cerqueda-García, D., Falcón, L. I., Vázquez-Domínguez, G., Valdespino-Castillo, P. M., and Neri-Barrios, C. X. 2019. Microbiota composition of the dorsal patch of reproductive male *Leptonycteris yerbabuenae*. *PLoS ONE* 14:e0226239. doi: 10.1371/journal.pone.0226239

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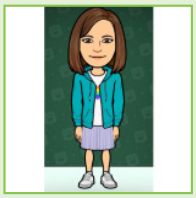
YOUNG REVIEWERS

JACK, AGE: 10
I am the neighbor of Nadia. I like learning about electricity, and I like to practice America ninja karate and karate.



NADIA, AGE: 9
I am the neighbor of Jack. I like going to nature camp and camping with my family.

AUTHORS

OSIRIS GAONA
Osiris Gaona, Ph.D., is a biologist from the Faculty of Sciences at the National Autonomous University of Mexico. She has worked for over 20 years at the Ecology Institute in the Wildlife Conservation and Management Lab and in the Bacterial Ecology Lab, where she is currently working to understand the relationships between bacteria and their animal hosts. During her doctoral studies, she researched the role of bacteria in *Leptonycteris yerbabuenae* bats through their various life

stages. Osiris is also the founder and director of "Soluciones Ambientales Itzeni AC," a non-governmental organization in Mexico focused on conservation and environmental education.

CARLA XIMENA NERI BARRIOS

Carla Ximena Neri has a bachelor's degree in Earth Sciences from the National Autonomous University of Mexico and a specialization in environmental sciences. She is currently working in a non-governmental organization, Soluciones Ambientales Itzeni AC. Her work focuses on wildlife conservation and working to improve human relationships with nature. Ximena has participated in wildlife management projects in the Peruvian Amazon and the Indian Western Ghats, and she has also studied human relationships with wolves in Mexico. She is coauthor of several animal microbiome research publications led by Dr. Osiris Gaona. *carlaxneri@gmail.com

frontiers FOR YOUNG MINDS

BIODIVERSITY
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WHAT STUDYING THE SONGS OF A DISTANT PRIMATE RELATIVE CAN TEACH US ABOUT OURSELVES

Dena Jane Clink *

K. Lisa Yang Center for Conservation Bioacoustics, Cornell Lab of Ornithology, Cornell University, Ithaca, NY, United States

YOUNG REVIEWER:

ADAM

AGE: 15

Tarsiers are nocturnal animals. They have eyes that are heavier than their brains. They eat only insects and other living things. Tarsiers are primates, just like humans. And some species of tarsiers sing! Tarsier songs and human language are different in many ways. But if we study the similarities, it may help us better understand human language. In our study, we recorded singing tarsiers on the Indonesian island of Sulawesi. With the help of computers, we found that we could tell individual tarsiers apart based on their songs. Being able to recognize who is singing from far away may be an important function of tarsier songs. We also found that if a female speeds up her song, then the male speeds up his song, too. The ability to modify vocal output based on what others are doing is a universal in human language. Our results show that tarsiers (like humans) can change their vocalizations based on what their partner is doing. The fact that tarsiers and humans are both able to do this indicates that their common ancestor probably had this ability. Our results add support to the idea that

Figure 1

A tarsier in Tangkoko National Park, North Sulawesi, Indonesia (Photo credit: DC).

Figure 1

flexibility in vocal interactions evolved long before the appearance of modern humans.

WHAT IS A TARSIER?

Tarsiers are **primates**, just like humans, but they have some pretty amazing **traits** that are very different from us. They are **nocturnal**, which means they are active at night. They have enormous eyes that help them see better in the dark (Figure 1). Tarsiers are the only primates in the world that are completely **faunivorous**, which means they eat only insects and other animals. Humans shared a common ancestor with tarsiers about 55 million years ago [1]. Most primates that are active during the day live in groups, but many nocturnal primates live alone. This is true for most tarsiers, except for the tarsiers found on the Indonesian island of Sulawesi. In Sulawesi, male and female tarsiers live in pairs with their offspring. This contrasts with the tarsiers found on Borneo and in the Philippines, which live alone. This difference in social structure may be related to the number of insects that live the in the forests: the forests of Sulawesi have a higher abundance of insects, which may allow tarsiers to live in larger groups.

The tarsiers on Sulawesi also have another unique trait: the males and females sing together [2]! We also call tarsier songs **duets** because the males and females coordinate and alternate their singing. Sometimes the juveniles will sing along with their parents, and in this case we call the song a chorus. There are many primates (over 500 species), but only a few of them sing. The singing primates include tarsiers, indris, titi monkeys, gibbons, and humans. Singing primates tend to live in small groups with just the adult male, adult female, and their offspring. They also tend to be territorial, which means they do not share their home range with other groups. Tarsiers on Sulawesi sing at dawn as they return to their sleeping trees. We think tarsier song has two functions: (1) to reunite group members after the night; and (2) to communicate

PRIMATE

A group of mammals that includes lemurs, lorises, tarsiers, monkeys, and apes (including humans).

TRAITS

Distinguishing qualities or characteristics.

NOCTURNAL

Active at night.

FAUNIVOROUS

An adjective that describes animals that eat other animals.

DUET

A vocal interaction between two individuals.

with their neighbors [2]. Scientists still do not understand why certain species of primates sing and others do not, but maybe one day you can help us figure it out!

WHAT CAN STUDYING TARSIERS TEACH US ABOUT HUMANS AND HUMAN SPEECH?

Humans can read, write, and speak about complex ideas. These abilities make us unique among animals. Scientists have been working for a long time to understand how these abilities came to be. One way that scientists can study this is by comparing humans to other animals. For example, if we find a shared trait in humans and a distant primate relative, this means that the trait was probably present in their **common ancestor**. If a trait is seen only in humans, and not a distantly related primate, then we assume that this trait was *not* present in the common ancestor. Such studies can help us understand which traits are new in humans, and this could give us clues about how unique human abilities evolved.

COMMON ANCESTOR

A concept in evolutionary biology where one species is an ancestor of two or more species that lived later in time.

Let us look at the example of speech. People take turns when speaking and tend to not overlap when someone else is talking. People can easily change what they say (and when they say it) depending on the person they are speaking to. These are patterns we see no matter what language people are speaking [3]. Early studies indicated that other primates did not have the same ability to learn sounds and language that humans do. Scientists assumed that primates were not able to change their vocalizations once they became adults. But scientists are now learning that this is not always true. Primates have some of the same abilities as humans, including **vocal flexibility** and turn-taking. If we see the same abilities in distantly related animals (like humans and tarsiers), this means that the trait evolved far back in **evolutionary history**.

VOCAL FLEXIBILITY

The ability to change the structure or use of vocalizations based on different social or environmental contexts.

EVOLUTIONARY HISTORY

A description of how extinct and living species evolved over time.

RECORDING TARSIERS AND LEARNING ABOUT THEIR SONGS

In our study, we recorded 15 pairs of tarsiers in Tangkoko National Park, Indonesia, using a acoustic recording device and a microphone. Our first goal was to see if we could tell tarsiers apart from each other based on their songs. In humans, if a family member or close friend calls, you can tell immediately who is calling just from the sound of the person's voice. We predicted that this would also be the case for tarsier songs. Our second goal was to test whether tarsier songs have rhythm. Across human cultures, music is an important aspect of everyday life, and almost all humans can dance to a beat. Whether this ability is seen in other animals is still an open question. Our third goal was to see if tarsiers, like humans, can change their songs depending on their partner's song.

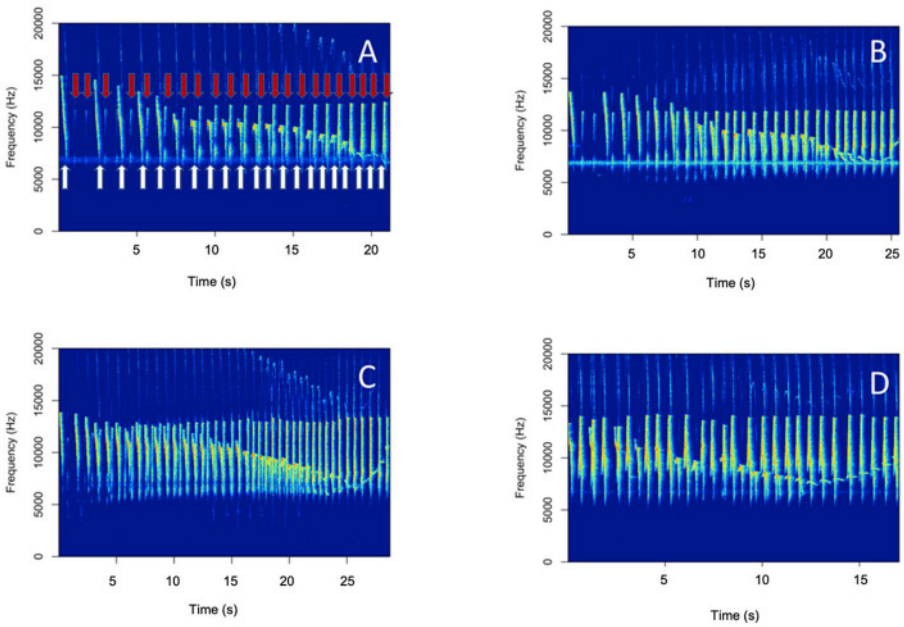

Figure 2

Figure 2

Spectrograms of songs from four different tarsier pairs. In the spectrograms, the x-axis represents time and the y-axis represents frequency or pitch of the sound. The colors on the spectrogram represent **amplitude** (or loudness) at a particular time and frequency. Green and red represent moderate and high amplitudes, whereas blue represents low amplitudes. In the first spectrogram **(A)** the male notes are shown with red arrows and the female notes are shown with white arrows. The male notes are very consistent, and the female notes change in frequency and duration. For all four songs, the male and female are singing together. Can you see the differences between male and female notes in the tarsier songs? How about differences between the different tarsier pairs?

Audio 1. Recording of a tarsier pair in Tangkoko National Park, Sulawesi, Indonesia. This recording was used to make spectrogram **(A)**. https://youtu.be/4kw8vsQR_qM.

Audio 2. Recording of a tarsier pair in Tangkoko National Park, Sulawesi, Indonesia. This recording was used to make spectrogram **(B)**. https://youtu.be/478o4RuJ6PQ.

Audio 3. Recording of a tarsier pair in Tangkoko National Park, Sulawesi, Indonesia. This recording was used to make spectrogram **(C)**. https://youtu.be/RMlbRgeiVrE.

A common way for scientists to study sound is by creating **spectrograms**, which provide visual representations of sounds. You can see spectrograms of tarsier songs in Figure 2. We made the spectrograms using specialized software [4].

WHAT WE FOUND

In tarsier songs the male and female parts sound different. After lots of practice, it became easy for us to tell the males and females apart just by listening and looking at the spectrograms. The male notes are pretty consistent, but the female notes get longer and change in **frequency** (or pitch) over time. Although we can tell the males and females apart, it is more difficult to tell different tarsier individuals or pairs apart from one another based on their songs—we needed the help of computers for that. Testing whether songs contain information about the identity of the individual or pair can help us understand the function of the song. We found that (with the help of computers) we could tell tarsier individuals apart based on their songs. We also found that it was easier to tell females apart from each other than males. We think that one of the functions of the female tarsier songs may be related to recognizing singing animals that are far way. We think this because female songs contain information about the identify of the calling animal.

We also found that tarsier songs have rhythm, but males have more consistent rhythm than females. This is an important finding because all humans have the ability to produce and perceive rhythmic sounds. We also found that, if a female speeds up her song, the male will then speed up his song. This important finding shows that tarsiers, like

humans, can change their song based on how their partner is singing. This ability to change their songs based on how their partners are singing have previously shown in indris and gibbons [5, 6]. We found this ability also exists in tarsiers. Since tarsiers have both rhythm and the capability to track their partners, our results indicate these abilities arose early in primate evolutionary history, and before the evolution of modern humans.

WE STILL HAVE A LOT TO LEARN

Individual tarsiers sound different from each other, but does this mean that tarsiers can tell each other apart based on their songs? And how do these song differences come about? Do young tarsiers learn their songs from their parents? If they do, do young tarsiers sound like their parents when they grow up? In many songbirds, those that have lived together longer sing in a more synchronized way. We do not know if this is the case with tarsiers, but it is possible. We hope to do future studies in which we start recording tarsiers when they are young. Studying tarsiers over their lifetimes will help us learn more about how tarsier songs develop. In science, there are always more questions to ask and more things to learn! And we still have much to learn about our tiny primate relatives, the tarsiers.

ORIGINAL SOURCE ARTICLE

Clink, D. J., Tasirin, J. S., and Klinck, H. 2019. Vocal individuality and rhythm in male and female duet contributions of a nonhuman primate. *Curr Zool.* 66:173–86. doi: 10.1093/cz/zoz035

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Figure 2

Audio 4. Recording of a tarsier pair in Tangkoko National Park, Sulawesi, Indonesia. This recording was used to make spectrogram **(D)**. https://youtu.be/DH5UhalxQso

SPECTROGRAM

A visual representation of sound. The x-axis represents time, the y-axis represents frequency, and the color corresponds to the strength or loudness of the signal at a particular time and frequency.

AMPLITUDE

A measure of the height of the sound wave. The amplitude of sound wave determines how loud it is.

FREQUENCY

The number of cycles of a sound wave per second; sometimes referred to as pitch. Humans can generally hear sounds between 20 and 20,000 Hz.

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YOUNG REVIEWER

ADAM, AGE: 15
Hi, my name is Adam. I live with my parents, older brother, dog, fish, and two birds. I am a big fan of Science and History. I like to draw, write, and read, My favorite sport is soccer (or football). I enjoy swimming in the ocean and playing video games.

AUTHOR

DENA JANE CLINK
Dena Jane Clink is the lead author on the original tarsier study. She is a research associate in the K. Lisa Yang Center for Conservation Bioacoustics in the Cornell Lab of Ornithology. She is particularly interested in species of primates that sing together, and has done work on tarsiers, titi monkeys, and gibbons. One of her passions is to make science more accessible for all. She also hopes that her work on vocal primates can be used to help improve conservation efforts for these species. When she is not in the jungle recording primates, she can be found hiking in upstate New York with her dog Monito or doing yoga. *dena.clink@cornell.edu

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ANIMAL EMOTIONS—DO ANIMALS FEEL AS WE DO?

Annika Krause [*†] *and Christian Nawroth* [*†]

Institute of Behavioural Physiology, Research Institute for Farm Animal Biology (FBN), Dummerstorf, Germany

YOUNG REVIEWERS:

CLUB DIVULGACIE-NCIA

AGES: 12–13

Emotions are an essential part of how we experience our world. Humans can express emotions by telling others how we feel—but what about animals? How can we tell whether they experience emotions and, if they do, which ones? When we think about the animals under human care, it is not only scientifically interesting but also ethically important to understand how these animals experience their worlds. Over the last 20 years, researchers have made considerable progress by identifying ways to assess emotions in animals. For example, researchers can look at the facial expressions of animals, record their vocalisations, or measure body processes such as changes in the heartbeat or hormone concentrations in the blood. This information can tell us more about how animals feel, why and how emotions have evolved, and what we, as humans, share with animals in our emotional experience of the world around us.

WHAT ARE EMOTIONS AND WHY DO WE EXPERIENCE THEM?

Emotions play a central role in our lives. But if we are asked, we might find it hard to describe what an emotion actually is! It is difficult to

know how many different emotions there are, or whether everyone experiences certain emotions in the same way. What we know for sure is that emotions arise from the activity of nerve cells in several parts of the brain. Emotions can be described as pleasant (positive) or unpleasant (negative) and more arousing or less arousing, which refers to the intensity of the emotion [1]. When we experience emotions, they are often linked to changes in our behaviour and our **physiology**, which means the functions of our bodies, such as changes in posture, blood pressure, sweating, or heartbeat. For example, imagine you see a bear approaching you in the forest. What would you feel? Probably fear! The emotion of fear would probably be accompanied by a fearful facial expression and a rising heart rate, and would probably result in you running away.

PHYSIOLOGY

Summary of all organic processes and phenomena of an organism.

But why do we experience emotions at all? While emotions are intangible and hard to describe—even for scientists—they serve important purposes. Emotions help us learn, initiate actions, and survive by adapting to new and sudden changes in the environment. Emotions change how we think, to prepare us to quickly select an appropriate response, such as running away when you see a bear approaching. Our behaviour can help us to avoid situations that evoke negative emotions (harm or punishment), or to seek out situations that generate positive emotions, such as joy. From an evolutionary perspective, experiencing emotions increases our ability to survive and reproduce.

DO ANIMALS EXPERIENCE EMOTIONS?

Since animals cannot tell us how they feel, how can we know whether they experience emotions? Because animal emotions are difficult to see, the question of whether animals experience emotions has historically been a philosophical one. Researchers have only started to investigate the emotional lives of animals in the past few decades. But when we think about farm animals, or any other animal under human care, it is not only scientifically interesting but also ethically important to try to understand how these animals emotionally experience their worlds. Farm animals are often kept in very large numbers in rather barren environments. This might lead to sickness, stress, and decreased well-being. If we could tell how animals emotionally experience their situations, this could help us to improve animal welfare. As we have already seen, emotional processes are complex and include feelings, behaviours, and physiological changes. Feelings are especially hard to assess in animals because they cannot tell us how they feel. However, when emotional things happen (such as when you see a bear approaching you), they cause changes in several biological processes. Based on these changes, researchers developed a wide set of methods to monitor emotions in animals, by measuring changes on the behavioural or physical levels, often at the same time (Figure 1) [2].

Figure 1

There are a variety of behavioural and physiological parameters that scientists can use to assess emotions in animals.

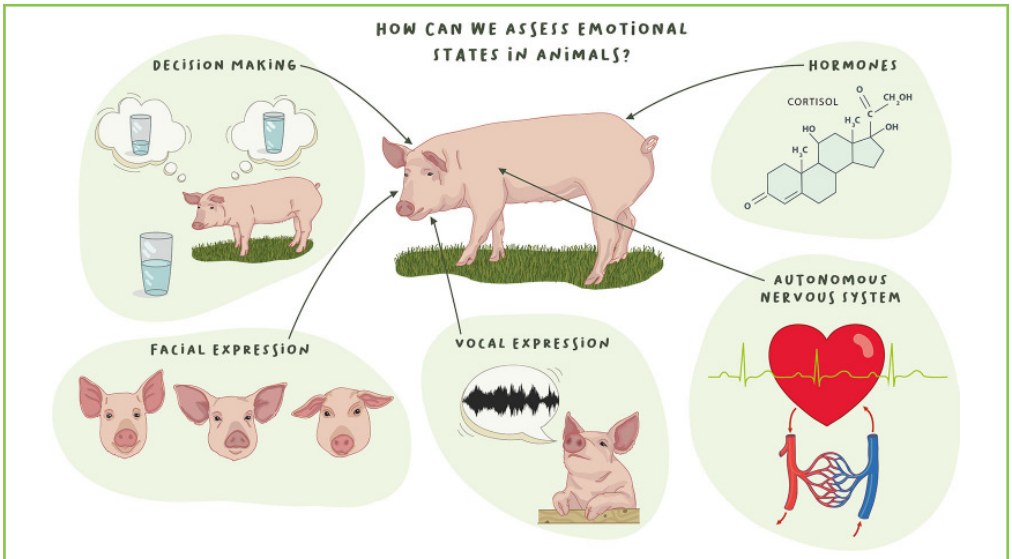

Figure 1

MEASURING THE BEHAVIOURAL COMPONENT OF ANIMAL EMOTIONS

GRIMACE SCALE

A methods of pain assessment for non-human animals that is based on changes in a number of "facial action units" in the animal, such as narrowing of the eyes.

The most easily detectable reaction of an animal to an event is how it changes its behaviour. Humans often change facial expressions and gestures depending on whether we experience an event as pleasant or not. If you look at your friends' faces, you can often very quickly assess if they are happy, fearful, angry, or disgusted. Animals show these characteristic facial expressions as well! So called **grimace scales** for horses, pigs, sheep, rats, mice, and cats have already been developed. For example, changes in ear position, the amount of visible eye white, and tension in the chewing muscles can indicate different levels of pain or fear in animals (Figure 1). It is important to remember that the facial expressions of animals usually look different than those of humans—joy might not be indicated by a smile (showing your teeth is often a signal of stress in other primates), while sadness is not accompanied by tears (pigs do not cry). In addition, prey animals (including all farm animals) tend not to show emotions that indicate pain or distress, as this might make them more vulnerable to predators.

Another example of animal behaviour that is linked to emotions involves vocalisations, such as grunts, bleats, and moos, which can indicate stress in many species. We know this is true for humans, too: imagine you are singing a song in front of many people; your voice might get shaky if you are nervous or experiencing stage fright. Researchers have found that the vocalisations of pigs, goats, and cows also change and get less harmonious when these animals are under stress, for example when they are isolated from the group, indicating negative emotions [3].

Our decision-making is also influenced by the emotions we experience. For example, we know that humans who are in a bad mood tend to judge situations more negatively compared to humans who are in a positive mood. We all know the saying about the glass being either half full or half empty, depending on how you look at it. Interestingly, this also appears to be the case for animals (Figure 1). Farm animals, such as pigs and horses, make more cautious and pessimistic decisions after a negative event and more optimistic decisions after a positive event [4], and sheep pay closer attention to negative events when they are in a bad mood. However, we must always keep in mind that behaviour in animal species can differ depending on the situation, and we need to be cautious when we interpret animal behaviour to assess emotions.

MEASURING THE PHYSIOLOGICAL COMPONENT OF ANIMAL EMOTIONS

Physiological changes are central to emotions, as they play an important role in preparing animals for potentially dangerous situations. These changes include the activity of the nervous system and the levels of certain hormones.

The **autonomic nervous system** regulates bodily functions including heart rate, blood pressure, respiration, and digestion. Changes in autonomic nervous system activity can be used to study emotions in animal species. This is so because the two major subsystems of the autonomic nervous system—the **sympathetic** (activating) and **parasympathetic** (deactivating) systems—are directly connected to the heart. Based on emotions and stress, the complex interaction of these two subsystems causes variations in both **heart rate** and the time between heartbeats, which is called **heart rate variability** [5]. But what exactly can these changes in heart rate and heart rate variability tell us about emotions? Parasympathetic activity tells us whether an animal experiences a situation as positive or negative, whereas sympathetic activity tells us whether an animal experiences low or high arousal, which means the level of attention and alertness toward the environment. In our bear example, your experience of the emotion of fear will be accompanied by an increased heartbeat (high sympathetic activity) and less variability in your heart beats (low parasympathetic activity). Researchers have found that animal and human nervous systems react in similar ways in fearful situations. This indicates that many emotions in animals physiologically mirror those in humans.

Another physiological reaction to emotions in both humans and animals involves changes in **hormone** concentrations. In stressful situations, an increase in a hormone called adrenaline immediately reduces the blood supply to all organs that are not absolutely needed in an emergency. At the same time, the blood flow to important

AUTONOMIC NERVOUS SYSTEM (ANS)

Part of the nervous system that acts largely unconsciously and regulates bodily functions including heart rate, blood pressure, respiration, and digestion.

SYMPATHETIC NERVOUS SYSTEM

Part of the ANS that is responsible for preparing the body for action, particularly in situations threatening survival. It increases heart rate, constricts blood vessels, and raises blood pressure.

PARASYMPATHETIC NERVOUS SYSTEM

Part of the ANS that is responsible for stimulation of activities that occur when the body is at rest, especially after eating. It decreases heart rate, and increases intestinal and gland activity.

HEART RATE

The number of heart beats per minute.

HEART RATE VARIABILITY

It is a measure of the variance in time between the beats of the heart and can be affected by the emotions and the stress that we currently experience.

HORMONES

Chemical messengers that carry information throughout the body. They are produced by glands and travel in the bloodstream to tissues and organs.

organs such as the brain, heart, and lungs is increased. The hormone noradrenaline provides increased alertness, and cortisol provides the energy to deal with stressful situations. Other hormones, such as dopamine, serotonin, and oxytocin, play important roles in joy, enthusiasm, and social bonding.

WHY SHOULD WE CARE IF ANIMALS EXPERIENCE EMOTIONS?

From all this research, it seems that the similarities between human and animal emotions might be closer than we would have expected a few decades ago. Animals react to their environments much as humans do. They respond emotionally to others and they evaluate situations in a similar way, becoming stressed and anxious in times of danger. While we may never know exactly how animals feel, studies have found that there are definite behavioural and physiological similarities in emotional expressions between humans and animals. We can thus infer, with quite some confidence, that animals can feel emotions. The more we discover about the behavioural and physiological components of emotions in animals, the more we understand about emotions, including our own ones, and how they affect the way we behave in our world.

The evidence of emotions in animals might also encourage us to re-think the environments in which we keep the animals that are under our care—on farms, in zoos, or in our houses. If we can better understand how animals interact and react to their environments, we can ultimately improve these environments, and thus improve human-animal relationships. It must be our ethical goal to decrease the negative emotions these animals experience, as well as to increase their experience of positive emotions.

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YOUNG REVIEWERS

CLUB DIVULGACIENCIA, AGES: 12–13

Members of Divulgaciencia are students from secondary school highly motivated in science and technology. This working team focus on communication and scientific dissemination. We enjoy looking for scientific channels, videos, publications, and conferences for general public to increase our knowledge and learn about communication skills. In this review students from IES Santa Eugenia (Madrid) and IES Profesor Domínguez Ortiz (Azuqueca de Henares) have been involved.

AUTHORS

ANNIKA KRAUSE

Annika is a behavioural biologist at the Leibniz-Institute for Farm Animal Biology, and she investigates emotions in farm animals, especially pigs. With her studies, she tries to understand how emotions are mediated by physiological and behavioural processes and how personality may shape emotional experiences in animals. Her research aims at a better understanding of the complexity of emotional states in animals, which plays a significant role in improving farm animal conditions and welfare. *krause@fbn-dummerstorf.de

CHRISTIAN NAWROTH

Christian is a trained biologist and a researcher at the Leibniz-Institute for Farm Animal Biology, where he is currently working on a project that asks how domestication and the selection for high milk yield has changed behaviour

and problem-solving abilities in goats. He is interested in how animals interact with their physical and social environments, and his research focuses on the mental capacities of farm (goats, horses, pigs, sheep) and zoo (great apes, penguins) animals and how this knowledge can be used to improve the animals' conditions and human-animal interactions. *nawroth.christian@gmail.com; orcid.org/0000-0003-4582-4057

†These authors have contributed equally to this work

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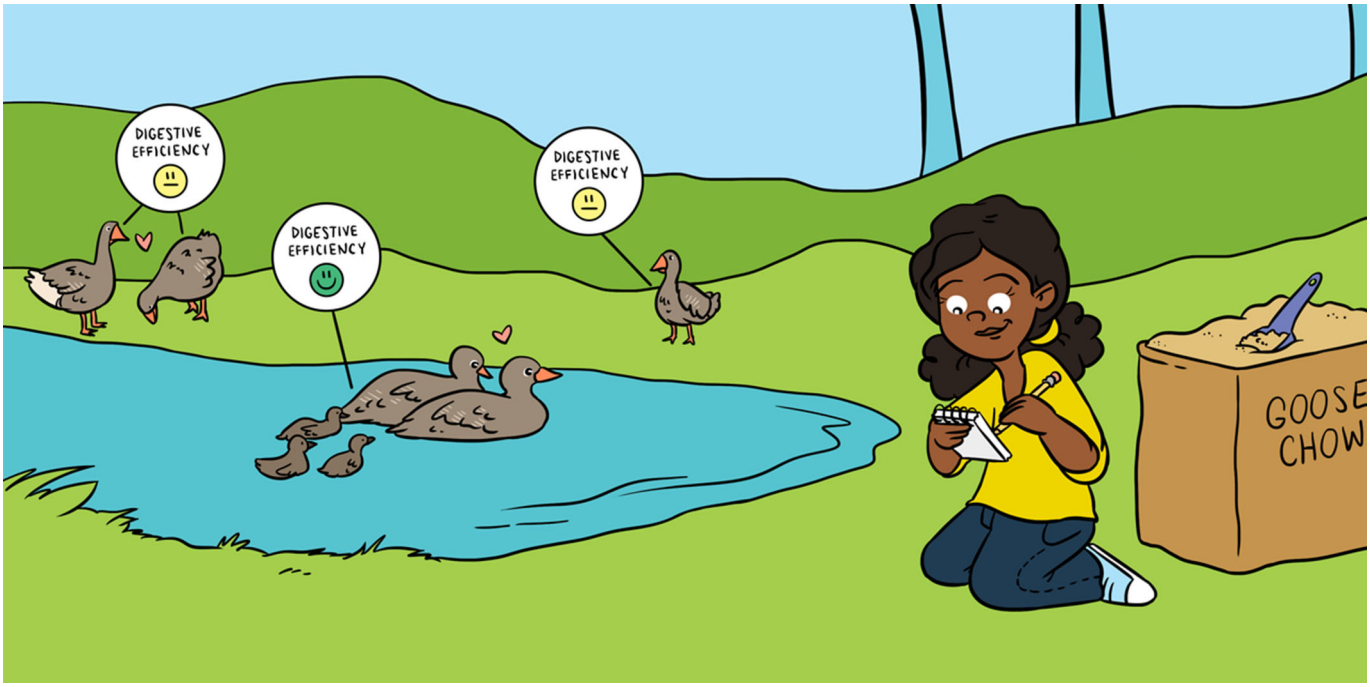

HOW HAVING A FAMILY IMPROVES DIGESTION IN SOCIAL GEESE

Gudrun Gegendorfer[1] *and Didone Frigerio*[1,2*]

[1] *Konrad Lorenz Research Center for Behaviour and Cognition, University of Vienna, Vienna, Austria*

[2] *Department of Behavioral and Cognitive Biology, University of Vienna, Vienna, Austria*

YOUNG REVIEWER:

FRESIA

AGE: 11

As a human being, having family and friends helps us in many ways. Animal societies are not much different: a stable social environment is essential for the health of the body. Among birds, graylag geese are highly social. Therefore, they are a very good example for studying the benefits of living in groups. In this study, we looked at the quality of the digestion and the breeding success of 38 free-living graylag geese. The birds were individually tagged and belonged to different social categories. The categories were pairs with offspring, pairs without offspring, and unpaired birds. We found that individuals that have stable social relationships with their family members have better digestion and are more likely to breed successfully in the following breeding season. These are new insights into the benefits of social life in birds.

STUDYING SOCIAL INTERACTIONS IN GRAYLAG GEESE

Have your parents ever told you to eat your peas? Have your parents ever cooked your favorite meal because they knew you would like it?

If so, then your health has probably benefited from being in a family. You and the rest of your family benefit nutritionally from the care you give each other. It turns out that the same thing happens in animal families and/or societies, where the social position of an individual animal affects its life in many ways. For instance, whether an animal has a mate or not may influence how much power it has within the group. Additionally, the social position of an individual within the group affects its behavior when feeding and therefore how much and what kind of food it gets to eat [1]. Generally, the dominant individuals in a group are faster at getting access to food and more motivated to defend food resources as compared to low-ranking individuals. This means that high-ranking individuals in the group have access to larger quantities of food, which is often of high quality, too. In addition, a high rank is often linked to better reproduction, lower stress [2], and good digestion [3].

Among birds, graylag geese (*Anser anser*) are highly social. These geese have been extensively studied and are an ideal species to use for research about social interactions in animals. They live in big flocks for most of the year and pair-partners (male and female) usually stay together for several years, similar to the way humans form couples. Paired birds often stay close to each other during the day no matter what they are doing, for example feeding or resting. After short separations, or simply when they get excited (when other geese are fighting, for example) they greet each other to show that they belong together. Furthermore, graylag geese have strong family ties. Goslings, which are young geese, stay close to their parents from hatching until the next breeding season, which means at least 1 year.

As in human society, disputes between pairs, families, and clans are common within flocks. Conflicts produce social instability and stress. However, a so-called social partner, which could be a mate, one of the parents, or a sibling, can reduce the stress caused by disputes in the social environment and improve the well-being of an individual. To investigate the relationship between the social environment and an individual's well-being, we looked at **digestive efficiency**. This measurement tells us how much of the food that was eaten was broken down for use by the body. We expected social relationships to affect digestive efficiency in graylag geese.

DIGESTIVE EFFICIENCY

The proportion of eaten food that gets broken down for use by the body.

WHAT DID WE INVESTIGATE?

We studied a group of graylag geese to find out if and how digestive efficiency and social environment, such as being paired or not, or having offspring or not, are related to each other. The study was conducted in February, when the ground was fully covered with snow and the geese were only able to feed on the food we provided. In this way, we regulated the quantity and quality of the food available.

First, we hypothesized that paired birds with offspring would have a better digestive efficiency than unpaired individuals. We considered the digestive efficiency to be an indicator of nutrition and therefore also of the overall body condition of an individual. At the end of winter, when these data were collected and the breeding season starts, an individual's body condition will play a major role with respect to reproduction. Animals with healthy bodies will be more likely to have offspring. Therefore, as a second hypothesis, we expected digestive efficiency to be related to **breeding success**.

BREEDING SUCCESS

The number of hatched eggs.

WHERE ARE THE BIRDS WE STUDIED?

The study was conducted at the Konrad Lorenz Research Center[1] in the valley of the river Alm in the northern part of the Austrian Alps, which are located in central Europe. A non-migratory flock of graylag geese was introduced there by Konrad Lorenz in 1973. The birds are free to move and fly around and generally spend their time close to the research center, where they are provided with food twice a day, all year round. All geese are tagged with colored rings on their legs and are used to the close presence of humans. Data about every individual goose has been collected since 1973, and therefore we know the friends and relatives of each bird in the flock.

[1] https://klf.univie.ac.at/

HOW DID WE STUDY DIGESTIVE EFFICIENCY IN GEESE?

During the period of data collection, the flock consisted of 167 individuals. **Droppings** from 38 individuals (20 males and 18 females) belonging to different social categories within the flock (paired with and without offspring, unpaired individuals, and juveniles) were collected during 9 consecutive days in winter 2017. During this period, the snowpack forced the birds to feed exclusively on the pellets we provided, which were made out of a mix of cereals, dried herbs, and grasses. In sum, 184 droppings were collected immediately after **defecation** (pooping) and were frozen at −20° C within 1 h, until further analysis.

DROPPINGS

The equivalent of feces and urine in mammals. In birds, they are eliminated together in the droppings.

DEFECATION

A nice way of saying "going poop."

To find out how efficiently the geese digested their food, both the food pellets and the droppings were analyzed by drying them in ovens and a test was performed to determine how much lignin was in them. Lignin is an indigestible plant component. Since lignin cannot be digested, it can be used as a natural marker providing information about the quantity of food ingested, assimilated and ejected (Figure 1). We then calculated the digestive efficiency of the geese using this equation: digestive efficiency (%) = [(1 − lignin in pellets)/lignin in droppings] × 100. This equation tells us which percentage of the ingested food was also retained in the body.

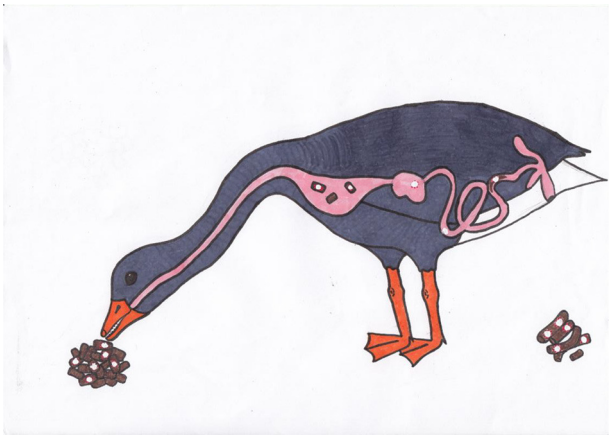

Figure 1

To calculate the digestive efficiency of the graylag geese, we measured the proportion of lignin (the white dots), an indigestible plant component, both in the food and in the droppings of the graylag geese. This tells us what proportion of the ingested food the goose was able to utilize. Credits: Helene Vesely.

WHAT DID WE FIND AND WHAT DO OUR RESULTS MEAN?

As expected, our results showed that social environment fine-tunes digestive efficiency. Paired individuals with offspring showed better digestive efficiency than paired individuals without offspring or unpaired birds (Figure 2). Additionally, the results suggest that individuals with stable social relationships had better digestive efficiency. We think that pairs with offspring benefit because the juveniles also help to look out for potential challenges, allowing the parents (or the entire family) to spend more time feeding. It is known from other goose species that long-lasting family ties are beneficial for both offspring and parents. For instance, young barnacle geese living in family units were less disturbed during feeding than those who had left the family unit [4]. The juveniles considered in our study were already 2 years of age and were no longer spending time with their parents. Nevertheless, they had a high digestive efficiency, which suggests that other factors are involved in the relationship between social environment and digestive efficiency. For instance, juvenile graylag geese may be comparable to adolescent humans, who are hungry all the time and do not really get fat, because they efficiently direct their food resources into growth.

Our study also showed that geese that hatched offspring in the breeding season following the data collection period showed higher digestive efficiency than those failing to hatch goslings (Figure 3). The egg-laying period, which starts at the end of winter, is energetically very demanding. Just consider that a female goose weighs ~3 kg, one goose egg weighs ~170 g and a female lays on average six eggs, which means about 1 kg of her body mass. Therefore, it might be essential for a goose, at the beginning of the breeding season, to be efficient in digesting food, to provide enough energy to lay eggs. However, we are still not sure if there is a direct cause/effect relationship between

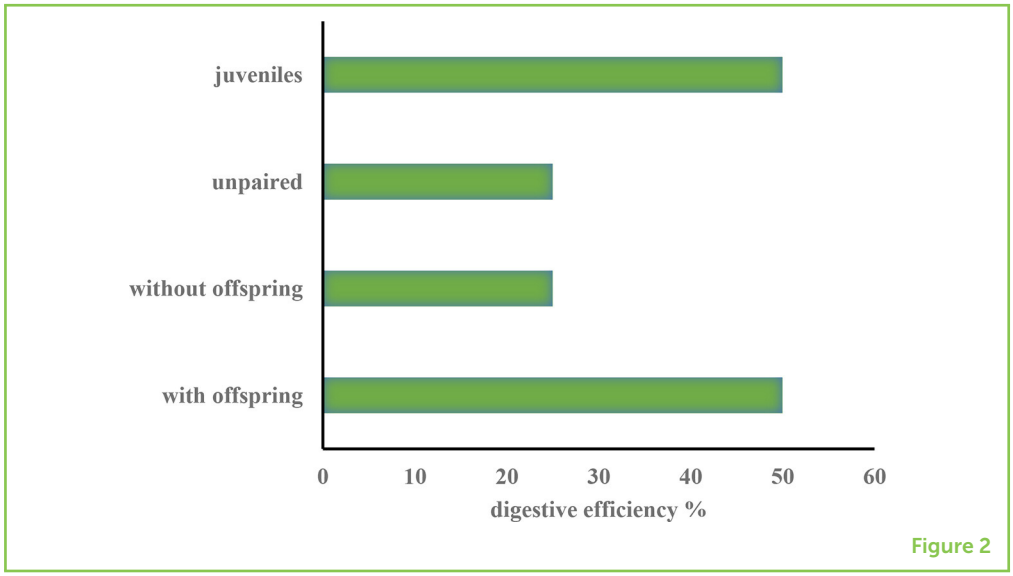

Figure 2

Differences in percentages of digestive efficiency between geese from different social categories. You can see that paired individuals with offspring showed better digestive efficiency than paired individuals without offspring or unpaired birds. The results suggest that individuals with stable social relationships had better digestive efficiency.

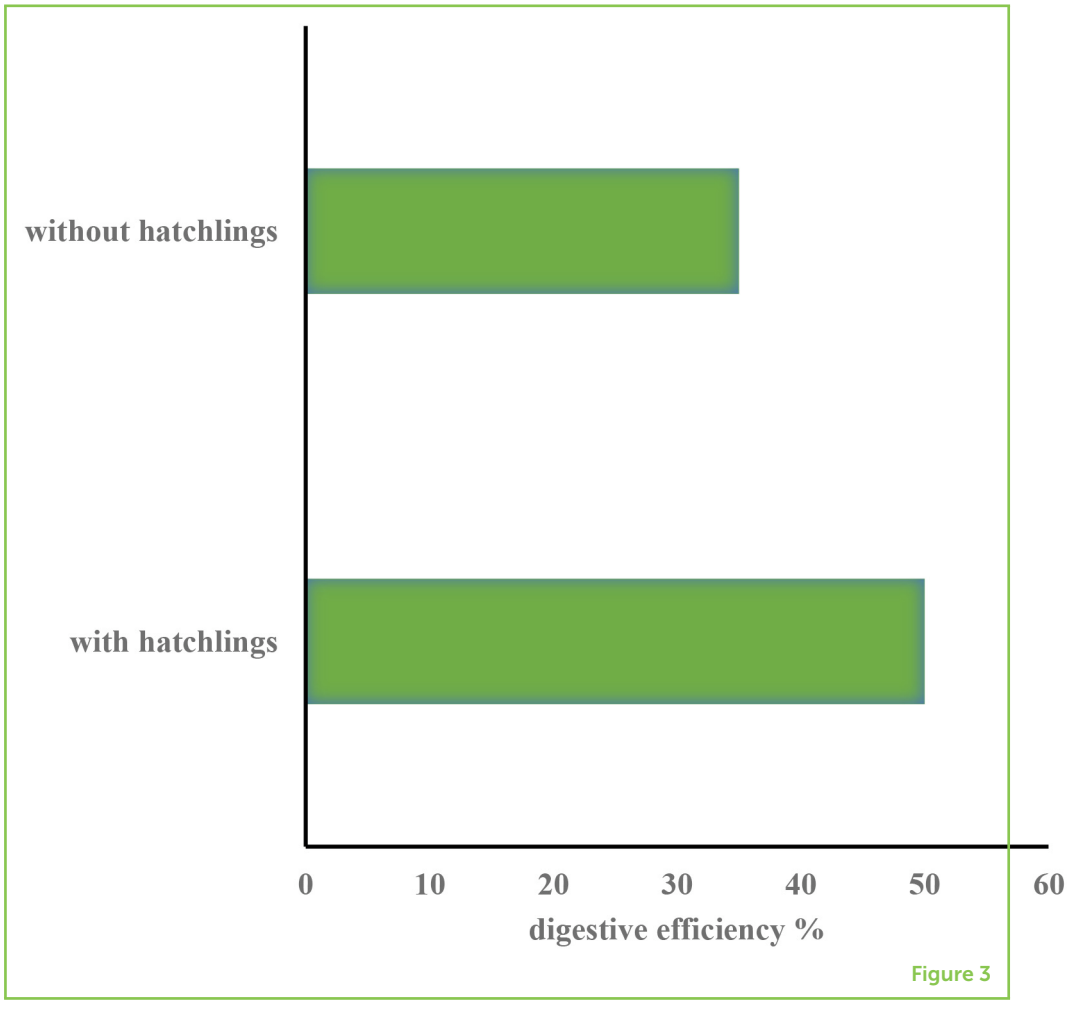

Figure 3

Differences in percentages of digestive efficiency between individuals with hatchlings and those without in the season following the study. You can see that geese that individual with hatched offspring in the breeding season following the period of data collection showed higher digestive efficiency than those failing to hatch goslings. This suggests that it might be important for a goose to be able to digest food efficiently at the beginning of the breeding season in order to store sufficient energy for egg laying.

digestive efficiency and reproductive success. To find this out, further experimental studies would be needed.

So now you know that digestive efficiency is considered to be an indicator of the overall body condition of an individual. Furthermore,

you know that the physical constitution and possibly also the reproductive success of an individual are supported by stable social relationships. This is important for all social animal species because it shows that the social environment may influence an animal's well-being in both the short- and long-term, by affecting breeding success.

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ORIGINAL SOURCE ARTICLE

Frigerio, D., Kotrschal, K., Fabro, C., Puehringer-Sturmayr, V., Iaiza, L., Hemetsberger, J., et al. 2018. Social context modulates digestive efficiency in graylag geese (*Anser anser*). *Sci. Rep.* 8:16498. doi: 10.1038/s41598-018-34337-3

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CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWER

FRESIA, AGE: 11

I love science and math, but I am not a fan of history and geography. My big passion is animals. I have a snake named Sacha Jr., and a rabbit named Luna, and I love to raise silkworms and search for lizards and other animals in the wild. I am also learning to ride horses and I love using creativity to make crafts.

AUTHORS

GUDRUN GEGENDORFER

Gudrun Gegendorfer is a biologist and is particularly interested in knowledge transfer. She is involved in the Citizen Science projects about behavioral research on graylag geese and northern bald ibises, which are carried out at the Konrad Lorenz Research Center. There, she supervises the Citizen Scientists, leads introductory workshops, and supports the participants in their tasks.

DIDONE FRIGERIO

Didone Frigerio is a behavioral biologist. Her main interest is the relationship between sociality and the processes that are going on inside the body (physiology) in group-living birds. She loves to work with graylag geese, even though northern bald ibises have also caught her attention recently. She applies citizen science by involving pupils and citizens in her behavioral research. *didone.frigerio@univie.ac.at

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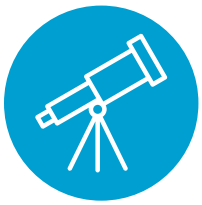

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